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ENHANCEMENT OF PROPULSION PERFORMANCE THROUGH FLUIDICS INSERTION TECHNOLOGY IN EV BURNER : A REVIEW

Sameh Hassan *, Ahmed Emara** , Mahmoud Elkady***

Abstract— The essential usage of the turbine engine in different ways as civilian and military branch made a lot of engineering sections searched for the enhancement of combustion performance by using different techniques one of this was the Fluidics insertion technology inorder to achieve our main goal which is stable combustion at low emissions . The main goal of this paper is to provide an overview of , the operation charactrestics , the flow field investigations, and flow field interaction of a fluidic oscillator . Inorder to fulfill our main goals, modern concept was inspected. This concept was applied by using a new model of feedback fluidic oscillator inserted in the EV burner (manufactured at the T.E.S company, cairo) , The effect of this modern technique on the flow field and on stability and combustion control was discussed .

Index Terms— **Fluidics , Emissions , EV burner , Combustion , Fluidic oscillator , Feedback ,Flow field visualization .**

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1 INTRODUCTION

THE fluidic oscillator is used as a new technology in different industrial applications. The usage in combustion field especially in the jet engines is new and may be the first in allover the world to be inserted in a swirl stabilized burner for emissions reduction and for stability performing. It considers a viable mean for systems implementation in industrial fields. One or more may be used together but they are synchronized with each other to perform the job better and faster than one oscillator at some applications. The fluidic oscillator possesses all the following characteristics: (1) Rapid response to changes in fluid flow rate, (2) Freedom from flow instabilities, (3) no power requirements, (4) Capability for scaling, to provide design flexibility, (5) Low cost, light weight, and ease of removal for servicing, (6) Low susceptibility to damage during installation. The present paper will discuss new designs for auxiliary parts used to achieve these goals of emissions reduction at stable combustion conditions. It was focused on the usage of the fluidic oscillator in performing the emission reduction at stable operating combustion conditions when inserted in ev burner . for fulfilling what mentioned before, manufacturing process was done also different models of fluidic oscillator which will be inserted in the EV burner .

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2 FLUIDIC OSCILLATOR HISTORY

Fluidic technology was spread in the last 30 years. Their reliability increased over the mechanical-pneumatic devices so they became the rivals of electrically operated components. This technology has proved to be an essential mean for systems implementation in industrial, commercial, and military systems [1]. The word "Fluidics" is derived from two words "fluid" and "logic" and is used specifically to describe the technology of the control of fluid force components [2]. The fluidic oscillator is a device that generates an oscillating jet when supplied with a pressurized fluid [3]. Based on the operation principles, the fluidic oscillators are categorized as the feedback oscillator, the Karman vortex oscillator, and relaxation oscillator [4]. The Coanda effect has a major contribution to fluidic technology first described in the 1930's [5]. It describes the tendency for a jet of fluid (the fluid can be a liquid or a gas) issuing from a nozzle to adhere to the surface of the wall adjacent to it [6]. Although the flow oscillation in a fluidic oscillator is usually initiated by the Coanda effect,as shown in Fig.1, the features of oscillation could be significantly altered by the design of feedback channels and the flow control loop [4]. The term fluidic device should be applied only to devices in which there are no moving parts except the fluid movement itself which works as a source of pulsations [6]. The oscillation comes without any external excitation and as such is described as "selfexciting". Fluidics is preferred to use in comparison to the valve arrangements. However, some tools that produce a pulsed jet through mechanical interruption or mechanical excitation of the normal or steady fluid flow would cause large

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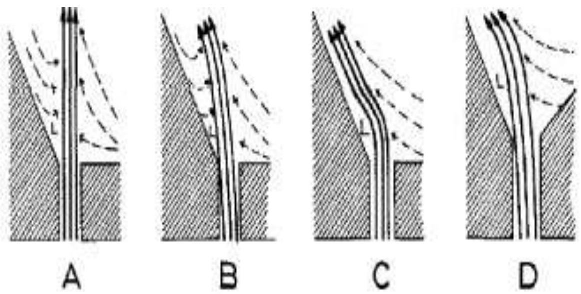

Fig. 1. The Conda Effect .

energy losses, as well as mechanical wear and fatigue on the indispensable moving parts and seals [6]. Thereby, it is no need for maintenance requirements in the fluidics system which makes it highly appropriate for application in industrial gas turbines and has a long lifetime [7] . The modulation of dynamic behavior of the fluidic oscillator is performed by interactions among flow fluctuations in the inlet area, the growth of the recirculation flow, and the flow structure near step-walls and splitters [8]. Yang also used this type of oscillators (conventional feedback fluidic oscillator) to measure the flow rate of the fluid as a flowmeter [4]. Gregory adapted a fluidic oscillator as a dynamic calibration device for pressure instrumentation such as pressure-sensitive paint (PSP) [9].

3 FLUIDIC OSCILLATOR DESIGN DESCRIPTION AND OPERATION

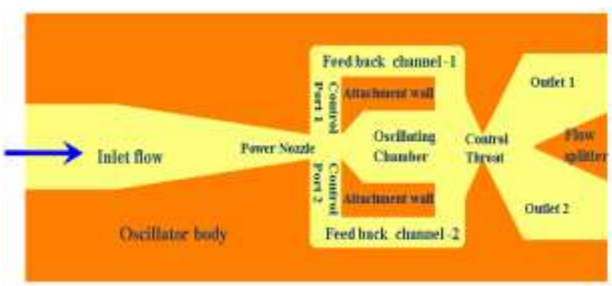

Fig. 2. Schematic diagram of the fluidic oscillator..

A fluidic oscillator as shown in Fig. 2, includes an oscillator body having two attachment walls defining an oscillating chamber there between, an inlet duct extended to the oscillating chamber for guiding a flow of fluid entering into the oscillating chamber, two outlet ducts communicatively extended from the oscillating chamber for guiding the flow of fluid exiting from the oscillating chamber, and two feedback channels communicating with the oscillating chamber. Each attachment wall has an upstream portion and a downstream portion integrally extended therefrom as a step shouldering manner to form a modulating shoulder for modulating an oscillation of the flow within the oscillation chamber so as to stabilize the flow of the fluid to pass through the oscillator body. A flow splitter divides the exit duct after the control throat into two equal parts.

To understand the idea of oscillation of fluidic oscillator as shown in Fig .3 , normally, electronic circuits are taken in consideration. In an electronic oscillator, a tuning element is selecting a specified frequency. Subsequently, an amplifier and a feedback mechanism are taking some of the amplified signal and feeding it back to the beginning with some phase according to the schematic Fig. 4. Oscillation will occur if the phase is correct. Feedback can influence the input signal in one of two ways; positive or negative. In a positive in-phase feedback signal, a positive-going wave on the input leads to a positive going change on the output. This will amplify the input signal leading to more modification. In a negative feedback, a feedback signal which is inverted, where a positive-going change on the input leads to a negative-going change on the output, will dampen the effect of the input signal, leading to less modification. A represents the amplification factor of the amplifier and +/-B the gain and phase of the feedback circuit.

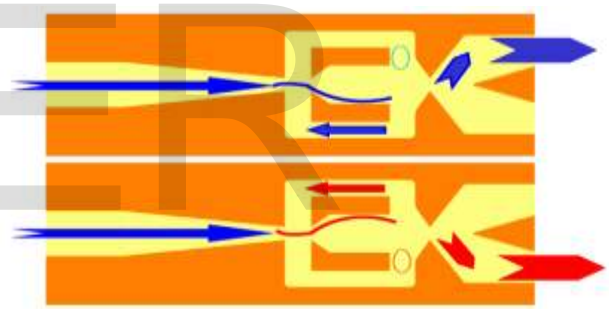

Fig. 3. Operation procedure of a fluidic oscillator .

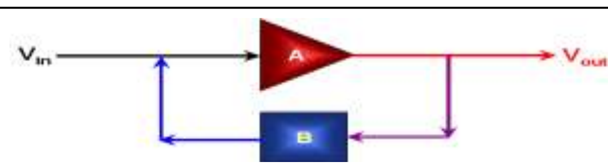

Fig. 4. The electronic oscillator..

\ΦΦA little algebra shows the origin of the gain G of the amplifier/oscillator. The amplifier multiplies the total input voltage Vin, composed of input plus feedback, by A yielding the output voltage Vout as shown in these equations.

$$A(V_{in} \pm BV_{out}) = V_{out} \qquad (1)$$

$$G = \frac{V_{out}}{V_{in}} = \frac{A}{1 \mp AB} \qquad (2)$$

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Similarly, when a flow of fluid passes through the inlet port to fill up the oscillating chamber, the fluid is guided to flow towards the outlet and back to the oscillating chamber through the feedback channels, such that the fluid is started to oscillate within the oscillating chamber and then guided to split at the splitter to two outlets. It is systematically evaluated the function of flow splitter while systematically varied its location and length and this has an effect on Strouhal number. When the fluid flows into a symmetric divergent or sudden-expansion channel, it often diverts toward either side in a specific range of Reynolds number due to the Coanda effect. Then the flow develops to be either an asymmetric flow structure or a periodically oscillating flow pattern. As the oscillation frequency is linearly proportional to the volume flow rate at certain range of flow, the oscillator could be adopted as a flow-meter at this range. Moreover, these specific correlations are also widely used for atomizers, mixers, and memory and control devices [4].

4 INSERTION OF FLUIDIC OSCILLATOR IN EV BURNER

Inserting of fluidic oscillator in ev burner is considered one of the new ideas which need to be investigated. The behavior of the fluid flow was investigated inside and outside the fluidic oscillator and the performance of the oscillator in active control schemes which include high frequencies flow modulation [10]. The influence of these oscillators on flame stability and combustion control without the need of complex and fast moving parts is the main goal. Based on the operation principles, this tested fluidic oscillator is categorized as feedback oscillator. The fluidic oscillator outer diameter is 16.8 mm (20.5% D of the burner diameter) and has two rectangular outlets. The design variation of certain oscillator dimensions from 102×38×22mm to 16.8Ø× 60mm was the challenge. For each exit limb, the dimensions are changed from 7×3 mm to 3.7×6 mm to keep the frequency fluctuations in the range of combustion stability depending on the operating range of fuel and air flows. The feed back effect and the inner dimensions are important in the oscillator modulation. Yang reveled that enhancing the feedback effect and lessening the inhibition of vortex evolution and residence time improve the oscillation characteristics [8].

5 TEST EQUIPMENTS SETUP FOR FLUIDIC OSCILLATOR EVALUATION

A small Plexiglass aquarium is used for the PIV and LIF measurements inside and out side the fluidic oscillator as shown in fig 5 . The Maximum mass flow passes inside the fluidics was 252.6 Lit/h. The used pump is a small fish aquarium one. Rotameter 500Lit/h maximum flow rate with fine adjusting flow valve are used to give the required water flow to the oscillator. A microphone is placed almost 3mm upstream of the fluidics (manufactured at the T.E.S company, cairo) and recorded the frequencies which were tuned by varying the inlet air mass flow to the oscillator and the pressure fluctuations are induced by the coherent structure. The power spectra, recorded of the microphone signal for different Re-numbers. Hot wire (IFA- 100) is used to investigate the oscillation characteristics for fluidic oscillator. Two hot wires of 5µm diameter and 2mm length at 6.41W/ 23°C are used. Hot wire and microphone signals offer a consistency of power spectra. The targeting fluidic oscillator is used in the emissions reduction for the combustion engines, mixing of gases, dispersal of liquids, and the application of cyclically repetitive momentum or pressure forces to various materials, structures of materials, and to living body tissue surfaces for therapeutic massaging and cleaning purposes. The tests are totally interested in the using only in the emission reduction in jet engines at a stable combustion's conditions.

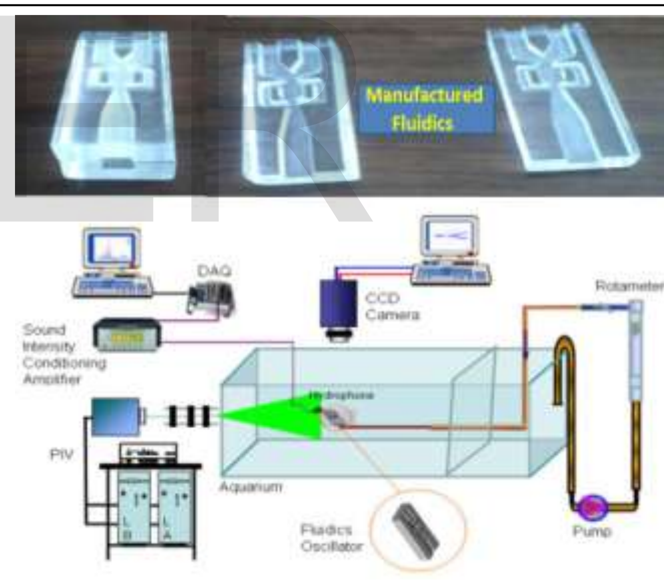

Fig. 5. Schematic diagram of the manufactured fluidics flow field measurements

5 OPERATION CHARACTRESTICS OF THE FLUIDIC OSCILLATOR MODEL

The fluidic actuator's capability to generate an oscillating flow was tested at ambient conditions (approximately 20°C, no combustion) for three fluids: water, natural gas, and nitrogen as shown in Fig.6,7,8 To visualize the oscillation of the fluidics' outlet jets, the fluidics was first mounted in front of a high speed camera (with the outlets facing upwards) and water was

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injected into the supply port.see fig 5 .Water flow rates between 50 and 250 liters per hour were investigated [11] . At each flow rate, a 30 second movie of the oscillating flow was acquired with the camera. The images were evaluated to obtain the fluidics (oscillation) frequency. The results are shown in Figure 9. The fluidics frequency ranges from 1.0 Hz to 5.2 Hz and increases approximately linearly with the water flow rate.

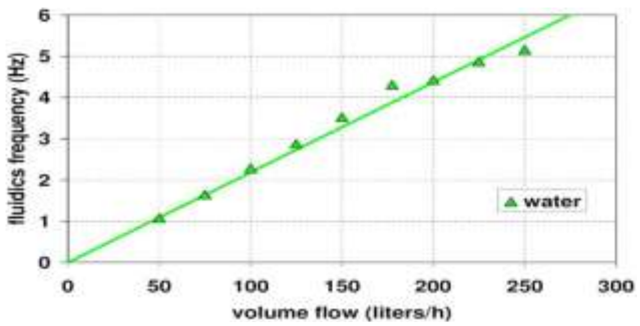

Fig. 6. Fluidics water flow rate vs. fluidics oscillation frequency obtained from the high speed camera image .

The fluidic oscillator was specially designed to generate an oscillating gas flow in an atmospheric combustor. The intended frequency range was 30 to 200 Hz. Therefore, the fluidics' capability to generate oscillations at such frequencies was tested for two gases: natural gas, the intended fuel for later combustion tests, and nitrogen, which is inert in the combustion process as shown in Fig. 8. Natural gas mass flows of 1.0 to 7.0 kg/h and nitrogen mass flows of 1.0 to 10.0 kg/h were investigated. Two hot wire probes were placed 10 mm downstream of the fluidics' two outlets to measure the velocity of the exiting jets.

The phase-averaged time traces of the velocity fluctuations for nitrogen mass flows of 2, 5, and 8 kg/h are plotted in Fig 7. The average is based on approximately 1000 recorded cycles. As in the water tests, the asymmetry of the velocity oscillation at the two outlets can clearly be seen in the velocity time traces. The fluctuation at each exit closely resembles an on-off characteristic with maximum velocities of up to 20 m/s and minimum velocities of 0 m/s. Increasing the mass flow through the fluidics as well as feeding the fluidics with natural gas instead of nitrogen resulted in higher oscillation frequencies. These trends can be seen in Figure 8 a, where the dominant oscillation frequency is plotted versus the fluidics mass flow. Within the mass flow ranges investigated, the minimum and maximum oscillation frequencies for both gases were in the order of 30 and 200 Hz, respectively, as desired. Additionally, the oscillation frequency increased approximately linear with increasing mass flow. The same mass flow rate resulted in higher oscillation frequencies for natural gas, due to its lower density, when compared to nitrogen injection. Plotting the fluidics frequency versus the volume flow rate of the gas feed into the fluidics' supply, as shown in Fig 8 b, revealed approximately the same linear increase with the flow rate for both gases, natural gas and nitrogen.

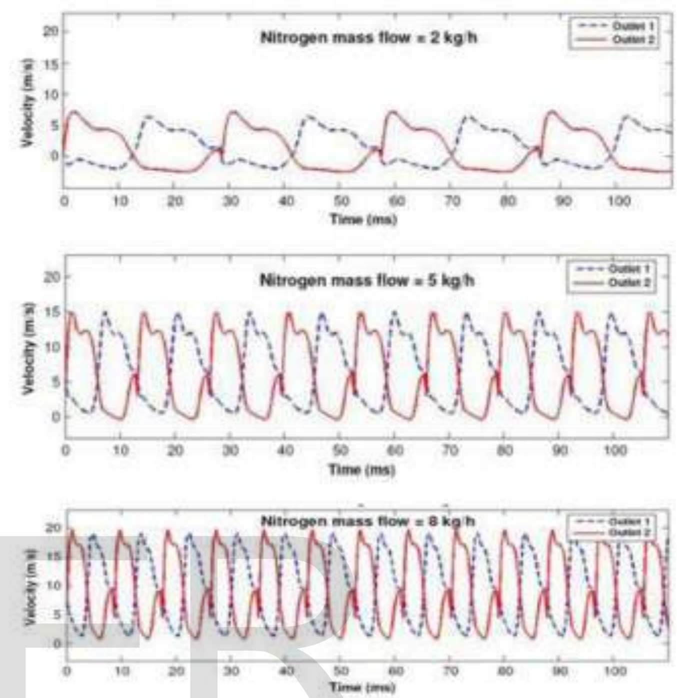

Fig. 7. Phase averaged time traces of the velocity fluctuations measured at the fluidics' outlets for a nitrogen mass flow of 2 kg/h (top), 5 kg/h (middle), and 8 kg/h (bottom) .

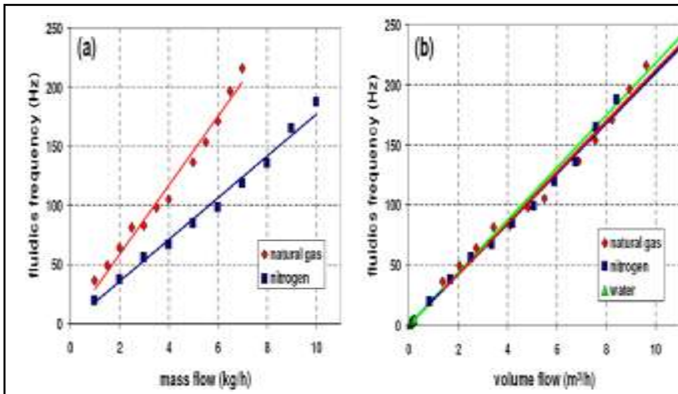

Fig. 8. Fluidics water flow rate vs. fluidics oscillation frequency obtained from the high speed camera image .

Also the trend line obtained from the water tests agrees remarkably well with the gas trend lines and data points, even though the investigated water flow range was 0.05 to 0.25 m^3/h,while the gas tests were conducted between approxi-

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mately 1 and 10 m^3/h. From the results presented in Figure 8, it can be concluded that the oscillation frequency of the fluidics is primarily a function of the volume flow rate within the investigated flow rate range. As shown in Fig 9. it presents a selection of the camera images captured of the oscillating outlet jets. The three columns correspond to water flow rates of 150 (left), 200 (middle), and 250 liters per hour (right), while the rows correspond to different phase angles of the oscillation. At zero phase angle, the right outlet jet is just about to start exiting.It was noted a lot of observations in the images. The height reached by the outlet jets and hence their velocity increases with the water flow rate. Due to the internal design of the fluidics, The jet stream is deflected towards the oscillating chamber according to the Coanda effect [12]. The water jets at the two outlets oscillate asymmetrically to each other. One outlet closes completely in between two consecutive jets, that is, the velocity of the exiting jet goes down to zero and the water jet stops. In this sense, an on-off oscillation is generated at each outlet.

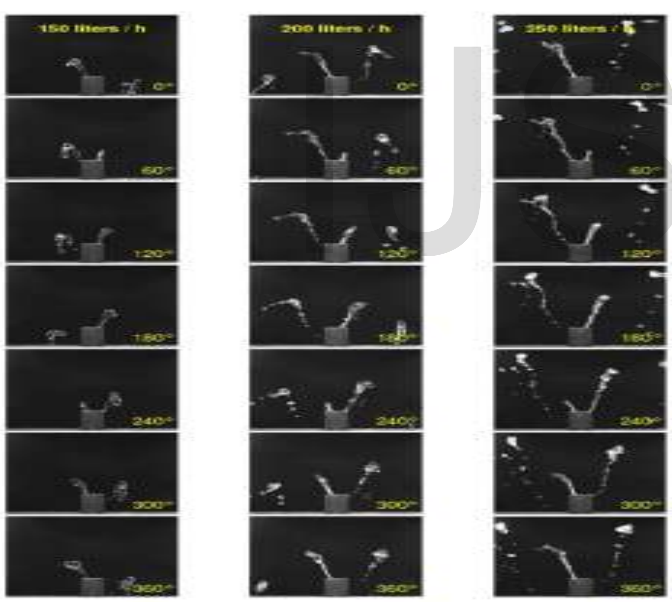

Fig. 9. High speed camera images of the fluidics' oscillating water jets captured at different oscillation phase angles for water flow rates of 150 (left), 200 (middle), and 250 liters per hour (right).

For the application of the fluidic oscillator in a combustion system as shown in Fig 10. it is important to control the actuation frequency and amplitude. This can be achieved as follows: The oscillator's actuation amplitude corresponds to the natural gas mass flow that is modulated by the fluidics. The actuation frequency corresponds to the fluidics' oscillation frequency. For a constant actuation amplitude (i.e., constant natural gas mass flow), the actuation frequency can be adjusted by blending the natural gas mass flow with additional nitrogen, thus increasing the fluidics volume flow [11]. The more nitrogen is added, the higher the actuation frequency. Hence, the fluidics' actuation amplitude and frequency can be controlled independently by controlling the natural gas and nitrogen flow fed into the fluidics supply. Note that the minimum frequency of oscillation is given by the selected natural gas mass flow, and that blending the natural gas flow with nitrogen does not only increases the fluidics frequency, but also the outlet jet velocity. Note also that two jets are generated in one oscillation cycle, one at each outlet.

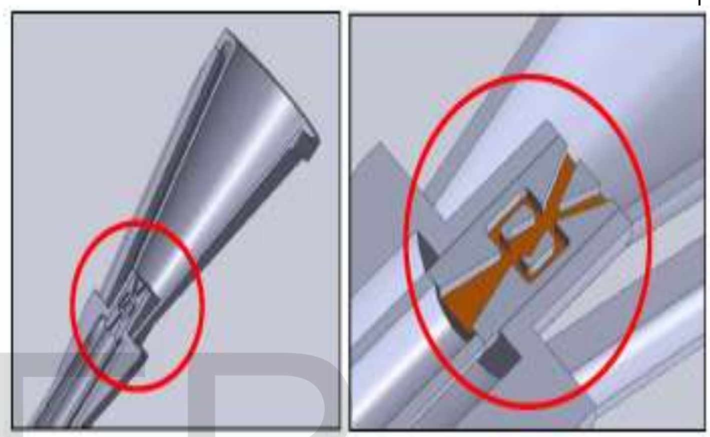

Fig. 10. Swirl burner with fluidic oscillator integrated into the pilot fuel lance and also into the premix fuel supply system.premix.

6 EVALUATION OF FLUIDIC OSCILLATOR WITH DESIGN VARIATIONS

The challenge of the research presented by Emara [10]. is to provide a fluidic oscillator of relatively small dimensions to meet practical size restrictions of the normal pilot lance in a swirl stabilized burner. Two design variations are performed to reach the final and optimum design.

At the first design variation of the new model, the reduction in size was almost to 53.3% from the original one used by Guyot [13] . This model was sustaining the ability of insertion inside the burner but was not suitable for the combustion stability job in the swirl stabilized burner according to higher produced frequencies. The projectile exit areas for the two limbs are altered from round in the original design to rectangular shape at this one. Each limb area is set at 3.3x1.6 mm.

At the second design variation, some changes in design configuration and channels features are done. Four Plexiglas models of the fluidic are investigated freely in cold air depending on changes in some control parameters. These control parameters shown in Fig. 11 are as follows:-

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(1) The depth of the whole fluidics channels.
(2) The width of the exit limbs.
(3) The throat width and length of fluidics.
(4) The angel of outlets.
(5) The thickness and the shape of the fluidics shoulder.
(6) The width of the feed back channels.
(7) The throat exit angle.

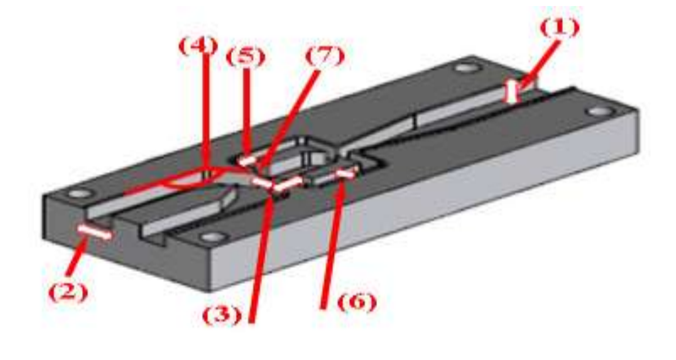

Fig. 11. Fluidics control parameters .

6.1 1ST DESIGN VARIATION- FX0.

As clarified in Fig. 12, the first oscillator design failed to produce a flow with fundamental frequencies coincide typically with those matching with combustion stability conditions. The microphone placed upstream of the fluidics recorded the pressure fluctuations induced by a coherent structure. A spectrum analysis displays the relative strengths of different frequencies in the sound signal over time. The power spectra, recorded for different Re-numbers, show a fundamental peak which clearly scales with the Reynolds number.

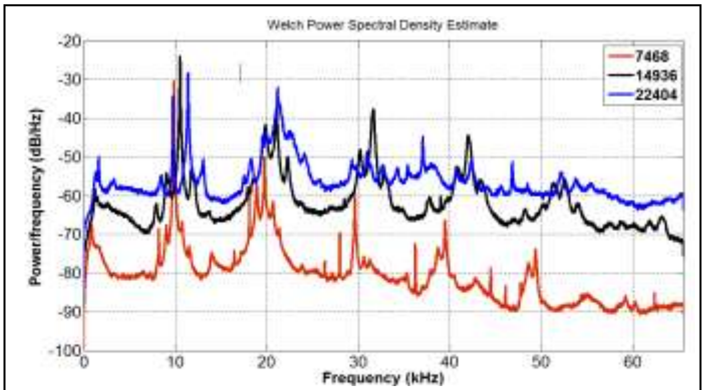

Fig. 12. Power Spectral Density of the microphone signals for different Re numbers.

The fundamental peak frequencies are from 9.89- 11.44 kHz which is too noisy in range of 7468-22404 Re number calculated from the equivalent mass flow rates. The first peak value is in range of 0.88- 1.664 kHz but not the fundamental one. Intuitively speaking, the spectral density characterizes the frequency content of the signal.

Through observing the signal peaks, the periodicity in the signal is noticed every 9.78 kHz The signal has a fundamental frequency of 9.89 -11.44 kHz in the named range of flow which depends slightly on the Reynolds number and shows also strong harmonics and linear relation, specifically for the lower Reynolds number see Fig.13.

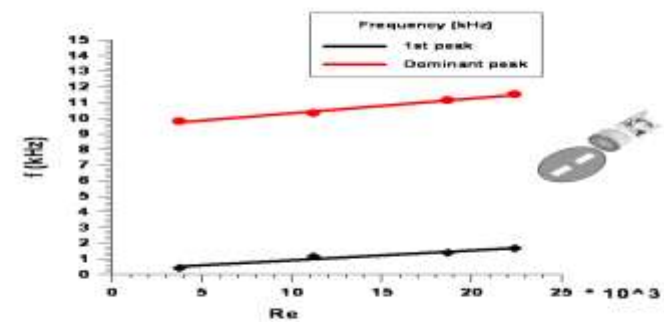

Fig. 13. Fluidics frequency at different Re numbers.

As the flow pattern in the oscillating chamber and particularly the vortex near the control throat provide flow aspiration on one side and surplus of flow on the opposite side of the chamber. This accelerates and respectively decelerates the working fluid in the feed back channels such as to cause a reversal of the vortex after a time delay [14].

The Strouhal numbers of the first and dominant peaks are plotted as a function of the calculated Reynolds number (Re) in Fig 14. It clearly shows that the Strouhal number remains almost constant around 0.04 with a slight decrease with increasing Reynolds number for the first peak which is relevant to the mass transfer and decreases from 0.58 to around 0.2 for the dominant peak. This shows that the microphone signal peaks presented in Fig. 14 are related to flow instability.

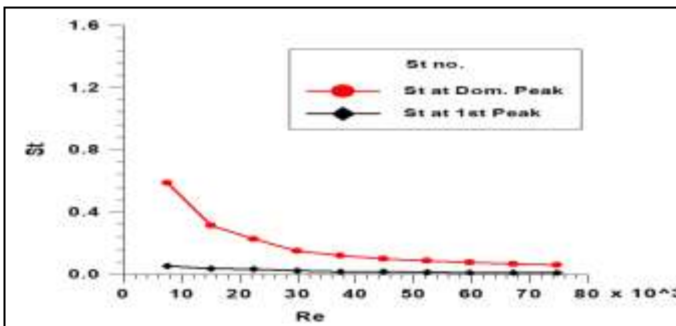

Fig. 14. Fluidics control parameters .

Upstream of the oscillator, the second harmonics of the helical structure is much stronger in amplitude than the first one. As the strouhal number is considered in-between large

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Strouhal number (order of 1) and low strouhal number (order of 10−4 and below), hence it is classified as an intermediate one. Oscillation at intermediate Strouhal numbers is characterized by the buildup and rapidly subsequent shedding of vortices [15]. The RMS values of the pressure oscillations are shown in Fig. 15. in unit of voltage comes out from the field point system and the microphone calibrated by using the piston phone with sensitivity of 867.5616 pa/v. Below the RMS value of 0.8v (694.04928 pa) the combustor was regarded being stable in reacting conditions as depicted by Emara. Values above unity were regarded being unstable and present a clear fundamental peak in the power spectrum density [16]. Up to Re of 22404 is free of these expected instabilities.

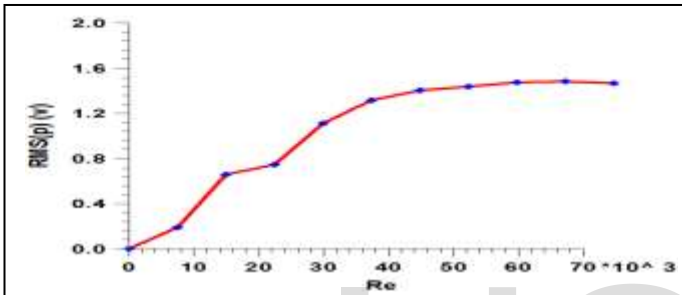

Fig. 15. RMS (p) at different Re.

The fluidics device operates at low to high frequencies depending on the length of the feedback channel and thus on it's physical size. Some tests are done in atmospheric conditions (20°C and atmospheric pressure) for air using microphone and hot wire techniques. Microphone was used to investigate the sound pressure oscillations and hot wire probes were used to measure the velocity fluctuations at the fluidics' outlets. Fig. 16 exhibits the time history of the velocity oscillations for the fluidics exit limbs at Re of 7468 (1kg/h) air. The mean velocity is around 20 m/s. The peak to peak oscillation period is almost 0.092 ms for each outlet limb corresponding to the dominant 10 kHz peak in spectra as demonstrated in Fig. 17.

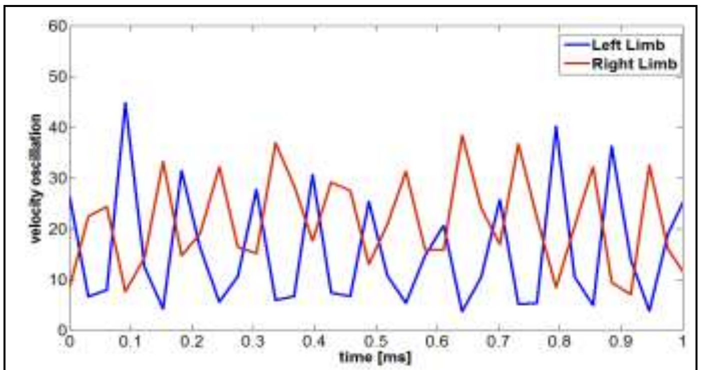

Fig. 16. Time history of the velocity oscillation for the Fluidics exit limbs at Re of 7468 for air.

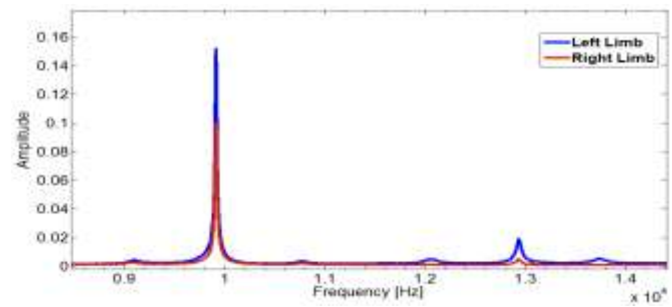

Fig. 17. RMS (p) at different Re.

6.2 2ND DESIGN VARIATION

The second design variation concentrated on how to make insertion of a fluidic actuator in a swirl stabilized burner in order to evaluate the flow field interaction at the outlet of the fluidics and the burner and to decrease the emissions at stable conditions. Four design variations were developed trying to reach the optimum one or more for working in the combustion field and achieving the goal [10] . Some parameters are changed in the previous design (Fx0) at the 1st variation and give these four new models as shown in Fig. 18.

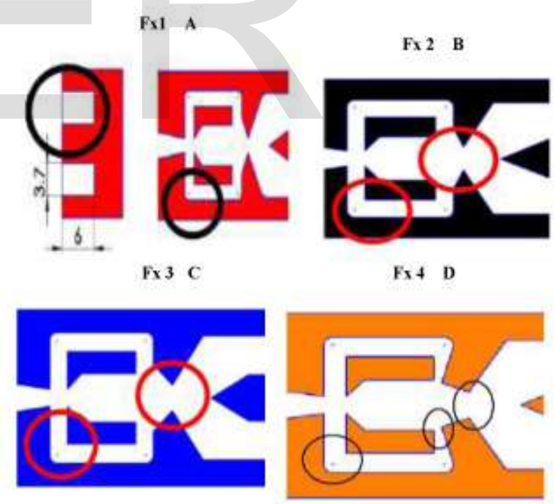

Fig. 18. Four fluidics models design variations .

The control parameters applied to model Fx 1 as shown in Fig. 18 A . are the depth of the whole fluidics channels which increased by magnification factor of 3.75, the width of the exit limbs which increased to 1.12 of the old one and the width of the feed back channels which reduced to 0.8 of the old width used in the 1st design variation. Other control parameters are applied to the design of Fx 2 as shown in Fig. 18 B . These parameters, applied to Fx2, are the control throat width which increased to 1.5 times the old width in addition to the whole

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changed parameters in Fx1- design. The control parameters applied to Fx 3 are as follows; the control throat angle increased to 1.7 times the old one in the 1st design variation (Fx0) and the throat length increased to 1.67 times Fx 0 in addition to the modulations parameters in Fx1 and Fx2. Figure 18 C shows Fx3 model with the new modifications.Finally some changes was applied to Fx 4 as shown in Figure 18 D. These changes are: the feed back channels' inlet width from the chamber side which decreased to 0.3 of the old width, the throat angle in exit direction increased to 2.64 times the old one, in turns the throat length increased to 1.83 times, and the throat exit width increased to 1.33 the old width.

These modulations are in addition to the modifications done in Fx1 from the 1st design variation.

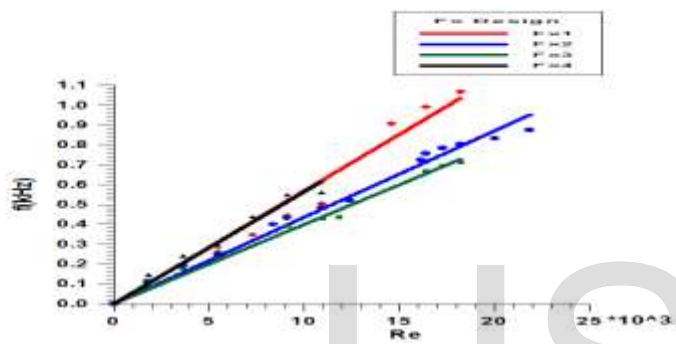

Fig. 19. Fluidics frequency comparison at different Re numbers of air flows for different fluidic oscillators.

The frequency contents of the signals at different mass flows offer a linear representation for the whole oscillator designed models as shown in Fig. 19. Up to Re 18205 (5kg/h) for the first three models, the relation is linear while it is only linear up to Re 10923 (3kg/h) for the last one. The trends for the first and the last models are almost symmetric in the common range. Also the pressure oscillations lie almost in the safe range far from the expected combustion instabilities up to Re 21846 (6kg/h) of air flow (see Fig. 20).

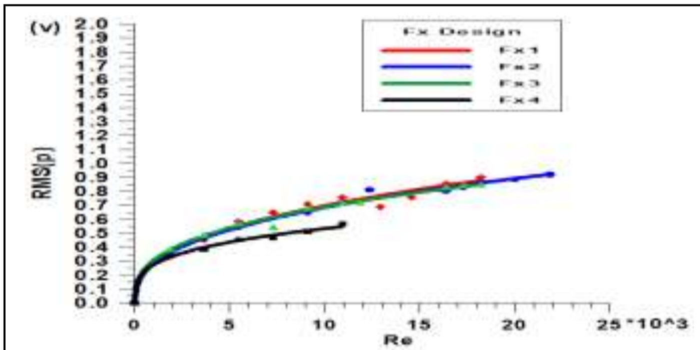

Fig. 20. RMS (p) [v] at different Re of flows for different fluidic oscillators.

than unity. The relation between Strouhal and Reynolds numbers for the whole four oscillator models appears in Fig. 21. The Strouhal number reduced to be in between 0.2-0.4 at about Re of 7*10^3. After that it gives almost linear trend for Fx1, Fx2 and F3. For the last model, the strouhal number was almost 0.8. Compared to Fx1, the strouhal number is reduced by 23.5% and 38.2% for Fx2 and Fx3 consecutively, while the number increased 2.35 times at Fx4. Oscillations as for Fx1 are characterized by the buildup and rapidly subsequent shedding of vortices for the whole models behind the flow splitter.

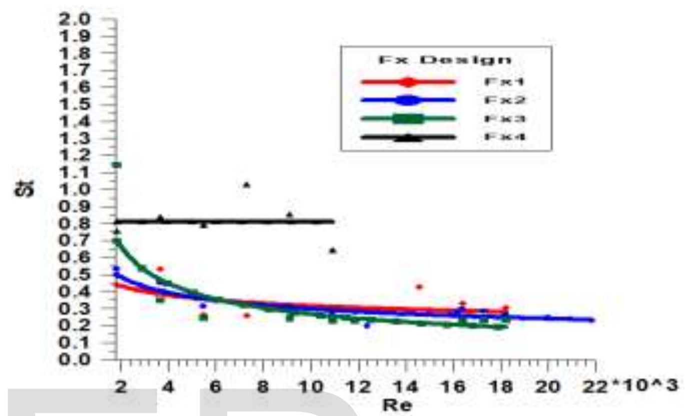

Fig. 21. St number at different Re numbers- HW mounted directly at exit of different fluidic oscillator models.

7 TEST RIG SETUP OF PIV AND WATER TUNNEL WITH THE FLUIDICS INSERTED INSIDE EV BURNER

The measurements when the fluidics is integrated in a lance inside a swirl stabilized burner are performed in a big water tunnel approximately 3000x 440x 440mm. The swirl stabilized burner with fluidic oscillator are mounted inside the big water tunnel and submersed in the water. Three water connections are required to simulate the gaseous flows in reacting combustion conditions with liquids as follows: one for the main flow, the second for the flow in fuel line, and the third one for fluidics flow (see Fig. 22). The Fuel line water flow rate is 224 Lit/h. The transfer of water from the main line inside the fluidic line is in maximum of 632 Lit/h from the total main water of 6.957 m^3/hr. The whole water momentum rates are equivalent to those of fuel and air at real reacting conditions.

One difficulty of applying PIV in liquid flow measurements in glass surfaces comes from the total reflection of a small part of the laser light inside the glass. These reflections lead to over exposure of the CCD chip and thus to velocity outliers in the PIV processing. If some of the minor reflections could be minimized through background subtraction, a major reflection was visible at the main flow field [17].

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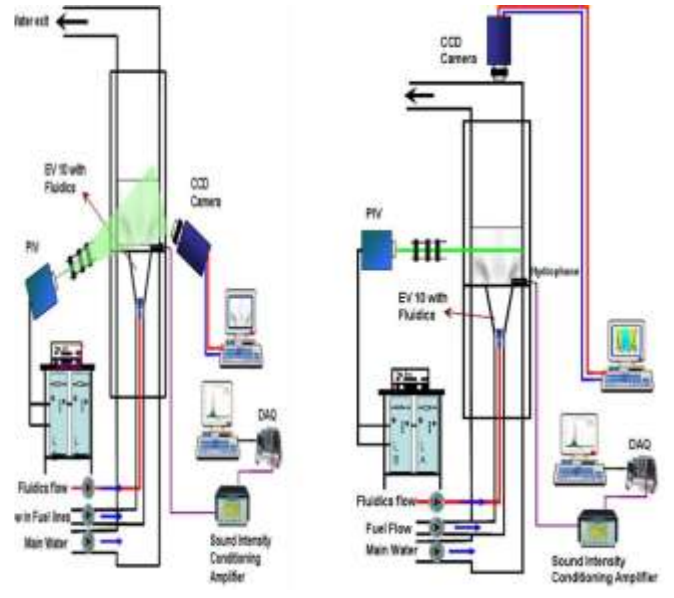

Fig. 22. Schematic diagram of the water tunnel with fluidics inside ev burner

The measurements schedule is performed in axial and azimuthal directions. In the axial measurements, the laser sheet was vertical and the camera was perpendicular to that sheet as shown in (figure 22 -A) while in the azimuthal measurements, the camera is mounted over the water tunnel in the direction of water flow and the laser sheet is horizontal (see figure 22 - B) .The hydrophone is mounted at the burner exit directly tangent to the dump plane while its sensor is adjacent to the flow field outer body for no resistance to the fluid flow. The momentum ratio is constant between water and air for Fx1, so the water flow rates are selected to be equivalent to the values of air flow rates. The total water mass flow is 6.957m3/h. This is equivalent to the main air value in the combustion test. The mass flow of water transferring inside the fluidic injector is selected in maximum of 474 kg/h. This water transfer keeps the total or the overall amount of water to be constant at the whole work.

8 THE FLUIDICS PERFORMANCE Fx1 AT THE BURNER BOTTOM (XF = 0).

The injection of fluid inside the oscillator at this location suppresses the oscillations and destroys the dominant peak by injecting around 2.3 % of the main flow (see Fig. 23) and more.This proves that the fluidic oscillator under test (Fx1) is able to dominate the oscillations produced from the main flow that exits downstream of the burner. This considers an indicator of stabilizing the flame in combustion tests. The corresponding frequency of the fluidics for the different pilot fuel ratios is as follows consecutively; at 0% (4.76 Hz), 2.3% (4.55 Hz), and 4.5% (4.57 Hz). The reduction ratio of the amplitude is almost 65% from the higher to the lower value by increasing the transferred fluid from 0% to 4.5%.

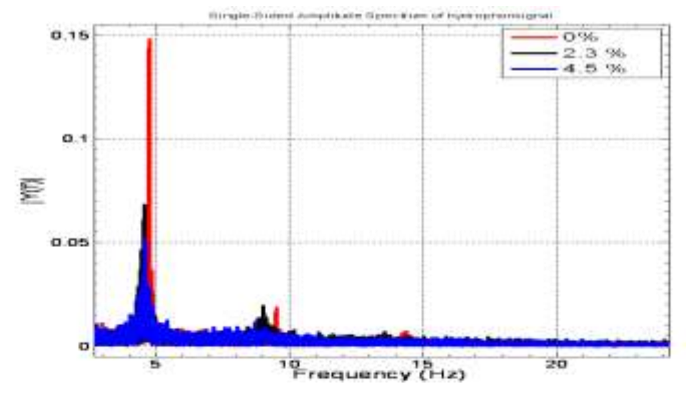

Fig. 23: Single-sided amplitude spectrum at different fluidics water volume flows % and at burner exit (XF=0)

The changes in the flow field are investigated by the laser PIV technique. Figure 24 shows the velocity profiles comparison between the base line and 4.5% of the main fluid flow as a stable case and at different axial locations. The increase in the fluidics fluid flow reduces the maximum streamwise velocity outside the burner at the location of the two lobes and increases the streamwise velocity at the centerline.

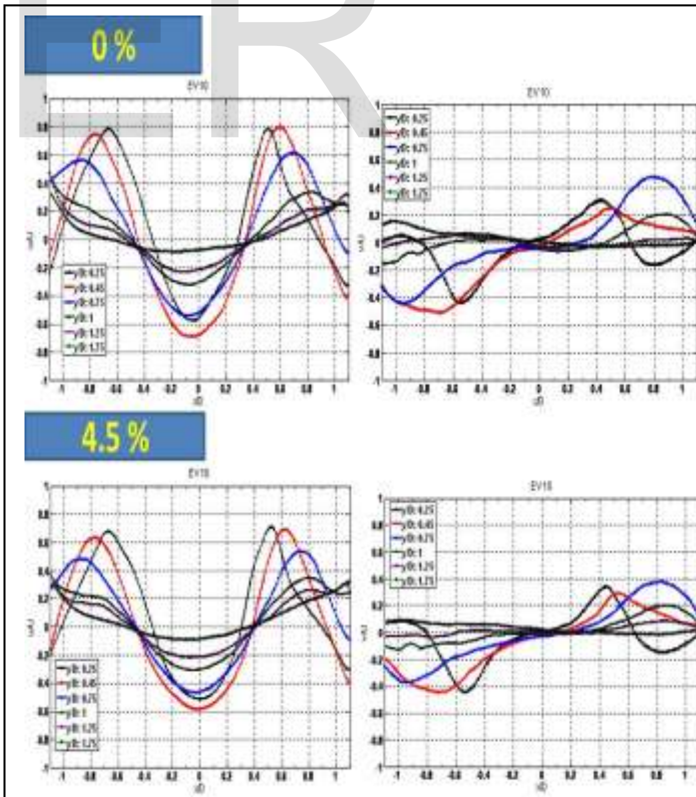

Fig. 24. velocity profiles comparison between the base line and 4.5% of the main water flow as a stable case at different axial locations (XF=0).

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The reduction ratio is about 9.4% of the maximum streamwise velocity lobes at no injection conditions or the base line at y/D = 0.25, 13.6% at y/D = 0.45, and 12.6% at y/D= 0.75. The increase of the central velocity is about 11% from the base line at y/D=0.25, 15% at y/D= 0.45, and 14% at y/D= 0.75. The reduction in the maximum radial velocity at y/D of 0.25 is 0%, 13.3% at y/D= 0.45, and 20.3% at y/D= 0.75 of the maximum one at the base line.The interaction between the central jet flow and the main flow is responsible for these changes in the velocities. The changes are also presented in the contour plots of velocity in Fig.25. The figure offers a window of flow field with the height of two times the burner diameter which is enough to cover the whole area of interest. The streamwise velocity reduction at the flow wings is noticed from the color plots while the central velocity increase is also represented by the change of color from dark blue to light blue. The changes in radial velocity are revealed in the right side color plots. Marginal changes are noticed in Fig. 26 for the vorticity and the shear strain rate by transfer of water from base case to 4.5% of the main flow.

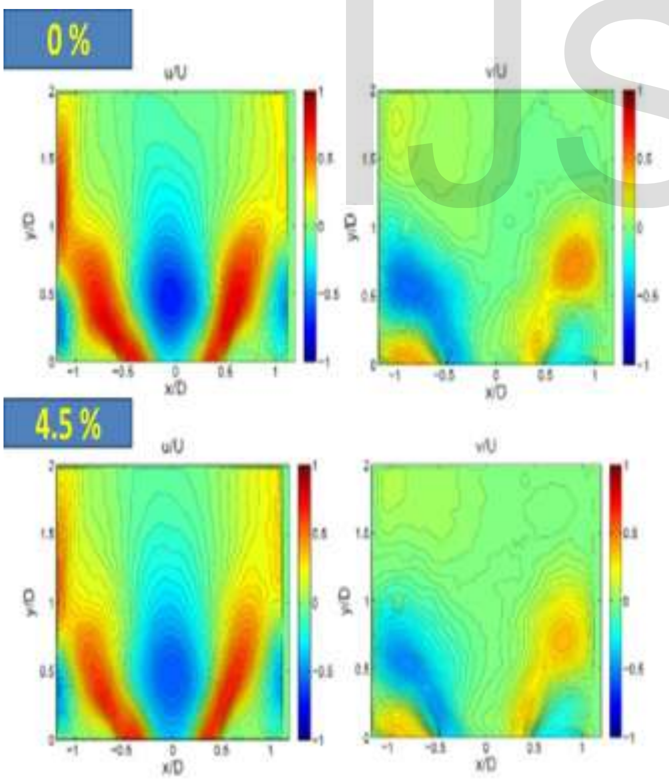

Fig. 25. Streamwise (left) and radial velocity (right) contour plots at fluidics water mass flows of 0% (up) and 4.5% (down) of the main water mass flow (XF=0).

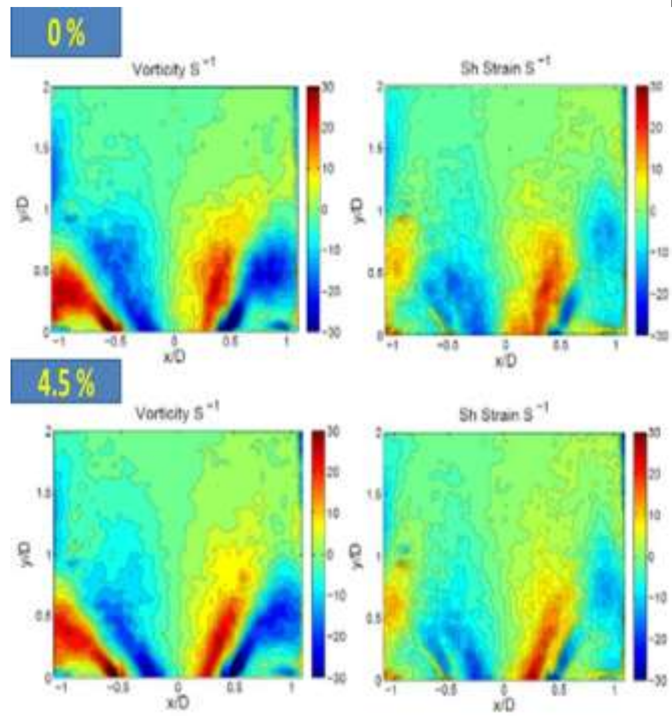

Fig. 25. Vorticity and shear strain contour plots at fluidics water mass flows of 0% (up) and 4.5% (down) of the main water mass flow (XF=0).

9 CONCLUSION

The fluidic oscillator is a device that generates an oscillating jet when supplied with a pressurized fluid.It considered also a feedback oscillator according to the conda effect described in the 1930's which describes the tendency for a jet of fluid issuing from a nozzle to adhere to the surface of the wall adjacent to it

The term fluidic device should be applied only to devices in which there are no moving parts except the fluid movement itself which works as a source of pulsations .The feedback oscillator is a free maintenance device which make it highly suitable for application in industrial gas turbines and besides that it has high durability. Also it can be used to measure the flow rate of the fluid as a flow meter or as a dynamic calibration device.

Inserting of fluidic oscillator in ev burner is considered one of the new ideas which need to be investigated. The performance of the oscillator in active control schemes which include high frequencies flow modulation. The influence of these oscillators on flame stability and combustion control.Also

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fluidic oscillator is used in the emissions reduction for the combustion engines, mixing of gases, dispersal of liquids.

The fluidic actuator's capability to generate an oscillating flow was tested at ambient conditions for three fluids: water, natural gas, and nitrogen. The fluidics frequency ranges from 1.0 Hz to 5.2 Hz and increases approximately linearly with the water flow rate. between 50 and 250 liters per hour. The intended frequency range was 30 to 200 Hz.with natural gas mass flows between 1 to 7.0 kg/h.While The intended frequency range was 20 to 180 Hz.with nitrogen mass flows between1.0 to 10.0 kg/h.

Increasing the mass flow through the fluidics as well as feeding the fluidics with natural gas instead of nitrogen resulted in higher oscillation frequencies. The minimum and maximum oscillation frequencies for both gases were in the order of 30 and 200 Hz, respectively, as desired.Additionally, the oscillation frequency increased approximately linear with increasing mass flow. Therefore the oscillation frequency of the fluidics is primarily a function of the volume flow rate between 1 and 10 m^3/h.

The fluidic oscillator in a combustion system is important to control the actuation frequency and amplitude. The fluidics' actuation amplitude and frequency can be controlled independently by controlling the natural gas and nitrogen flow fed into the fluidics supply. the actuation frequency can be adjusted by blending the natural gas mass flow with additional nitrogen, thus increasing the fluidics volume flow. The more nitrogen is added, the higher the actuation frequency.

The first oscillator design (Fx0) failed to produce a flow with fundamental frequencies coincide typically with those matching with combustion stability conditions. The fundamental peak frequencies are from 9.89- 11.44 kHz which is too noisy in range of 7468-22404 Re number calculated from the equivalent mass flow rates. In the oscillating chamber the working fluid in the feed back channels accelerates and respectively decelerates which leads to cause a reversal of the vortex after a time delay.

At 2nd design variation, four models are modulated from Fx0 and tested to find out the optimum one or more for pilot injector work inside the swirl stabilized burner in reacting flows. The depth of Fx0 rose to 3.75 times as performed in Fx1 while the width of the outlet channels increased to 1.12 times and the feed back channels reduced to 0.8 of the old one at Fx0.

The data evidenced that the fluid flow inside the fluidic oscillator can be modulated by the oscillator itself which is able to generate the oscillated flow without any other means or valves. The time history of the pressure oscillations for both outlets recorded at the vicinity of exit using couple of hot wires which present two sinusoidal signals. These signals, having the same frequency and referenced to the same point in time, are said to be out of phase with each other. The modification parameters reduce the frequency by around 10 times and increase the oscillation period to 11.41 times. Strouhal and Reynolds numbers are in linear relation. Oscillation at this range is characterized by the build-up and rapidly subsequent shedding of vortices and the oscillation is due to the flow instabilities as the Strouhal number is in intermediate range (0.34). Pressure oscillations are in the expected stable range of the reacting flow.

Other control parameters are applied to the design of Fx0 and produce three other models (Fx2, Fx3, and Fx4). The frequency contents of the signals at different mass flows show a linear representation for these oscillator models. Also the pressure oscillations lie almost in safe range of expected combustion instabilities. The Strouhal number is almost linear at a specified range which contains the combustion investigations. The velocity measurements demonstrate that the first fluidics is higher in velocity at the same Re with higher signal amplitudes.

The study of the flow field in the fluidics models using LIF and PIV is performed at a water aquarium. Subsequent applied Fourier transformation produced from the hydrophone signal exhibits a linear relation between the frequency and the volume flow rate. The oscillating period is affected by the volume flow rate as demonstrated from LIF recorded 250 fps data. The deflection in the jet stream towards the oscillating chamber is according to Coanda effect. The change in the modulation parameters of the different fluidic oscillators has an influence on the oscillating period also. This deflection period may control the industrial applications of the fluidics or may affect the exhaust emissions and instability if used in reacting flows.

Fx1 is inserted inside the swirl stabilized burner to study the flow field interaction between the oscillator and the burner. The test of Fx1 is performed in a big water tunnel (3000x 440x440mm) equipped with PIV technique for measurements of flow field and hydrophone system for detection of pressure oscillations inside the water regimes of the flow field.One axial location inside the swirl stabilized burner was investigated

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which was the burner bottom XF = 0. The injection of certain amount of fluid (air or water) inside the oscillator at this location suppresses the oscillations and destroys the dominant peak by injecting more than 2.3 % of the main flow for XF = 0 This proves that the fluidic oscillator Fx1 is able to dominate the oscillations produced from the main flow downstream of the burner. Also this considers an indicator of overcoming the instability in reacting flows. At the burner underside (XF=0), the increase in the fluidics water flow reduces the maximum streamwise velocity outside the burner at the location of the two lobes and increases the streamwise velocity at the centerline. The interaction between the central jet flow and the main flow is responsible for these changes in the velocities.

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