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An Experimental Study of the Micro Turbojet Engine Fuel Injection System

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Abstract

An experimental study was performed to develop the rotational fuel injection system of the micro turbojet engine. In this system, fuel is sprayed by centrifugal forces of engine shaft. The test rig was designed and manufactured to get droplet information on combustion space. This experimental apparatus consist of a high speed rotational device (Air-Spindle), fuel feeder, rotational fuel injector and acrylic case. To understand spray characteristics, spray droplet size, velocity and distribution were measured by PDPA (Phase Doppler Particle Analyzer) and spray was visualized by using Nd-Yag laser-based flash photography. From the test results, the length of liquid column from injection orifice is controlled by the rotational speeds and Sauter Mean Diameter(SMD) is decreased with rotational speed. Also, Sauter Mean Diameter is increased as increasing mass flow rate at same rotational speeds.

Introduction

The pressure atomizer, air-blast and rotary atomizer are used for fuel injection system of gas turbine combustor. Generally pressure atomizer or air-blast fuel injection system could be well meet the spray quality required from the gas turbine combustor. But these injection systems require precise and complicated components. So, it is very expensive and required long time to manufacturing its component. On the other hand, the rotary atomizer system operated by centrifugal force of the engine shaft doesn’t need the high pressure fuel pump. Also it is small and very simple in comparison with other fuel injection systems[1]. It was successfully adopted in Marbore engine of Turbomecha Company. Since then, it was adopted in J402 of Teledyne, F107 of Williams International and the others.

This rotational fuel injection system has been studied by Norster, Morishita and Dahm. According to Norster, SMD is order of 50 μm at the idle condition and 30 μm at the full load. He also deduced approximation equation (1) for the dependence of the droplet size(SMD) on the peripheral velocity V_P[1].

$$SMD = \frac{3,962}{V_P} \qquad (1)$$

From the study of Morishita, empirical equation (2) was derived for the droplet size(SMD) with peripheral velocity V_P, mass flow rate and diameter of rotational nozzle. This equation was obtained by measured droplet size from the photograph of collecting droplet on a silicon oil film on the glass plate which was located at 100 mm of radial distance away from rotating nozzle[2].

$$SMD = 3,300\frac{Q^{0.2}D^{0.3}}{V_P} \qquad (2)$$

Dahm performed the spray visualization for various shape of rotating fuel nozzle and tried to make some correlations of experimental data by Morishita[3].
When designing and developing the gas turbine combustor, it is very important to know the spray distribution, droplet size and velocity fields in all combustion area with respect to ignition and flame stability.

In this study, a spray test rig has been constructed for measuring spray characteristics of rotational fuel injection system by applying PDPA(Phase Doppler Particle Analyzer) laser diagnostic technique. By using this system, we measured droplet diameter (SMD), velocity distribution and spray pattern.

Experimental Apparatus

Spray Test Rig

Schematic diagram of spray test rig is shown in Fig. 1. The experimental apparatus consist of a high speed rotational device(Air-Spindle), fuel feeder, pressurizing water tank, rotational fuel injection nozzle, acrylic case and PDPA(Phase Doppler Particle Analyzer) system. The Air-Spindle and shaft are directly connected with rotational fuel injection nozzle. The axial direction of metering orifice and injection orifice is coincided. The measuring window was located on acrylic case which can be removed during the test.

We used water as test fluid. The water supplying process is as follows. Water is pressurized by high pressure air and it goes to metering orifices of fuel supplying nozzle. By the centrifugal force water is spread out on the inner wall of the rotational injection nozzle and then water enters several injection orifices. After passing through injection orifices water is spouted to ambient. Then the thin film or ligament is gradually broken and finally atomized to droplets. Sprayed water is continuously drained through the drain port at bottom side of acrylic case.

PDPA system is composed of a laser source(6W Ar-Ion), a transmitter, a receiver, a signal processor and 3-D traverse system.

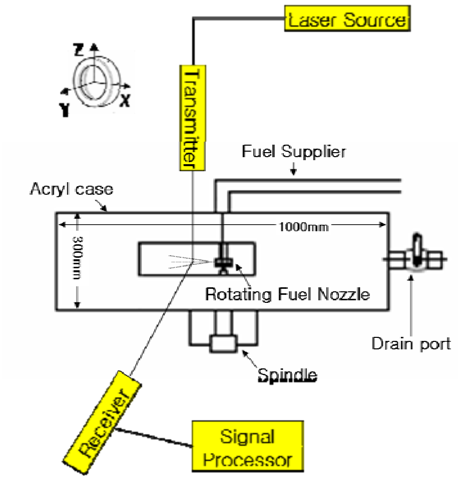
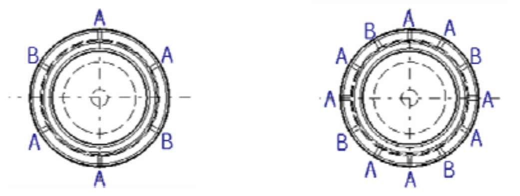


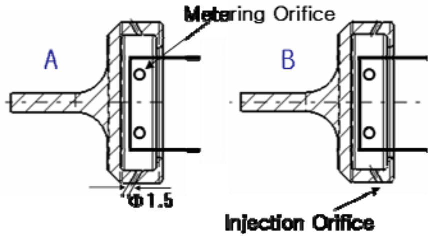
Fig. 1 Schematic Diagram of Spray Test Rig with PDPA System

Test Conditions

The spray test was performed under ambient conditions with water, 15, 30, 45, 60, 75, 90 kg/h of mass flow rate and 15,000, 20,000, 25,000, 30,000, 40,000 rpm. The rotational fuel injection nozzle is shown in Fig. 2. The diameter of injection orifice is 1.5 mm. We used two types of injection orifices which are shown in Fig. 2.



(a) 6 Injection Orifices (b) 12 Injection Orifices



A Section B Section

(c)

Fig. 2 Rotational Fuel Injection Nozzle

Fig. 3 shows PDPA measuring grids. The measuring positions are 720 points(360 points on x-y and y-z plane) and are automatically moved by 3-D traversing system. The maximum sampling data is 30,000 and maximum measuring time is 20 seconds for each point.

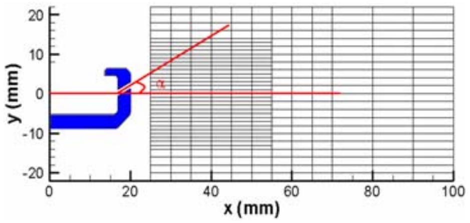


Fig. 3 PDPA Measurement Points

Results and discussion

Spray Visualization

Marshall divided breakup process with sub-critical, transition and super-critical breakup[4]. At sub-critical breakup with small Reynolds number, the liquid sheets spouted from injection orifice disintegrate a single liquid column and then is evolved into large drops of fairly uniform size. This is the Rayleigh mechanism of breakup. At transition breakup, the breakup of the jet is by jet oscillations with respect to the jet axis. The magnitude of these oscillations increases with air resistance until complete disintegration of the jet occurs. A wide range of drop sizes is produced. At super-critical breakup, atomization is complete within a short distance from the discharge orifice.

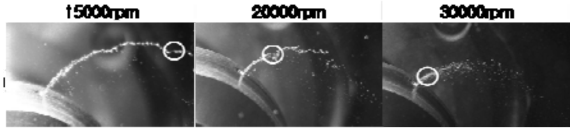


Fig. 4 Spray Visualization with Rotational Speed

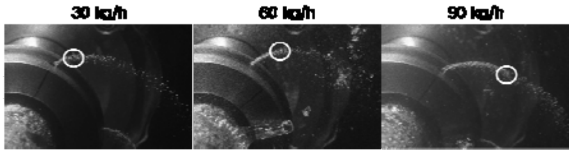


Fig. 5 Spray Visualization with Mass Flow Rate

Fig. 4 shows breakup process of spray with rotational speed of 15,000 20,000, 30,000 rpm on mass flow rate of 15 kg/h. As shown in Fig. 4, the breakup process of spray on 15,000 rpm is corresponded to sub-critical breakup and the liquid sheets that issues from injection orifice are drawn into a single liquid column that then undergoes breakup process. The distance of liquid column is rapidly decreased at 20,000 rpm. Over than 30,000 rpm, the jet nearly disintegrates from injection orifice. Hence, we can understand that this condition is reached to the super-critical breakup.

Fig. 5 shows breakup process of spray with mass flow rate on 30,000 rpm. The length of liquid column is increased with increasing mass flow rate.

From this visualization, we could understand general spray pattern of the rotational fuel injection system.

PDPA Measurement

Fig. 6 shows volume flux at rotational speed of 20,000 rpm and mass flow rate of 15 kg/h. The jet is concentrated along injection orifice angle(30^{o}) on 6 injection orifice case. On the other hand, the spray is dispersed wider area on 12 injection orifice case. Also, the volume flux is appeared larger on y (-) zone corresponded to A section of rotational nozzle than y (+) zone corresponded to B section.

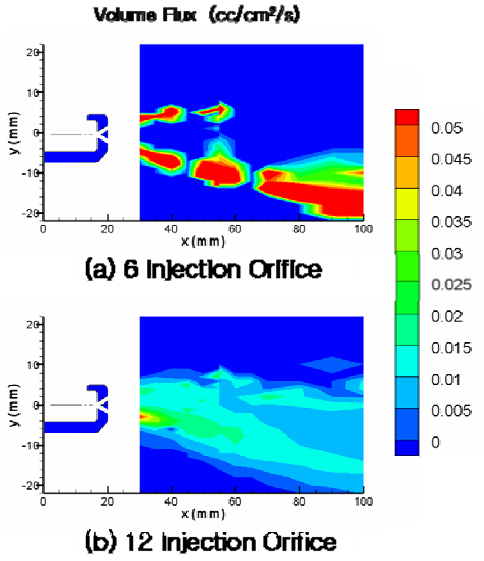
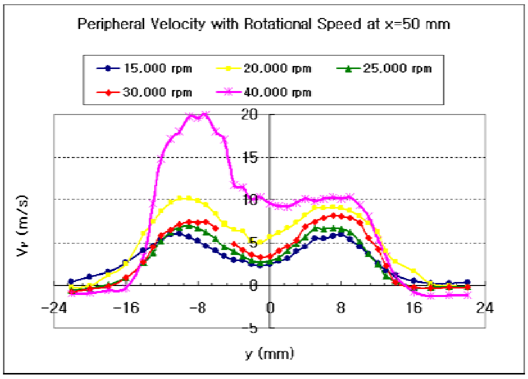


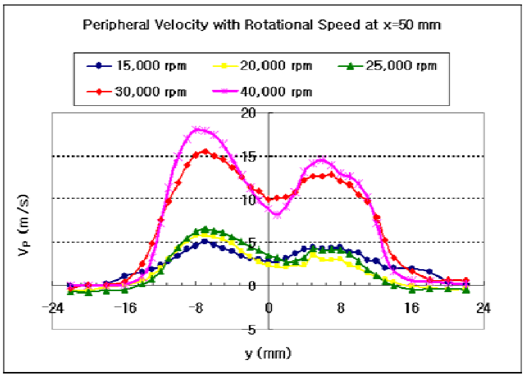
Fig. 6 Contour of Volume Flux

Fig. 7 shows peripheral velocity with rotational speed at x = 50 mm. The peripheral velocity is increased with rotational speed. From Fig. 7(a), the peripheral velocity is slightly increased with increasing rotational speed from 15,000 rpm to 30,000 rpm. But peripheral velocity is rapidly increased at 40,000 rpm. Also, the peripheral velocity of y (-) and y (+) zone is similar at rotational speed of 15,000, 25,000 and 30,000 rpm. But the peripheral velocity of 40,000 rpm is more largely increased on y (-) zone than y (+) zone. From Fig. 7(b), the peripheral velocity is rapidly increased over than rotational speed of 30,000 rpm. Also, over then 30,000 rpm, the peripheral velocity is appeared larger on y (-) zone than y (+) zone.

Fig. 8 shows peripheral velocity with mass flow rate at x = 50 mm. When increasing mass flow rate, the peripheral velocity is also increased. When increasing mass flow rate from 15 kg/h to 60 kg/h, the peripheral velocity is increased on 6 injection orifice case at (a) in Fig. 8. But the peripheral velocity is similar on 12 injection orifice case at (b) in Fig. 8

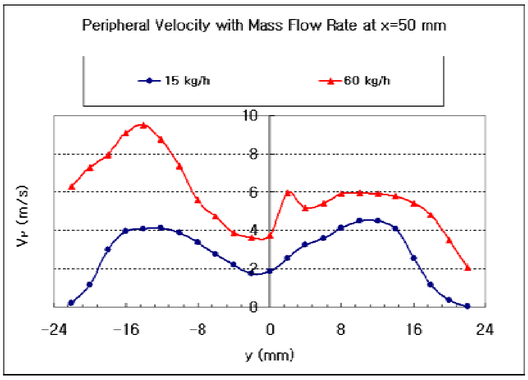


(a) 6 Injection Orifices

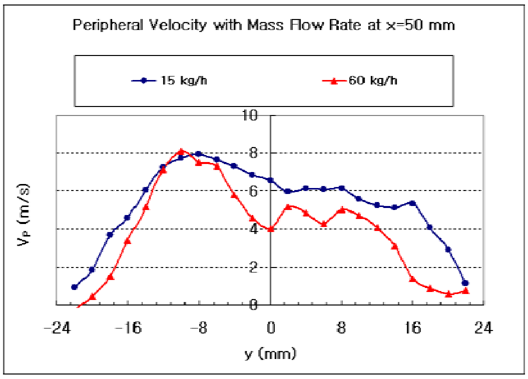


(b) 12 Injection Orifices

Fig. 7 Peripheral Velocity with Rotational Speed at x = 50 mm



(a) 6 Injection Orifices

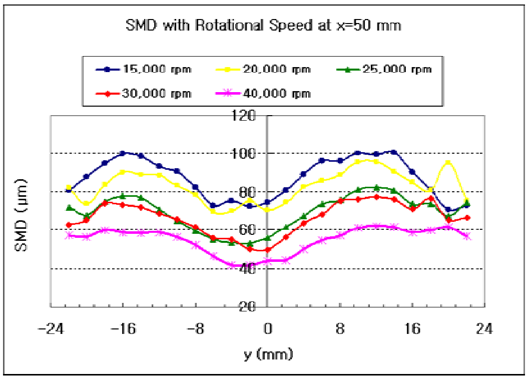


(b) 12 Injection Orifices

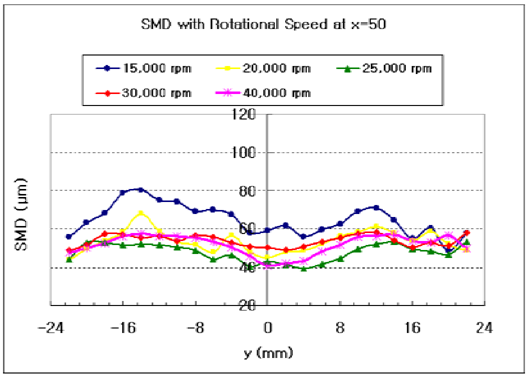
Fig. 8 Peripheral Velocity with Mass Flow Rate at x = 50 mm

Fig. 9 shows droplet diameter(SMD) with rotational speed on mass flow rate of 15 kg/h. The SMD(Sauter Mean Diameter) is decreased with rotational speed. This result can be explained by the visualization from Fig. 4 and the velocity data from Fig. 7. When rotational speed is increased, the peripheral velocity is also increased. So, the relative velocity between surround gas and ejected water is increased. As shown in Fig. 4, these velocity differences make short length of liquid column and finally it goes well atomization. The Sauter mean diameter which is below then 60 μm is founded on 40,000 rpm at 6 injection orifices case and 20,000 rpm at 12 injection orifices case. Therefore, 12 injection orifices case gets smaller droplet size at lower rotational speed.

Fig. 10 shows SMD with mass flow rate on rotational speed of 30,000 rpm. As shown in Fig. 5, the length of liquid column is proportional to mass flow rate. Since inertial force and surface tension is increased with increasing mass flow rate, the droplet size(SMD) is increased with mass flow rate. This result is considered that the atomization with increasing mass flow rate is largely affected by inertial force and surface tension than peripheral velocity. In the axial direction, the droplet diameter difference for 30 kg/h is about 30 μm at the 6 injection orifices case and 10 μm at the 12 injection orifices case. From this, 12 injection orifices case is more uniform spray than 6 injection orifices case.

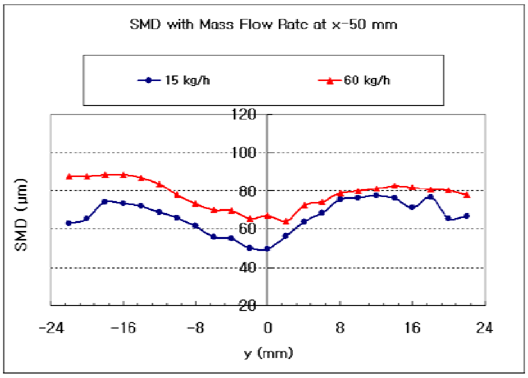


(a) 6 Injection Orifices

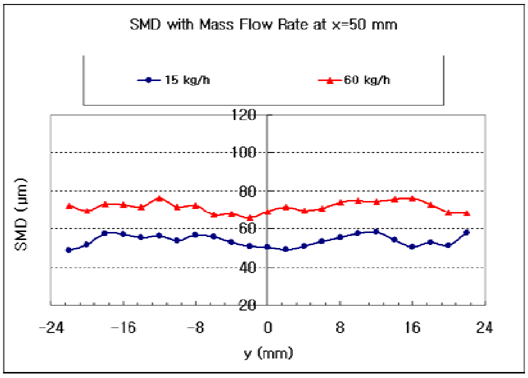


(b) 12 Injection Orifices

Fig. 9 SMD with Rotational Speed at x = 50 mm



(a) 6 Injection Orifices



(b) 12 Injection Orifices

Fig. 10 SMD with Mass Flow Rate at x = 50 mm

Conclusions

The objective of this study is to understand spray characteristics of high speed rotational fuel injection system with rotational speed, mass flow rate and the number of injection orifices. The droplet size, distribution and velocity of spray were measured by PDPA(Phase Doppler Particle Analyzer) and spray was visualized by using Nd-Yag laser-based flash photography. The summaries of test results are as follows:

1. When increasing rotational speed, the length of liquid column is diminished, the peripheral velocity is increased and the SMD is decreased.

2. The length of liquid column, the peripheral velocity and the droplet size(SMD) are increased with mass flow rate.

3. The jet is concentrated along injection orifice on 6 injection orifice case. The spray is dispersed wider area on 12 injection orifice case.

4. The SMD is smaller on 12 injection orifice case than 6 injection orifice case. In the 12 injection orifices case, the spray is more uniform and droplet diameter is smaller than 6 injection orifices case.

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