Study of the Thermal Bubble Inkjet Technology on Motorcycle Engine Application

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Abstract

A new fuel injection concept called micro-pulsation fuel injection (μPFi) system had been installed in a commercial 4 stroke, 125 c.c. motorcycle engine for feasibility study. The thermal bubble inkjet technology is used on the design of digital controlled μPFi system in this study. This system is composite by the arrays of the thermal bubble micro-fuel injectors, which could be operating in high ejection frequency and with fine fuel droplets into the intake pipe on engines by accurate control mode. The advantages of digital control on fuel droplet atomization are active control of fuel ejection volume and optimization of combustion efficiency. The atomized fuel droplet volumes are controlled within 100 ~ 500 pl. The endurance test of the μPFi fuel supply assemblage had accumulated over 200 hours in a bench. It could be afforded a motorcycle to drive more than 10,000 km accumulated-mileage at constant speed 50 kph. The engine tests show that the μPFi engine improved BSFC by up to 15%, relative to carburetor engine. In addition, the motorcycle with μPFi system achieves superior exhaust CO emissions than the carburetor system while keeping comparable performance.

Introduction

The application opportunities of MEMS (Microelectromechanical Systems) in the automotive market are expected to continuously constitute a significant part of the MEMS market by the year 2005. MEMS offer the major advantages of cost and performance to automotives because of its promising characters on mass-production and miniaturezation. It is apparent that there have been many mature MEMS applications in the automotive industry, such as MAP and airbag acceleration applications. Today, there are a number of concepts or MEMS approaches in early stage including wheel speed sensor, coolant pressure, and engine oil pressure sensor. Up to now, nearly all systems in automobiles are being evaluated for possible MEMS solutions. However, the only known fuel injection application used MEMS approach is fuel injector nozzles, which have been used micro-machined silicon to create highly uniform and rectangular orifices.[1]

Microsystems packaging is a critical factor in commercializing micro systems. For example, the cost of packaging micro pressure sensors can vary from 20% to 95% of the product's total cost. Due to the lack of micro systems packaging standards and design methodology, most of the MEMS concepts are usually diminished.[2] Thus, adopting the familiar packaging technology of micro systems is the best way to reduce engineering tasks for favoring commercialization in the future.

In addition, the needs to precisely control the movement of micro scale have become increasingly important for dosing, metering and spraying fluids. Therefore, various applications are rapidly adopted by the inkjet technology in recent years. The estimated market value is more than $2.5bn after four years.[3]

The concept of MEMS application in automotive to replace solenoid injectors for vehicle evaluation has not been mentioned by others. This study adopted the thermal bubble inkjet printing technology for packaging gasoline fuel injectors. At the same time, in order to add fuel-circulating device and to overcome different fluid properties between ink and gasoline, various fabrication and testing approaches are investigated.[4-6] In this study, a prototype μPFi system was developed and installed in a commercial 125c.c. motorcycle to compare the vehicle performance of the carburetor system.

The schematic concept of μPFi is shown in Figure 1. The potential advantages of μPFi system include:

- Fuel quantity can be metered and delivered in accurate amount by the engine management system to obtain optimum combustion efficiency.
- The fuel can be spatially distributed by activating each micro pump individually to achieve stratified-charge mixture.
- Minimization of mechanical moving parts of the micro pump has potential benefit to be a low cost injection system as MEMS technology progresses.

In this study, an application to a 4-stroke 125c.c. motorcycle, fuel is injected into the intake duct through array of 8 sets of thermal bubble fuel injector. Figure 2 is a photo of the thermal bubble fuel injector. Each thermal bubble fuel injector has a chip with the size of 5.5 mm × 7.75 mm. The interior of chip has 100 nozzles and which diameter is 80μm.

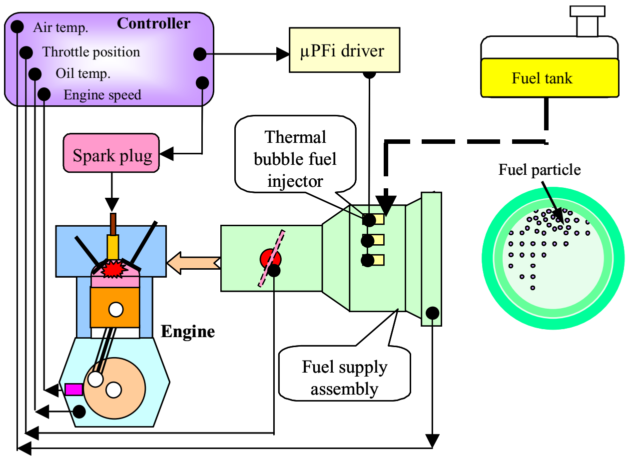


Figure 1. Schematic concept of µPFi.

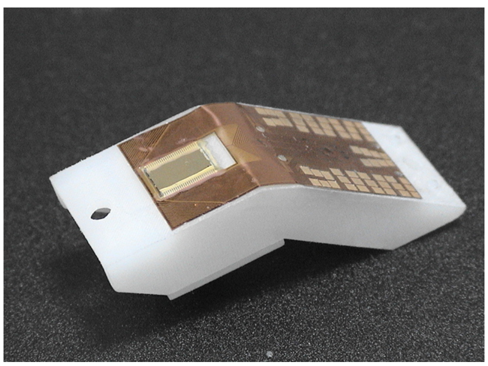


Figure 2. Thermal bubble fuel injector.

Testing Apparatus

(1) Testing Apparatus of Thermal Bubble Fuel Injector

The experimental apparatus to validate the thermal bubble fuel injector is shown in Figure 3. The function of this rig is to investigate fuel-circulating feasibility, to observe fuel spray characteristic, and to measure injection flow rate. A fuel-circulating device and a fuel temperature regulator are set up to regulate negative fuel line pressure and fuel temperature in the interior of the thermal bubble fuel injector. All the controllable parameters in this rig include: negative fuel line pressure, fuel temperature and control signal.

(2) Engine Testing Apparatus

The constant 50km/h road load is considered as the most representative operation condition of the ECE-40 test mode in chassis dynamometer for small scooters. This road load is equivalent to engine torque 2.8N-m and 5160rpm for a 125c.c. 4-stroke motorcycle engine. The verification of µPFi system on an engine is tested without catalyst and secondary air to get raw emissions. Also, a same engine with solenoid injector and a carburetor fuel system are tested for comparison.

Figure 4 shows the engine testing apparatus, which include the 125 c.c. 4-stroke motorcycle engine, system controller, µPfi driver, fuel tank, pressure control system, throttle body and µPFi module. The photography of engine testing apparatus was shown in figure 5.

Figure 6 is a fuel supply assembly of the throttle body, adapter, 8 sets of thermal bubble fuel injectors, and flexible cables. The connection of flexible cables and signal contact pads are located between injector and flat upholder at the upstream throttle body. The upstream and downstream ducks near the throttle plate are non-concentric design. The purpose is to eliminate the problem that the wetting fuel at the bottom of the upstream duck could not easily flow across the barrier, which will happen if it adopts concentric design.

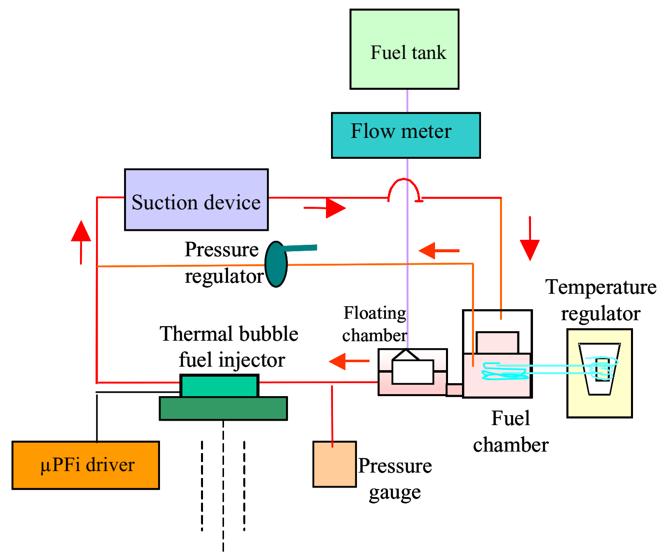


Figure 3. Flow testing rig of the thermal bubble fuel injector.

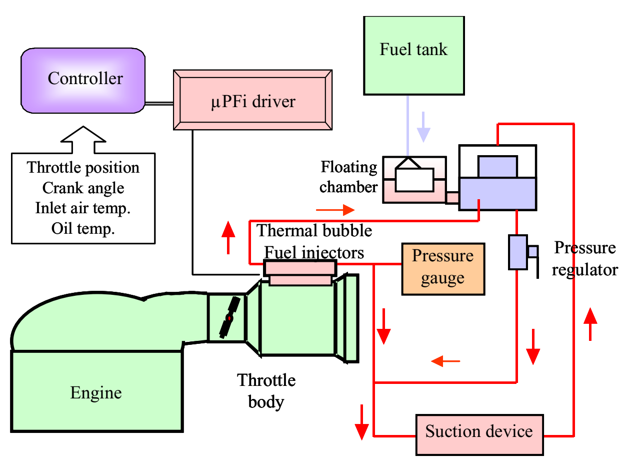


Figure 4. Engine testing apparatus.

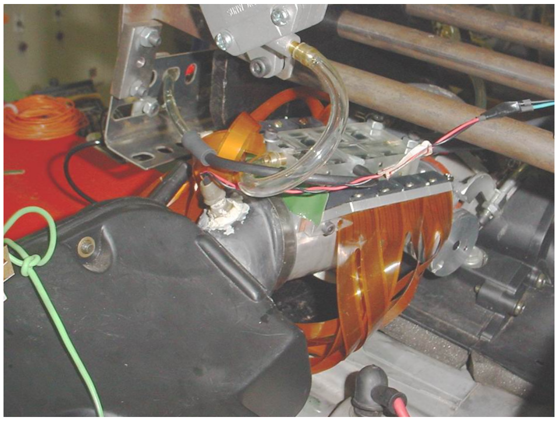


Figure 5. Photography of engine testing apparatus.

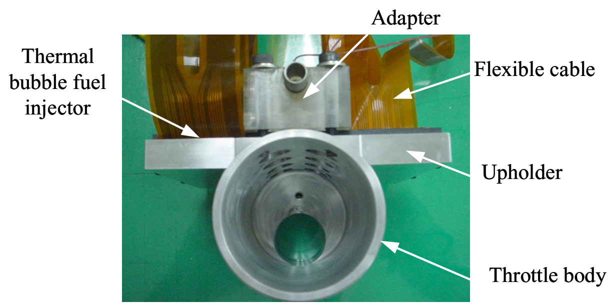


Figure 6. Throttle body module.

Results and Discussion

(1) Observation

In this study, the observations of fuel droplet ejection include fuel droplet observation, fuel spray into atmosphere, and the fuel particle flight images near nozzles. When using a CCD camera with microscope and image acquisition system photos the droplet ejection, it could find the velocity of the front edge in fuel droplet (see Figure 7). In the figure 8, the particle flight image was observed by LED stroboscope. Furthermore, the spray pattern influenced by airflow is also photo by digital camera. Figure 9 shows the comparison of fuel penetration and particle spray pattern between two different conditions of input electrical power. The higher electrical power will get the shorter penetration and the smaller size of fuel particles in comparison with the other.

(2) Backpressure of the Throttle Body in Different Vehicle

Figure 10 shows the backpressure in the throttle body near the micro pumps is measured in different vehicle speed. If the negative fuel line pressure of μPFi is maintained constant, over-suction will occur as engine load increase, which greater pressure difference between intake duck and micro pumps. The fuel inside micro pump will be forced to drip. In other words, the larger backpressure will get suction effect relative to micro pumps. If the vehicle speed increased, part fuel consumption will come from the suction effect due to backpressure. Thus worse spray will come out. However, the way to control and preserve constant differential pressure is not considered. For simplifying the experiment, the negative fuel pressure of μPFi was regulated to constant –20mmH_2O in this study.

Figure 7. LED stroboscope for droplet observation.

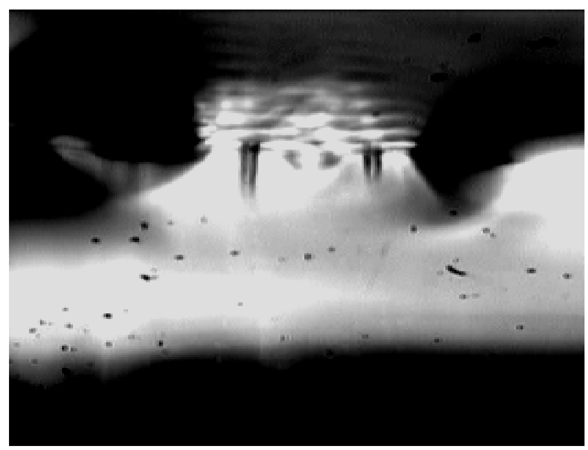


Figure 8. Particle flight by LED stroboscope photography.

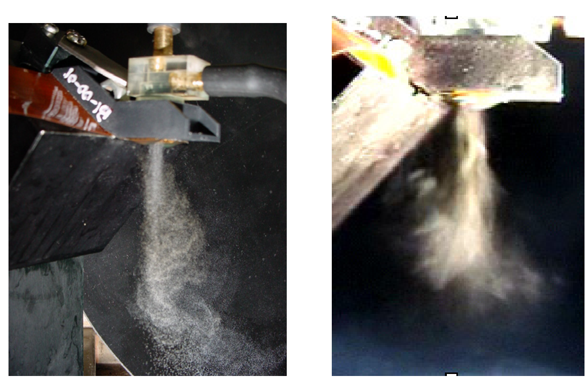


Figure 9. Spray pattern with one shot flash in different electrical power.

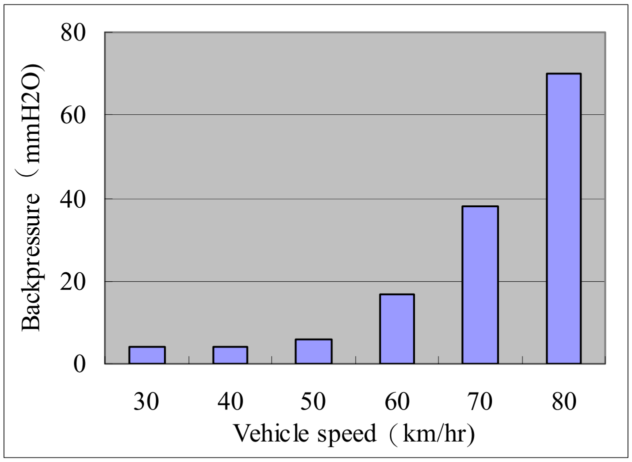


Figure 10. Effect of vehicle speed on backpressure.

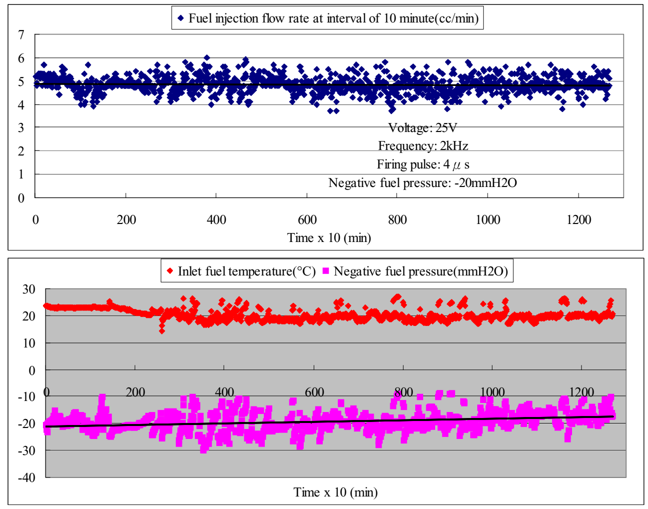


Figure 11. Endurance test for thermal bubble injector.

(3) Injector Endurance Testing

The endurance bench test condition is also set as 25V, 2kHz frequency, 4 µs firing pulse, –20mmH_2O negative pressure, and gasoline temperature 22°C. The bench test for the µPFi fuel supply assembly is shown in Figure 11. The endurance test of the µPFi fuel supply assembly accumulated over 200hrs in a bench. It is equivalent to $1.5x10^9$ injection lifetime for micro pumps. In other words, it is equivalent to motorcycle to drive more than 10,000 km accumulated-mileage at constant speed 50 kph. In comparison with starting value, the ending injection flow rate remains the same (4.9 cc/min for a thermal bubble injector). However, it is also found that the variation of negative fuel line pressure during test had effect on stable injection flow rate.

(4) Engine Testing

The engine test results of fuel consumption and emissions are shown in figure 12 and Figure 13. In the figure 17, the fuel consumption results show that the µPFi engine improved BSFC (Brake Specific Fuel Consumption) by up to 15%, compare to carburetor engine. In addition, the µPFi has the potential for leaner engine operation. However, the stability of µPFi system is worse than the other fuel systems. The comparison of HC emission shows that the motorcycle engine with µPFi system achieves superior exhaust HC than the injector system if air-fuel ratio is exceeded 16 at the condition of suitable control. In addition, it also achieves superior exhaust CO emission than the carburetor system.

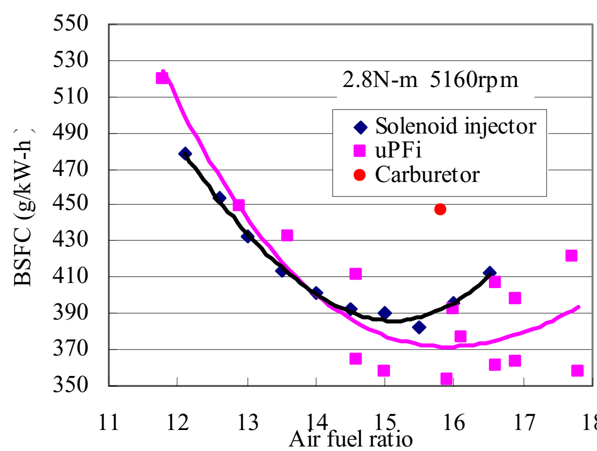
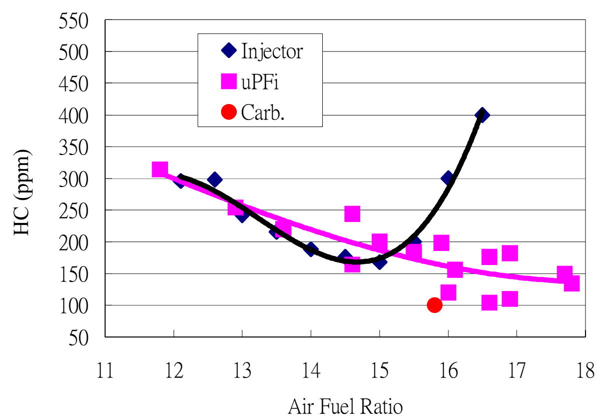


Figure 12. Comparison of BSFC with different fuel supply system (without catalyst and secondary air)



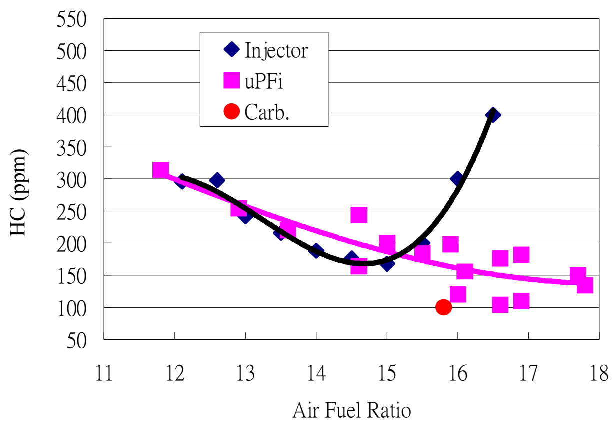


Figure 13. Comparison of CO and HC emission with different fuel supply system.

Conclusion

In this study, the thermal bubble fuel injector was developed and installed in a commercial 125 c.c. motorcycle engine, successfully. In the bench testing, the life of fuel injector is more than 200 hrs, it is equivalent to 1.5×10^9 times ejecting by each of every nozzle. In the part of fuel consumption and emissions, the fuel consumption of µPFi was improved BSFC (Brake Specific Fuel Consumption) by up to 15% compare to carburetor engine.

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Biographies

Yu-Yin Peng joined the Advanced Vehicle and Power Technology Division of MIRL/ITRI in 1983. He received his M.S. degree from Department of Power Mechanical Engineering of National Tsing Hua University in 2001. His research always focused on combustion system of engine in past twenty years. Recent research is regarding to application investigation of MEMS technology on fuel system of small engines. He was awarded the national inventor prize of Taiwan in 1992.

Ching-Yi Mao received his M.S. degree in Institute of Electronic Engineering from National Tsing Hua University, Hsinchu, Taiwan, in 1999. He joined the Printing Technology Division of OES/ITRI in 2000. His current research includes thin film process, ink jet print head chip design and failure analysis of ink jet head. He is the section manager of Print Head Development & Manufacturing Section.

Tien-Ho Gau joined the Advanced Vehicle and Power Technology Division of MIRL/ITRI in 1987. He received his M.S. degree from Department of Mechanical Engineering of Tamkang University in 1986. His interest lies in the technology related to the emissions & engine power improvements on small engines, and the system integration with innovations.

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Jinn-Cherng Yang jointed the Printing Technology Division of OES/ITRI in 2001. He received his M.S. and Ph.D from Institute of Aeronautical and Astronautical Engineering of National Cheng Kung University. His interest lies in the turbulent flow field of computational fluid dynamics, numerical simulation of two-phase flow. He is the section manager of Print Head Testing Section.