

Flow Modulation Valve Evaluation for Active Combustion Control Applications

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Objective: Perform experiments on electromagnetic (EM) valve to demonstrate its flow modulation performance.

Achievements:

- Helped Parker R&D team configure experimental hardware and prepare data acquisition software
- Analyzed EM modulation valve's characteristic behavior in a series of flow modulation experiments.

Comments on the UTSR Fellowship Program:

- My summer fellowship at Parker Hannifin was a great opportunity to apply concepts and abilities learned in academia on a real world application in the combustion field. I acquired new skills (ex. learned to use DAQ hardware and software) and expanded my knowledge base (ex. learned concepts of active combustion control).
- Parker engineers and staff were very helpful and supportive. While being supervised and working alongside workplace professionals from various engineering disciplines I gained valuable industry experience and expanded my knowledge of engineering fields outside my own.
- UTSR Gas Turbine Industrial Fellowship program made it possible for me to learn engineering field from inside, which in turn helped me confirm my career choice and focused my interests – an important milestone for entering graduate student like myself.
- Working for a big company, such as Parker Hannifin, allowed me to meet lots of new people and practice networking skills. Working in a team on the same goal is an excellent opportunity to practice communication and teamwork skills.

Acknowledgements

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- Adel Mansour, Ph.D., R&D Technical Team Leader
- Westley Latuch, Lead Laboratory Technician

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Project Background

In propulsion, active combustion control systems (ACCS) are desired to continuously monitor and actively stabilize the combustion process in modern aircraft gas turbines. As set out by the Propulsion Control and Diagnostics Research Program under NASA Aeronautics Research Mission active control of aircraft engine combustion systems has the potential to significantly reduce emissions in gas turbine engines, increase efficiency of fuel burning, suppress thermo-acoustic instability and blowout, increase life of turbine blades, and dampen other structural damage of gas turbine components.

Active combustion control schemes target the following objectives: emission reduction, combustion instability control, and pattern factor control. Emission minimizing control is mainly focused on reducing NO_x (Nitrogen Oxides) production through active control of the fuel/air mixture ratio. Combustion instability control involves controlling thermo-acoustic instabilities

associated with lean burning (i.e. fuel/air ratio less than one). Lean burning allows for reduced combustion temperature, high efficiency, and lower NO_x emissions. However, running combustion “lean” makes it susceptible to thermo-acoustic driven pressure oscillations. Active control of these instabilities will allow combustor designs to move towards a lean burning solution without sacrificing engine safety. Pattern factor control is intended to control thermal loads of turbine engine combustor. Pattern factor is a measure of the spatial uniformity of the temperature at the combustor exit. Temperature gradients (the cause of hot spots) determined by temperature pattern factor increase emissions and shorten the life of downstream turbine engine components.

A key technology required for ACCS systems is a fuel flow modulation valves. Incorporation of such valves with appropriate sensors and a closed-loop control system should produce “smart” components (e.g. fuel injectors) that accomplish ACCS objectives. Successful implementation of these control systems would result in safer, more efficient, and longer lasting engines.

Valve Description

There are a number of valves that can be used for fuel modulation in gas turbine engines. Piezoelectric valves, for example, operate by electrically stimulating piezo actuators. They are effective for low-power valve drive systems but have a drawback in limited stroke and the need for temperature compensation because of difference in thermal expansion coefficient between a piezo actuator and its housing. Other existing flow modulation valves are insufficiently responsive or accurate at regulating fuel sent through the fuel injection systems. There is a need

for high modulation frequency and fast response valves, without the drawbacks of piezoelectric valves.

The electromagnetic valve tested in this project is based on electromagnetically actuated spool. By actuating electromagnet(s), the spool can be driven open or closed to modify fuel flowrate. The open/close movement of the spool within valve housing, controls fuel flow through the valve. The modulation authority (percentage of the maximum flow) can be controlled, for example, by an actuation duty cycle while keeping inlet pressure and actuation frequency constant. The EM valve tested on this project is capable of high frequency actuation – frequencies ranging from 0-600Hz. It is potentially viable for implementation as part of an ACCS system.

Experimental Setup

A test rig was assembled to characterize the EM valve described above. It consists of two flow legs connected in parallel (Figure 1). The merged flow exits to a flow restrictor with predetermined flow number. The two legs are constructed for maximum flexibility in testing. There are two pressure sensors, one upstream of the modulation valve and one downstream; these are used to determine the effective flow number of the valve during operation. Measurements were recorded for two different DAQ configurations: one using existing hardware and software, and a second using National Instruments (NI) data acquisition card and LabVIEW software. Driving the valve controller electronics as high as 600Hz required implementation of new hardware and software, this was a key objective of this project. Delivery pressure was controlled by 3-way servo valve, and flow rate was measured using a precision flow meter. An accumulator was installed upstream to dampen pressure spikes generated by fuel modulation.

Hydraulic fluid for testing purposes was a widely used fluid in the calibration of aircraft fuel system components.

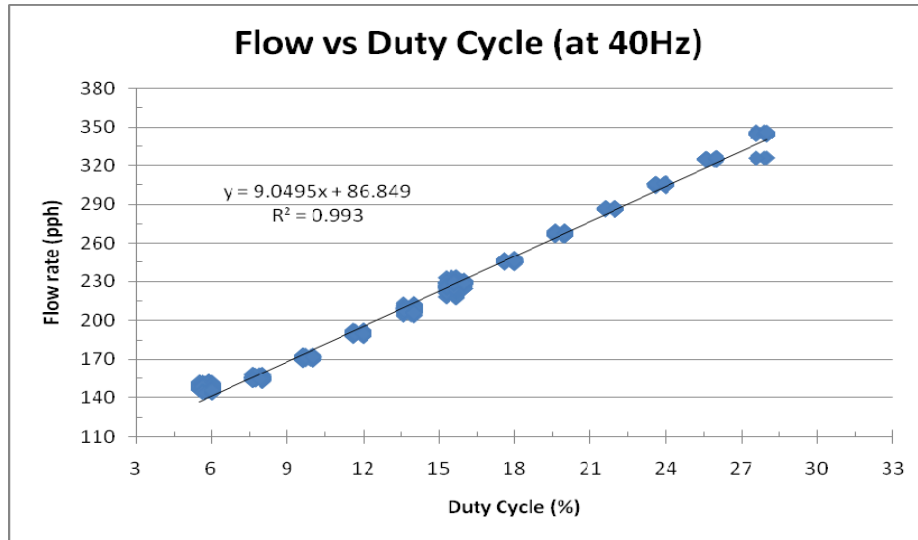
Figure 1. Test rig configuration schematic.

Data acquisition software code for NI LabVIEW was written to vary: (1) pulse width of the pulses to EM coils, (2) actuation frequency, and (3) actuation duty cycle. Duty cycle is controlled by changing the ratio of open time to closed time. Data from pressure sensors and flow meter with corresponding frequency and duty cycle values were recorded and exported to MS Excel for analysis.

Results Summary

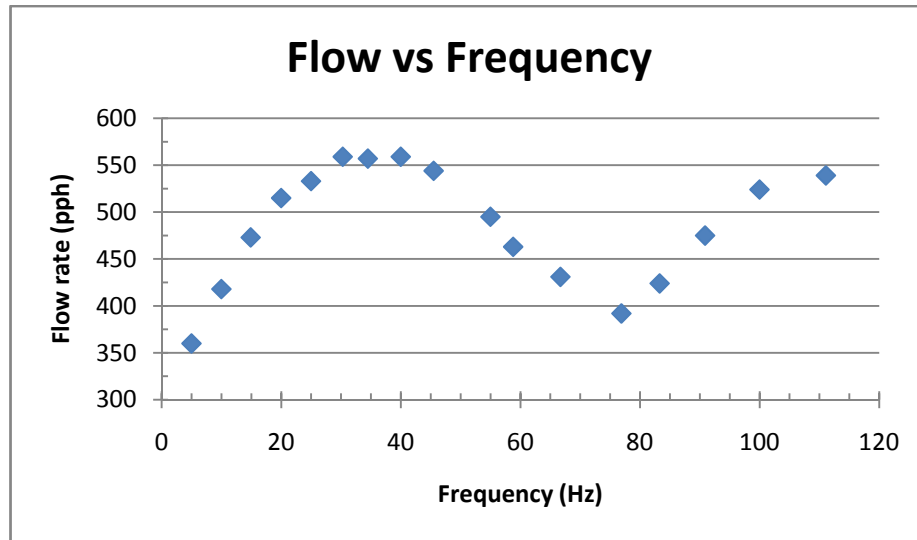
The goal of testing EM valve was to measure the valve's ability to adjust fuel flow under a variety of experimental conditions, which include varying inlet pressure, fuel flowrate, actuation frequency, and actuation duty cycle. Fuel flow rate is modulated by adjusting actuation frequency and actuation duty cycle for a given set inlet pressure. The first set of experiments was done by fixing inlet pressure and frequency, and then adjusting duty cycle to vary flow

modulation authority. The relationship observed between flowrate and duty cycle was linear, independent of pressure or frequency values (see Graph 1 for a sample graph obtained in the experiments, the graph contains about 5000 data points). However, pressure and frequency determined the slope and y-intercept of the linear fit.



Graph 1. Sample Data of Flow vs Duty Cycle.

From the control standpoint, it would be ideal if duty cycle could be the only variable in controlling authority of fuel modulation, i.e., actuation frequency did not have any effect on flow rate. However, testing showed that flow rate is a function of frequency for this configuration, as Graph 2 illustrates.



Graph 2. Flow as a function of frequency.

Concluding Remarks

The time spent working in industry with accomplished Parker engineers was not only a wonderful educational experience unto itself, but has proven invaluable to me as a graduate student. Day to day errands often required interaction with Parker staff from a variety of backgrounds and specialties which enabled me to learn much about fields I knew very little about. The project assigned to me was a demanding assignment. The necessary analytical skills and technical analysis tools required in graduate school were sharpened and honed as I employed them through out the summer in my daily tasks. There was plenty of stuff I had to learn from scratch, such as how to use common workplace mechanical tools and electronic equipment, how to implement data acquisition software and understand its interaction with hardware, and a variety of other workplace chores. Overcoming daily challenges was emotionally rewarding and made me truly appreciate the value of engineering education.

As for the project, I established that electromagnetic actuation of duty cycle enables proportional flow modulation authority over the injector's control valve. This authority allows

the integrated fuel injection system to provide electronically controlled fuel flow rate modulation capability. Successful fuel flow modulation was shown in the laboratory, and future developments will focus on a combustor demonstration of fuel flow modulation presented in this report.