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LOW-COST, LIGHTWEIGHT ELECTRONIC FLOW REGULATORS FOR THROTTLING LIQUID ROCKET ENGINES

Abstract

The need for robust pressure-reducing regulators that are able to operate throughout large changes in upstream pressure is becoming increasingly common as more work is done on small-scale pressure-fed liquid rocketry. Accurate regulation of both tank pressures and injector pressures can allow for higher engine efficiency and optimized tank construction with the system operating closer to target design parameters.

Methods currently used for gas regulation, including dome-loaded pressure regulators and solenoid systems, are often inflexible and require extensive characterization. Moreover, electro-mechanical limitations such as limited orifice size, droop, slow reaction times, and cryogenic incompatibility make them unsuitable for applications such as throttling, which are increasingly important as vertical take-off vertical landing rockets become more ubiquitous.

To overcome these challenges, we designed an electronic pressure regulator (eReg), a multi-input multi-output system utilizing closed loop feedback to accurately control downstream pressures. Consisting of a single ball valve actuated by a motor, its robust design allows eRegs to regulate both gaseous pressurant and cryogenic liquid propellant at high flow rates (1.14 kg/s of liquid; 0.39 kg/s of gas) and upstream pressures (310 bar). By using 4 eRegs in conjunction (2 regulating propellant tank pressures and the other 2 regulating flow of propellants to the engine), we are able to operate our engine at a near optimal oxidizer-fuel ratio while throttling over a wide range of thrust.

To reduce system mass, powerful motors and compact planetary gearboxes were used. For high flow rates, serviceability, and manufacturing considerations, commercial full port ball valves were chosen as the flow control orifice. High flight reliability in the face of vibrations was accomplished through the use of castellated components and nylon thread-locking components.

Each eReg uses a cascaded controller, with the outer PID loop monitoring downstream pressure and computing valve angle setpoints for the inner PID loop. However, the control problem is complicated by the constantly changing ullage volume and upstream pressures, which result in a non-linear, time-dependent system. We found that adding feedforward and using dynamic PID gains significantly improved controller performance, thus allowing us to achieve precise control despite the challenging environment.

We also verified the design's performance and reliability through a testing campaign, culminating in a static fire test demonstrating eReg's ability to regulate pressures accurately (within 0.2 bar) while simultaneously throttling our engine. To the best of our knowledge, this is the first time any undergraduate team has successfully throttled a liquid bipropellant engine.