DESIGN AND SHAPE OPTIMIZATION OF VALVE STEM FOR SEALING PERFORMANCE OF PROPORTIONAL VALVE USED IN A COLD GAS PROPULSION SYSTEM

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KEYWORDS
Wear; Experiments in tribology; Contact and adhesion; Space tribology

ABSTRACT
Cold gas propulsion systems are frequently used in airborne vehicles, such as aerospace vehicles and satellites. Before the thrust nozzles, pressure and flow rate are controlled depending on the required thrust. The proportional valves used for this role are crucial components of the entire thruster system and should provide quick response, high resolution, and variable amplitude dynamics. However, the primary challenge with motorized rotary stem proportional valves operating under high pressure is the high rotational torque required by the valve as it transitions from closed to open position due to the pressure drop resulting from the high-pressure differential. This increased torque requirement leads to higher system electrical power demands, the need for larger motors and wear of the stem tip, which results in leakage. Furthermore, the geometry of the stem tip used and the turbulence intensity resulting from the sudden change in diameter increases the forces affecting the stem. Therefore, the specific geometry of the stem tip is critical for proportional valve design.

METHODOLGY
This study investigates the influence of stem geometry on proportional fluid control and assesses how combinations of the stem tip material and body material affect both sealing effectiveness and the electrical motor starting torque. Initially, the characteristic equation of the valve is derived while concurrently developing the Computational Fluid Dynamics (CFD) model. Tip geometry optimized to minimize the forces acting on the stem and the resulting geometry's effects on the flow are thoroughly examined (Fig 2). The analysis examines into the effects of abrupt pressure changes around the tip, particularly evident at smaller openings, on turbulence intensity. In addition to this, different material pairs for the stem tip and body were investigated to minimize the frictional forces. A test rig in Figure 2 is designed to examine the flow and tribological characteristics under high pressure [1]. Here, the optimized stem tip geometry and a steel body valve and a supersonic nozzle connected to this valve are employed to examine flow control characteristics, sealing conditions, and the impact of material pairs on the opening and closing torque [2]. This investigation encompassed the dynamic behaviors of steel-steel, aluminum-steel, Nylon 66 (PA66)-steel, and POM (Polyacetal)-steel material pairs under various high-pressure operating conditions by using different stem tip materials. The measurements were conducted while adjusting different speed and torque inputs to the system, providing insights into the valve's performance across a range of different scenarios [3]. The measurement results show that using a POM (Poliasetal)-steel material pair and optimized tip requires lower opening torque than other material pairs. The comparison shows that the proposed material pairs can be potentially useful in the design of proportional valves for the control of cold gas propulsion systems.

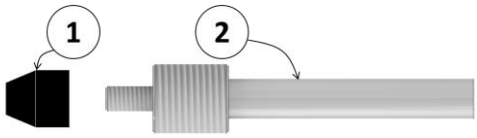

Figure 1 – Proportional valve stem (1) and tip (2)

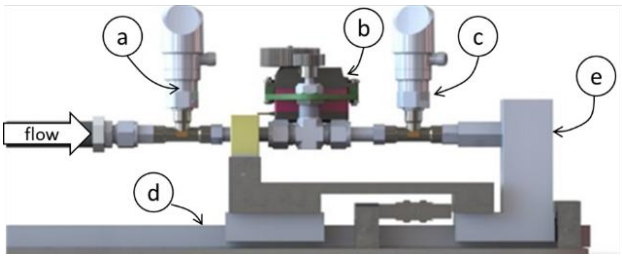

Figure 2 - High pressure stem test rig, a. pressure gauge (inlet), b. Proportional valve, c. pressure gauge (outlet), d. linear guide, e. Supersonic Nozzle

REFERENCES
[1] D. Hauser and F. Quinn, “Simulation of a Cold Gas Thruster System and Test Data Correlation,” in *47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit*, Reston, Virigina: American Institute of Aeronautics and Astronautics, Jul. 2011. doi: 10.2514/6.2011-5769.

[2] S. A. Gafurov, V. A. Salmina, and Y. I. Kondrashov, “Pneumatic Valve’s Seal Dynamic Load,” *Procedia Eng.*, vol. 176, pp. 699–705, 2017, doi: 10.1016/j.proeng.2017.02.315.

[3] T. Qiu, H. Dai, Y. Lei, and Y. Liu, “Effects of valve needle speed on flow characteristics in control valve for unit pump fuel system,” *Adv. Mech. Eng.*, vol. 10, no. 4, p. 168781401877079, Apr. 2018, doi: 10.1177/1687814018770791.