Guide to Flow Measurement for Electric Propulsion Systems

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Abstract: In electric propulsion (EP) systems, accurate measurement of the propellant mass flow rate of gas or liquid to the thruster and external cathode is a key input in the calculation of thruster efficiency and specific impulse. Although such measurements are often achieved with commercial mass flow controllers and meters integrated into propellant feed systems, the variability in potential propellant options and flow requirements amongst the spectrum of EP power regimes and devices complicates meter selection, integration, and operation. At the direction of the Committee on Standards for Electric Propulsion Testing, a guide was jointly developed by members of the electric propulsion community to establish a unified document that contains the working principles, methods of implementation and analysis, and calibration techniques and recommendations on the use of mass flow meters in laboratory and spacecraft electric propulsion systems. The guide is applicable to EP devices of all types and power levels ranging from microthrusters to high-power ion engines and Hall effect thrusters. The establishment of a community standard on mass flow metering will help ensure the selection of the proper meter for each application. It will also improve the quality of system performance estimates by providing comprehensive information on the physical phenomena and systematic errors that must be accounted for during the analysis of flow measurement data. This paper will outline the standard methods and recommended practices described in the guide titled "Flow Measurement for Electric Propulsion Systems."

I. Introduction

THE Electric Propulsion Technical Committee (EPTC) of the American Institute of Aeronautics and Astronautics (AIAA) was asked to assemble a Committee on Standards (CoS) for Electric Propulsion Testing. The assembled CoS was tasked with developing Standards and Recommended Practices for various diagnostic techniques used in the evaluation of electric propulsion (EP) devices. These include measurements that can yield global information related to a thruster and its performance. This paper provides an overview of the guide developed for the working principles, methods of implementation and analysis, calibration techniques, and recommendations on the use of mass flow meters in laboratory and spacecraft EP systems.

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II. Overview of Flow Measurement

The dependence of several key performance and systematic parameters (e.g. thrust, specific impulse, and maximum theoretical efficiency) on propellant properties makes the selection of the optimal propellant for a given EP system an area of great research interest.[1, 2] The resulting variability in potential propellant options along with the simultaneous dependence of the aforementioned performance parameters on the accurate knowledge of propellant mass flow rate makes the selection of the proper mass flow meter for a given system a nontrivial task.[1] Recommendations and common practices for the selection of liquid and gas mass flow meters for colloid microthrusters, arc microthrusters, ion engines, and Hall effect thrusters are presented alongside descriptions of the implementation of these devices into common systems of practical interest to the EP community.

III. Working Principles

Due to variability in working fluid and flow range, mass flow meters of interest for EP applications do not use a single uniform method of flow measurement or control. Instead, for gases, these controllers can be separated into four major types based upon the employed flow measurement technique: thermal mass flow controllers (TMFC), pressure-based mass flow controllers (PMFC), variable-area meters, and pressure-fed flow restrictors.[3-6] For liquids, there are two primary flow measurement techniques: gravity-driven and time-of-flight.[7, 8] The physical phenomena and working principles for each type of flow controller are presented alongside the qualitative physical models used by the controllers in measuring flow rates.

IV. Error Analysis and Uncertainty

A brief overview of the types of errors that can arise in a measurement system are presented including a discussion on how specific types of errors can affect the stated accuracy of a flow measurement apparatus. Several examples are provided outlining error estimation techniques useful for a variety of practical EP flow measurement devices. Specifically, a thorough analysis of the NIST-identified potential sources of uncertainty for mass flow meters is presented including those associated with calibration accuracy, reliance on gas correction factors (GCFs), and device susceptibility to changes in orientation, temperature, pressure, and flow rate.[4] Furthermore, recommendations and examples are presented for proper calibration of mass flow meters in a variety of potential applications alongside an assessment of the resultant calibration errors that must be accounted for during data analysis.

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References

[1]D. M. Goebel and I. Katz, *Fundamentals of Electric Propulsion: Ion and Hall Thrusters*. Hoboken, NJ: John Wiley & Sons, Inc., 2008.

[2]A. Kieckhafer and L. B. King, "Energetics of Propellant Options for High-Power Hall Thrusters," *Journal of Propulsion and Power,* vol. 23, pp. 21-26, 2007/01/01 2007.

[3]D. M. Pehrson, "Continuing Development of the Proportional Flow Control Valve (PFCV) for Electric Propulsion Systems," presented at the 30th International Electric Propulsion Conference, Florence, Italy, IEPC-2007-346, 2007.

[4]S. A. Tison, "A critical evaulation of thermal mass flow meters," *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films,* vol. 14, pp. 2582-2591, January 5, 1996 1996.

[5]R. L. Brown and J. M. Schwartz, "Pressure Based Mass Flow Control for Ion Implant SDS Applications," in *1998 International Conference on Ion Implantation Technology*, Kyoto, 1998, pp. 369-372.

[6]E. L. Upp, *Fluid flow measurement a practical guide to accurate flow measurement*, 2nd ed. ed. Gulf Professional Pub.: Boston, 2002.

[7]C. N. Ryan, K. L. Smith, M. S. Alexander, and J. P. W. Stark, "Performance Modulation of Colloid thrusters by the Variation of Flow rate with Applied Voltage," presented at the 31st International Electric Propulsion Conference, University of Michigan, Ann Arbor, Michigan, IEPC-2009-187, 2009.

[8]K. L. Smith, J. P. W. Stark, R. Krpoun, and H. Shea, "Performance of a micro-fabricated Colloid thruster system," presented at the 31st International Electric Propulsion Conference, University of Michigan, Ann Arbor, Michigan, IEPC-2009-189, 2009.