ME – PhD Thesis Colloquium

Design, development, and characterization of a capillary-fed evaporative microthruster for micro- and nano-satellites

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ABSTRACT

Small satellites offer a unique platform for short-term and low-cost communications and surveillance missions. Despite their potential, small satellites face significant challenges, particularly in propulsion, due to their compact size, weight limitations, and restricted power availability. Addressing these challenges is crucial to unlocking their full potential and expanding their range of applications in the space industry.

The thesis explores the development, fabrication, and experimental characterization of a capillary-fed evaporative microthruster. Initially a silicon-based microthruster was developed using standard photolithography and thin-film deposition techniques. This MEMS-based vaporizing liquid microthruster utilizes silicon microtextures for passive feeding of the propellant (water) via capillary force and subsequent thin film evaporation through localized heating. The generated vapor flows through a converging nozzle to produce thrust. The first part of the thesis details the microfabrication techniques employed in creating various generations of silicon microthruster devices, their experimental characterization, and the numerical estimation of the performance of the device. The numerical model developed couples the evaporation characteristics at the liquid-vapor interface with compressible flow dynamics through the micro-nozzle. The developed methodology can be extended to estimate thrust characteristics of vaporizing liquid microthrusters. The results show that the proposed device can generate a thrust of approximately 60 μN and an ISP of around 67 seconds with a power input of approximately 3W.

The second part of the thesis provides design, fabrication, and experimental characterization of a scaled-up microthruster. The microthruster consists of a reservoir, evaporation chamber, and a capillary wick. The capillary wick enables passive transport of the propellant (deionized water) from the reservoir to the vapor chamber, where the water evaporates upon the application of electric heating. The generated vapor is expelled through a nozzle in the evaporation chamber to generate thrust. Pressure and temperature measurements in the evaporation chamber along with side-view imaging, facilitate real-time monitoring to understand the behavior of the device at different input power under vacuum conditions (~ 50 Pa) of the ambient. We present the relevant design parameters of the microthruster device to mitigate issues such as two-phase boiling, water ejection or ice formation, which are detrimental to the performance of vaporizing liquid microthrusters. We show that the evaporative microthruster can achieve thrust ranging from approximately 200 μN to 820 μN, with a specific impulse of around 100 seconds, for power input of 0 W to 3 W.

The last part of this work focuses on the design, fabrication, and calibration of a torsional pendulum-type thrust stand. The calibration results reveal that the thrust stand can measure thrusts ranging from 30 μN to 340 μN.

ABOUT THE SPEAKER

Akshay Sharma is a PhD student in the Department of Mechanical Engineering at IISc Bangalore. He completed his M. Tech in Thermal Science and Engineering from the IIT Bhubaneswar in 2018. He then joined IISc Bangalore as a PhD student in 2018 and got a Prime Minister's Research Fellow (PMRF) scholarship in 2020. His research interests include fluid mechanics, heat transfer and CFD.