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MICRO THRUSTER FOR MINIATURIZED SPACE SYSTEMS - NEED AND PERSPECTIVE

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1. INTRODUCTION

Space program strongly depends on the national political and economic conditions. Differently from the period of 60's and 70's, when many remarkable achievements represented by the Apollo program were accomplished in space, the current huge missions often receive unfavorable reviews because the Cold War ended 15 years ago and the budget deficit has to be reduced in many nations. While such national space program is still indispensable for long-term vision of the progress of human being, it is reasonable that miniaturized autonomous space systems are attractive as the cost-effective and short-term-development tools for near-earth science mission and even deep-space exploration.

Japan recently restructured the three-separated aerospace agencies, which were merged into the Japan Aerospace Exploration Agency (JAXA) after repeated troubles of rocket launch and supersonic experimental plane. The No.1 priority of JAXA program is the realization of highest reliability of space transportation but this topic looks slightly conservative and even increases our anxiety of little innovative progress for space exploration. However, new space activities are starting including recently launched three micro satellites, two of which are universities CubeSats and the other is JAXA's μLabSat. All of them are education-oriented projects but miniaturized space systems are absolutely attracting social interests.

This kind of environment provides a great opportunity for MEMS devices to demonstrate its feasibility in space. MEMS technology is fundamentally suited for aerospace applications because of its low mass with multifunctional capabilities. There exist many concepts and projects to apply MEMS to future space exploration since the national nanotechnology initiative and even Mars human exploration plan started. But space program is a small market and cost is not the first priority there, which means the MEMS capability of mass production loses its advantage. Reliability is still the first priority in miniaturized space systems. Such thinking on cost and reliability turns out that matured components are employed rather than even functional MEMS devices. In order to apply a new technology in space, it is necessary to validate its indispensability that there is no alternative.

2. MICRO THRUSTERS

While most sensors for space applications are on the extension of mass-products technology, thruster is a unique issue for aerospace engineering. Consequently, a great opportunity exists for MEMS thrusters to appeal its suitability due to small volume/mass and power consumption because there is no matured propulsion device for nano/pico-satellites. Success of MEMS thruster of precise position and attitude control would result in public acknowledgment of growing potential of small satellites.

So far, many MEMS-based thrusters were fabricated and tested [1-2]. Most of them are fuel-tank-based system: cold-gas jet, monopropellant thruster, bi-propellant rocket, colloid thruster and FEEP. Because space system cannot refill the tank, the thruster lifetime depends on tank size and valve performance. Because high-pressure tank needs volume and mass, which reduces MEMS advantage, MEMS turbo-pump is also desired in future but the development of microvalve [3-5] is definitely the current major topic.

MEMS valve also contributes the realization of single-chip thruster, which is the best choice for pico-satellites. However, thermal management becomes additional requisite for such integrated system if hotter jet is pursued for higher specific thrust because IC cannot resist too much thermally harsh environment.

Valve-less micro thrusters such as micro PPT and MEMS rocket array [6-9] are advantageous due to their disengagement of movable parts. However, the large power supply is a big concern for electrical propulsions even though they have huge specific thrust due to the electrostatic acceleration using high voltage. On the other hand, the physics of MEMS solid rocket is not yet fully explored even though its array concept is excellent and heat transfer from this type of pulsed engine has less damage on the control part than the continuous working thrusters.

As an overview, all micro thrusters are still immature even if cost is not considered, but there is not so long time left for their improvement to catch up with the emerging miniaturized space systems. Considering such needs for space system, best two promising candidates for nano/pico-satellites in near-term are micro cold-gas jet and MEMS rocket array. Valve and propellant are discussed here as the key issues for their improvement.

3. MICROVALVE

Microvalve development has a huge impact on a variety of micro fluidic systems including bio-MEMS, μTAS and Power MEMS. However, because space program requires the highest reliability with high pressure and low leak rate, MEMS valve is still difficult to take place of the conventional valve. There are reported several microvalve trials for thruster application. The PZT valves have been well developed using MEMS technologies but its reliability of membrane/bridge and piezo-actuator itself is still questionable. Phase-change-based thermal valve is interesting but it is not sure that its performance of response and life-time satisfies the space need.

Solenoid valve which is used for automobile fuel injection is another promising candidate but still there are many barriers against MEMS fabrication of solenoid due to its three dimensional structure and material issues. As well as the nozzle fabrication, choice of conventional solenoid system seems most feasible for nano/pico-satellite in near future.

4. SOLID PROPELLANT

Most of the MEMS rockets employ similar structure of the large solid rocket booster (SRB). However, SRB design comes from empirical data and especially the ignition mechanisms is not yet enough understood. It is known from experiences that reaction of explosive is dependent on many factors; temperature, friction, shock, etc. The sensitivity of such high-energy material also changes by its particle size, shape, density, composition ratio, etc. This suggests that composite solid propellant is another concern for reliability when the rocket size is further reduced. [10] Because the particle sizes of fuel, oxidizer and even binder are mainly from 10μm to 100μm order, its inhomogeneity turns to have relatively large effects for micro rocket application and degrades the reproducibility of operation and experiment.

There are two more concerns on solid propellant. One is handling issue when charged into the tank. The conventional SRB design of sequential ignition system using different propellants cannot be applied when the rocket size is reduced to 100μm order in order for precise control using tiny impulse and high number density for large shot numbers. Finally, ecological consideration is also not negligible. It is well known that lead-based explosives are of highest sensitivity but unleaded propellant with similar property is desirable. Choice and development of propellant is pivotal at the current development stage of MEMS solid rocket.

5. SUMMARY

This paper discusses the near-term perspective of MEMS thrusters for the emerging micro satellite activities. Their state of art is not yet satisfying but cold-gas thruster and MEMS solid rocket array are promising for their lowest complexity which results in the highest reliability. The existing concerns of microvalve and solid propellant are reviewed and it is noted that appropriate choice of fabrication technique including conventional machining and prompt employment of best propellant are the vital way for their improvements.

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