Taylor Cone Experiment with Slit Type Emitter and Thrust Measurement Device for FEEP Thruster

By Chanearl Kwon1, Pravendra Kumar1, Meung-gil Kim2, Kybeom Kwon3, and Jack. Yoh1

1Department of Aerospace Engineering, Seoul National University, Seoul, Republic of Korea
2The SpaceK, Daejeon, Republic of Korea

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Abstract

Formation of the Taylor cone is an important technique for understanding the basic principle of the field emission electric propulsion (FEEP), which is used for the nanosatellites’ attitude control and orbit maintenance. This study compares the Taylor cone formation using a capillary, linear and annular slit type emitters by considering different working fluids. The initial experiments with olive oil show that the multi-Taylor cones can be generated at the periphery of annular slit emitter. Also, torsional balance to measure the performance of the thruster under vacuum condition is designed and fabricated. The results obtained in this study will be used in designing an engineering model of FEEP thruster.

1.0 Introduction

Electrospray or field emission electric propulsion (FEEP) thruster is a promising technology for nanosatellite’s application for their orbital maintenance and attitude control due to its outstanding capability to produce precise thrust level order of μN. In recent years, several types of the emitter configurations are investigated to explore their potential in producing the efficient thrust with minimum required power. The use of nanosatellite constellation is growing in the recent years. Therefore, propulsion system such as electric propulsion system for orbit maintenance and attitude control is required. Field emission electric propulsion (FEEP), one of the electric propulsion system, has an advantage of its simple structure and thrust level order of 1 μN ~ 1 mN. The FEEP utilizes the Taylor cone formation to extract the ions from the liquid metal ion source is studied.

Electrospray refers to a method in which a liquid is sprayed by an electric field formed due to an electric potential difference between the emitter and accelerator. When a conductive liquid is placed in an electric field, the liquid is deformed due to electric force which overcomes the liquid surface tension force. Thereafter, when the strength of the electric field becomes equal to the surface tension, the liquid forms conical shape, which is called a Taylor cone. Taylor cone visualized it with water by Taylor, G.I. [1]. In FEEP thruster, the emitter can be classified into three main types, such as needle type, capillary type, and slit type. Among them, the slit type of emitter has advantage of higher thrust than other two types, by forming multi-Taylor cones. In this study, Taylor cone experiments are conducted to visualize the Taylor cone formation with different working fluids for developing a FEEP thruster with annular slit type emitter.

2.0 Experiment Setup

The Taylor cone was formed by using an experimental setup shown below which is a similar concept of the device used by G.I. Taylor (1964); however, in a modified way. In this setup, a simple circular hole extractor plate of aluminum material was used. The emitter body has the capability to change the different emitters with push-fit arrangement, which is connected to a fluid inlet source. The working fluid is transported to the periphery of the emitter via gravity and syringe pump. The distance between extractor hole and the emitter tip can be adjusted by varying the extractor position on the holding plate, which has the screw and fasten arrangements. A high-speed camera is used to visualize the Taylor cone.

![Figure 1 Experimental setup](Image)

2.1 Working fluids

The physical and electrical properties of liquids play important role in Taylor cone formation in different modes from pulsating to stable jet. The present study includes different working fluids such as water, olive oil, and liquid indium, which are completely distinguish with each other. Table 1 illustrate the physical and electrical properties of the working fluids considered in this work.
2.2 Emitter Configuration

Three emitter configurations were tested to form the Taylor cone with working fluids. First kind of emitter was capillary with diameter of 2 mm, which is very common configuration and investigated widely. Second type was linear slit, which one is investigated first by J. Mitterauer in 1987 and used for to demonstrate its application for FEEP thruster with liquid indium. Taylor cone formation in linear configuration is highly dependant on slit height, which was order of 4 µm. However, in the present study, the goal is to first form the Taylor cone with water and olive oil, which can further be investigated for indium propellant. The last configuration is annular slit type, which one is the novel configuration considered in this work. Annular slit configuration is never tested before, thus make this study unique and has potential significance in generating the higher thrust as compared to currently available needle type emitter configuration.

3.0 Results and discussions

Figure 3 shows the Taylor cone formed using capillary of 2 mm diameter with water at various electric potential. The liquid meniscus starts rising when the electric potential increases. At around 14 kV, Taylor cone appeared, which become more stable at 14.84 kV. On further increase in the electric potential, multi-Taylor cones appeared around the periphery of capillary tube at 17 kV.

Figure 4 shows the Taylor cone formation for linear emitter with water where a single Taylor is formed. On the other hand, with annular slit, a single Taylor cone is formed with water, however, with olive oil we observed multiple Taylor cones at the periphery of the annular slit as shown in Fig.5

4.0 Conclusion

Experimental results of the linear and annular slit and the capillary emitter were compared, and in the case of the capillary type emitter, Taylor cone was easily generated. However, in the case of the linear and annular slit, multi-Taylor cone was formed only with olive oil because of a high viscosity and electrical conductivity. For the future study, linear and annular slit of small slit height will be considered for the working fluids considered in this work.

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References