

# Development Status of 200mN class Xenon Hall Thruster of MELCO

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**Abstract:** MELCO is developing a Hall Thruster Subsystem under the national project for 5 years. The main developed items are a thruster and PPU. The target specification is that the thrust level is over 250mN, the Isp is over 1,500s under the PPU input power of 5kW, and the life time is over 3,000 hours. To date, the development status is engineering model after the evaluation of BBM and DM. The thruster DM with ceramic channel showed the thrust level of 256mN, the Isp of 1,670s under the thruster input power of 4.91kW. Now we investigate the some problem of DM thruster and develop the EM for lifetime test in next year.

## Nomenclature

$I_a$	=	anode discharge current of accelerator, A
$I_c$	=	collector current, A
$I_k$	=	keeper discharge current of hollow cathode, A
$P$	=	input power, W
$ma$	=	xenon mass flow rate of accelerator, mg/s
$m_{HC}$	=	xenon mass flow rate of hollow cathode, mg/s
$F$	=	thrust, mN
$V_a$	=	anode voltage of accelerator, V
$V_c$	=	collector voltage, V
$V_k$	=	keeper voltage of hollow cathode, V
$\eta$	=	total thrust efficiency

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## I. Introduction

Mitsubishi Electric Corporation (MELCO) participates in the project of development of the next generation electric propulsion technology for the next generation satellite systems under the contract of Institute for Unmanned Space Experiment Free Flyer (USEF) and Ministry of Economy, Trade and Industry (METI) in five years. The final target specification is that the thrust level is over 250mN under supplying the electric power of 5kW and the life time is over 3,000 hours. The developed items are both a thruster and a power-processing unit (PPU). MELCO has developed 20mN class xenon ion engine subsystems from 1980s and the subsystems was applied for Engineering Test Satellite VI (ETS-VI)<sup>1-8</sup> and Communications and Broadcasting Engineering Test Satellite (COMETS)<sup>9</sup> of Japan Aerospace Exploration Agency (JAXA). Modified xenon ion engine subsystem has been developed for ETS-VIII<sup>10-20</sup>, which will be launched in 2006. For the next generation electric propulsion system, we decided a hall effect thruster because of both the electric power budget from a general commercial satellite system and the thrust level requirement. The development was initiated in 2003. In 2003, we designed, manufactured and tested the bread board model (BBM) of both the thruster and the anode and keeper power supplies. Typical two kinds of the thruster, that is the stationary plasma thruster (SPT)<sup>21</sup> type and the thruster with anode layer (TAL)<sup>22</sup> type, were manufactured. Both thrusters were successfully operated under 3kW class anode discharge. However, we decided the continuation of the SPT type thruster development because of its better discharge stability. In 2004, we developed the development model (DM) of the thruster and the PPU. The DM thruster satisfied the target performance such as thrust level and Isp, and in 2005 the design of the DM thruster is modified to the engineering model (EM) for endurance test in next year. The PPU development status is described in other paper<sup>23</sup>.

## II. Thruster BBM

There are two main kinds of hall thrusters. One is an accelerator with a dielectric channel, and another is one with a conductor channel. In 2003, both type thrusters were designed, manufactured and performed the anode discharge test.

### A. Thruster description and feature

#### 1. Accelerator BBM

Two kinds of accelerator BBMs were designed by static magnetic field analysis and thermal analysis. Accelerator with ceramic channel consists of a center electromagnetic coil, six outer electromagnetic coils, disk-shaped inner pole piece, ring-shaped outer pole piece, ceramic channel of BN-AlN, and a ring-shaped anode distributor as shown in Figure 1a. Mid diameter, width, and depth of the channel are 110 mm, 25 mm, and 25 mm, respectively. The depth of the channel is the distance between outlet plane of channel and top of anode. Accelerator with conductor channel consists of a center electromagnetic coil, four outer electromagnetic coils, disk-shaped inner pole piece, square-shaped outer pole piece, stainless-steel channel, and a ring-shaped anode distributor as shown in Figure 1b. Mid diameter, width, and depth of the channel are 71 mm, 17 mm, and 2 mm, respectively.

#### 2. Hollow cathode

A hollow cathode assembly for thruster BBM was assembled from the commercial hollow cathode insert of the Veeco-Ion Tech Inc. and some keeper discharge parts as shown in Figure 2. Because the nominal electron current of the commercial insert was 3A, we used four hollow cathode assemblies for performance test.

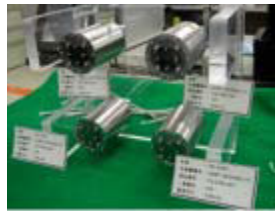
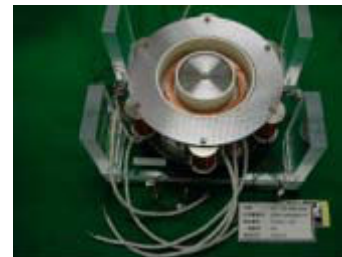


Figure 2. Hollow cathodes for accelerator BBM.



a) The accelerator with ceramic channel



b) The accelerator with conductor channel

Figure 1. Accelerator BBM.

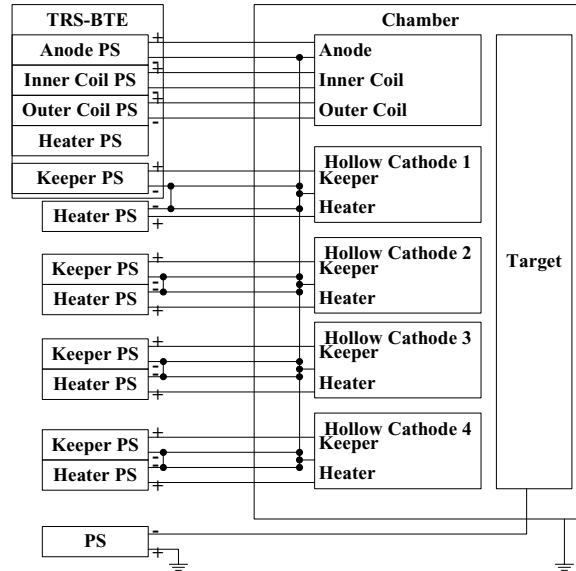
## B. Performance Test

### 1. Test configuration

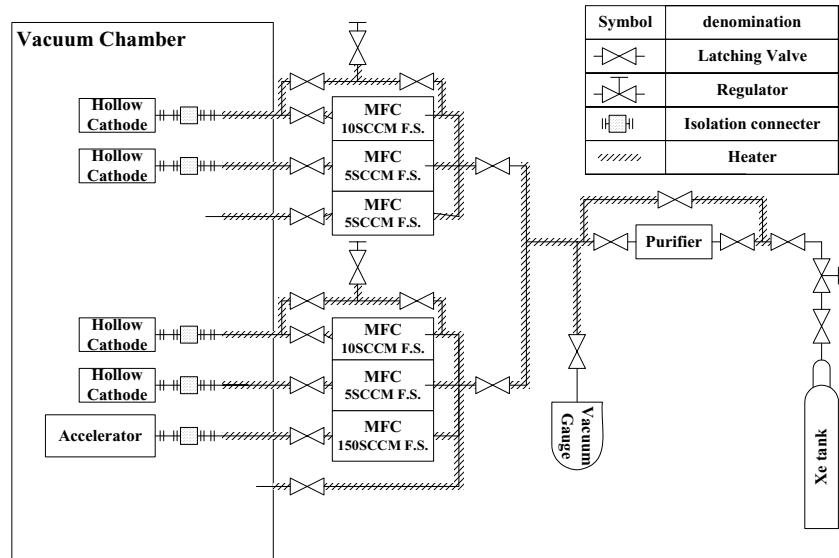
The performance test of the thruster was performed in Ion Engine Space Chamber at Kamakura Works of MELCO. The space chamber is a 3 m in diameter and 5 m in length, and has a cryo-pumping unit. The thruster can be operated under the ambient pressure of  $2 \cdot 10^{-3}$  Pa with xenon flow of 14.6 mg/s. The thruster is located in the chamber and the beam is irradiated on a titanium target plate, which is mounted on the end wall of the chamber and without a cooling system. The thruster is operated using a power supply unit. The power supply unit contains the five commercial power supplies (anode discharge, hollow cathode keeper discharge, hollow cathode heater, and two electromagnets). The power supply unit is controlled by a personal computer. The propellant feed system provides a controlled flow of xenon to the thruster through five separate feed lines, for the four hollow cathodes and the accelerator. Each propellant flow rate is independently controlled by commercial mass-flow-controllers. The test configuration is shown in Figure 3.

### 2. Test results

The anode discharge tests of both thrusters were conducted. The photographs of the test setup are shown in Figure 4. Both thrusters were operated under the operating points as shown in Table 1. The test results are shown in Figure 5. Both thrusters generated about 3kW discharge. The thruster with ceramic channel operated with better stability than one with conductor channel. Therefore we decided continuing development of the thruster with ceramic channel.



a) Power supply system

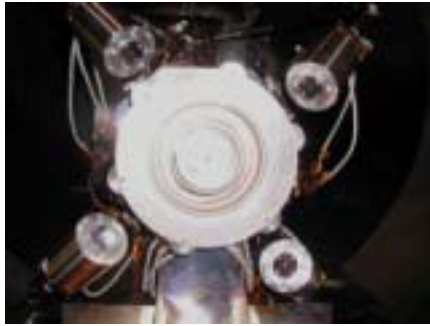


b) Propellant feed system

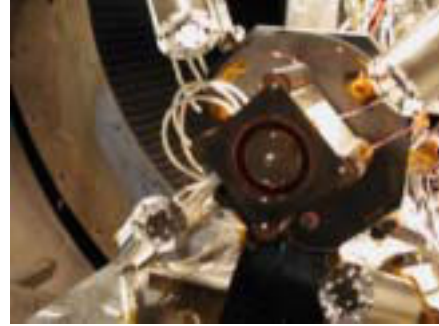
Figure 3. Test configuration of thruster BBM.

Table 1. Operating points

Parameter	value
Xenon mass flow rate, mg/s	4.9, 7.3, 9.8, 11.7
Anode voltage, V	200, 250, 300, 350
Electromagnetic coil current, A	0.25-2.25



a) Thruster BBM with ceramic channel  
Figure 4. Set up of thruster BBMs



b) Thruster BBM with conductor channel

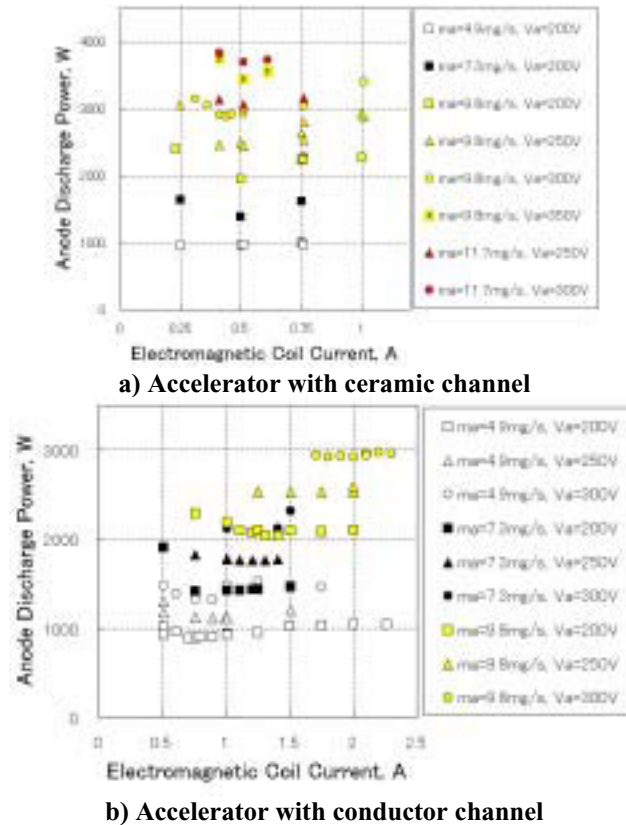


Figure 5. Anode discharge power to electromagnetic coil current.

### III. Thruster DM

#### A. Description

##### 1. Accelerator DM

Accelerator DM has same configuration as accelerator BBM with ceramic channel. The accelerator additionally has a plume shield, a heat path contacted the bottom of a channel and a cylindrical side radiator. A plume shield intercepts high energy ions with higher angle beyond 45 degree. Mid diameter, width, and depth of the channel are 120 mm, 25 mm, and 50 mm, respectively. The photograph of the accelerator DM is shown in Figure 6.

##### 2. Hollow cathode DM

On basis of the MELCO's hollow cathode, which had been manufactured for 20mN class gridded ion thruster, large scale hollow cathode for 200mN class hall thruster was designed and manufactured. The hollow cathode uses

S411 impregnant cathode. The nominal emission current is 15 A under the xenon flow rate of 0.98mg/s. The photograph of the hollow cathode DM is shown in Figure 7.



Figure 6. Accelerator DM with plume shield.



Figure 7. Hollow Cathode DM.

## B. Performance Test

### 1. Test configuration

The performance test of the thruster was performed in same configuration about electric power supply system and propellant feed system. The thrust level was measured by pendulum type thrust stand, which has specification as shown in Table 2 and the block diagram as shown in Figure 8. The thrust stand consists of measurement unit, pendulum unit and calibration unit. The measurement unit has a load cell for measuring force at one end of the pendulum arm. The calibration unit has a linear driving rod, which pushes the point on the arm corresponding thrust point, and a load cell, which measures the force when the rod pushes the point on the arm. Before and after the thrust measurement, a correlation curve between output of load cell of the measurement unit and one of load cell of the calibration unit by giving dummy load. The distance between the fulcrum and thruster centerline is 750mm.

Before thruster performance test, the stand-alone test of hollow cathode DM was performed in diode test configuration as shown in Figure 9. The distance between the hollow cathode and the collector electrode, which is made by molybdenum and 300 mm in diameter, was 60mm. The hollow cathode was operated under the ambient pressure of  $1.5 \cdot 10^{-2}$  Pa with xenon flow of 10sccm.

### 2. Stand-alone Hollow Cathode performance test result

The photograph of the hollow cathode test set up is shown in Figure 10. The ignition time was inside five minutes under the xenon flow rate of 0.98mg/s and keeper voltage of 100 V. The current-voltage characteristics of the discharge are shown in Figure 11. The photograph of the hollow cathode on operation is shown in Figure 12. Operational condition is that the collector current is 15A, keeper current is 0.5A, and xenon flow rate is 8sccm. The hollow cathode DM showed good performance and operational stability in the stand-alone test.

Table 2. Specification of thrust stand.

parameter	value
Thrust measurement range	0-500mN
Measurement accuracy	+/-5mN
Maximum thruster weight	20kg

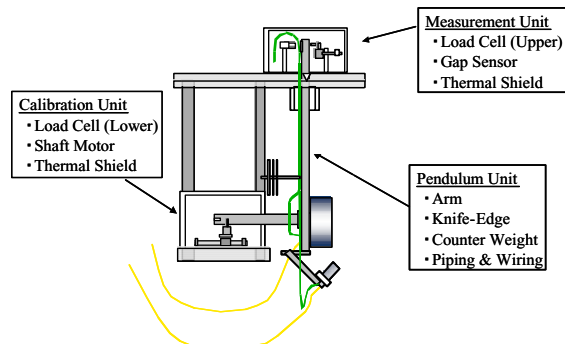


Figure 8. Block diagram of the thrust stand.

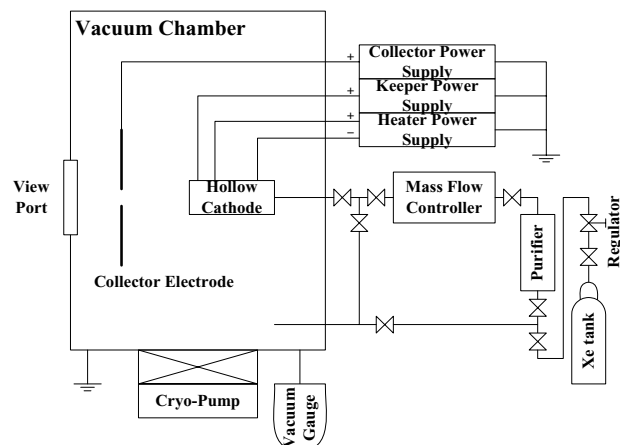


Figure 9. Block diagram of hollow cathode performance test.

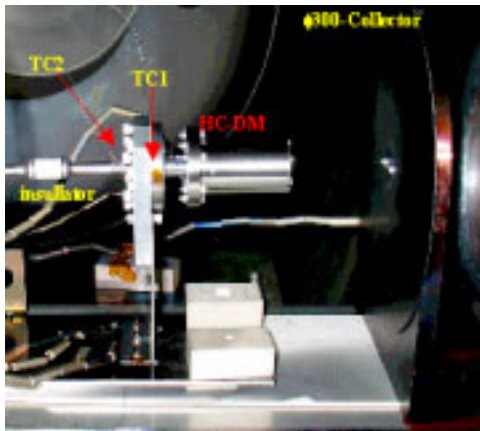


Figure 10. Hollow cathode DM test set up.



Figure 12. Photograph of the hollow cathode on operation.

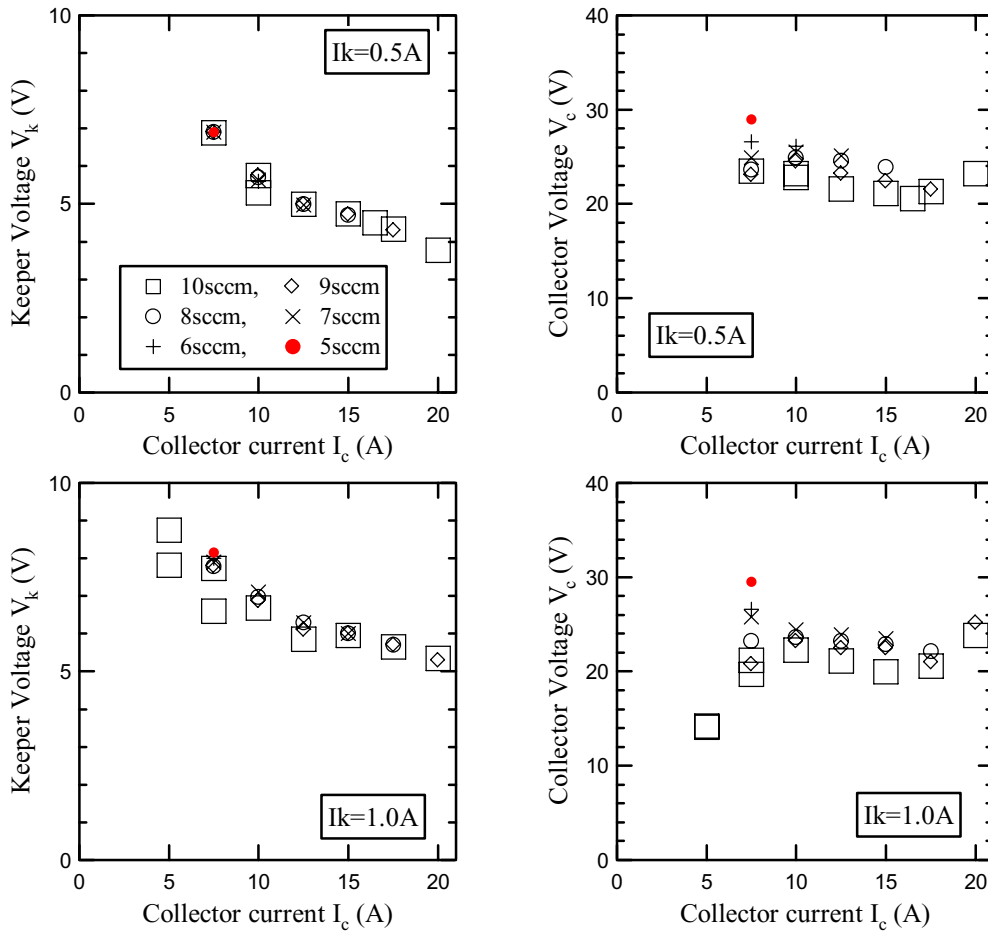


Figure 11. Voltage-current characteristics of hollow cathode DM.

### 3. Hall Thruster DM performance test result

The thruster was mounted on the thrust stand as shown in Figure 14. The thruster was operated under the operating points as shown in Table 3. The xenon flow rate of the hollow cathode was the value of 0.98mg/s in all case. The thrust, Isp, and total thrust efficiency to input power are shown in Figure 15 to 17, respectively. Isp and total thrust efficiency are calculated as follows :

$$I_{sp} = \frac{F}{(m_a + m_{HC})g}$$

$$\eta = \frac{F^2}{2(m_a + m_{HC})(V_a \cdot I_a + V_k \cdot I_k)}$$

The performance test of the thruster without the plume shield was conducted. Thrust level of the thruster with the plume shield was a little lower than the thruster without it under the same input power. Lower total thrust efficiency is due to shielding plume ions with high angle by the plume shield, we believe. The photograph of the thruster DM in operation is shown in Figure 18. Operational condition is that anode voltage is 275V, discharge current is 16A, and the xenon flow rate is 14.6mg/s.

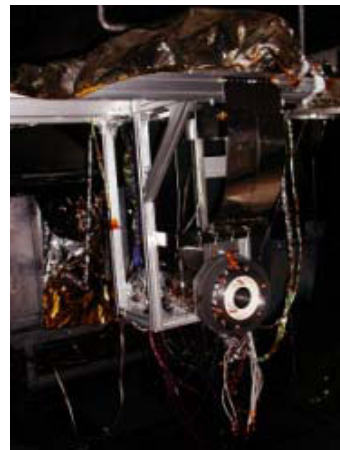


Figure 14. Thruster DM mounted on thrust stand.

Table 3. Operating point

Parameter	value
Xenon flow rate, mg/s	4.9, 7.3, 9.8, 12.2, 14.6
Anode voltage, V	200, 225, 250, 275, 300, 325, 375

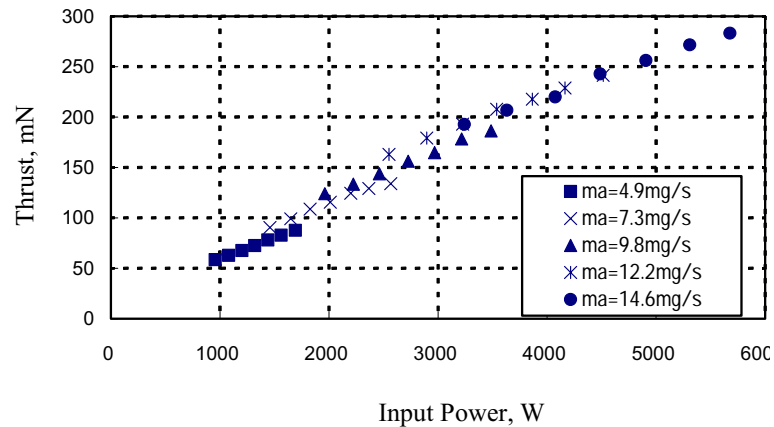
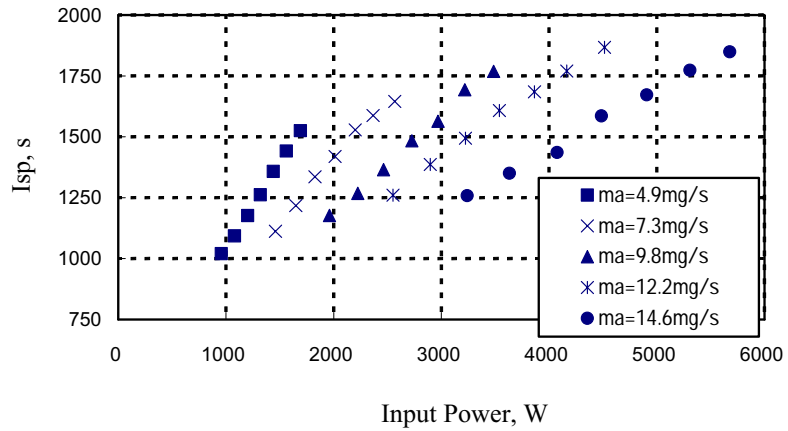
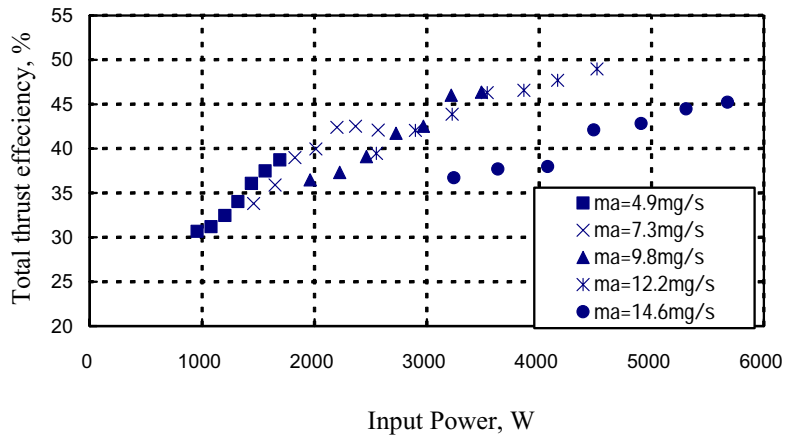


Figure 15. Thrust to thruster input power.



**Figure 16. Isp to thruster input power.**



**Figure 17. Total thrust efficiency to thruster input power.**



**Figure 18. Hall Thruster DM is on operation.**



#### IV. Further Work

Now we design and manufacture the thruster EM for a 3,000 hours life test in next year. Performance test, contamination measurement test, plume diagnosis, mechanical environment test, and electromagnetic radiated emission measurement from the thruster are being prepared and will be conducted before the life test. In 2007, a matching test of the hall thruster subsystem including the thruster, PPU, xenon feed system, and pressure regulation system is scheduled.

#### V. Conclusion

MELCO is developing 200mN class hall thruster subsystem including the thruster and PPU. The thruster DM with the plume shield showed the thrust level of 256mN and the Isp of 1,670s under the thruster input power of 4.91kW. Considering the efficiency of PPU, which will be 90%, the total thrust efficiency needs to be improved. Now we design and manufacture the thruster EM by reviewing both magnetic circuit and thermal design of the thruster DM. For a practical application, we plan some verification test, measurement and life test in the next couple years.

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