Evolutional Electrical Propulsion with Water Propellant DC Arcjet

IEPC-2017-413

Presented at the 35th International Electric Propulsion Conference
Georgia Institute of Technology • Atlanta, Georgia • USA
October 8 – 12, 2017

Yuichiro Nogawa [1]
Splije L.L.C, Tsukuba, 3050032, Japan

and

Hirokazu Tahara [2]
Osaka Institute of Technology, Osaka, 5358585, Japan

Abstract: New evolutional type of electric propulsion system what we call WEPS (Water Electric Propulsion System) has been studied for years between Splije LLC and OIT (Osaka Institute of Technology). This directly utilizes "water" as a fuel, and would get space environment near Earth or ground facility safer and cleaner. WEPS is also expected to resolve a lot of difficulties in perspective of re-fuel and we believe WEPS could be a high contributor to cost saving for near future deep (Moon and beyond) manned space mission. To seek less complicated design for WEPS, we select as a primary option to use water directly as a fuel. Another option like producing H_2/O_2 by water electrolysis can be selected as backup but we are focusing on direct usage of water. For the thruster, we decide DC Arc jet thruster is the best as a perspective of a light weight and low power consumption. But just replacing from NH_3 or N_2H_4 to water is not enough because our existing mass flow controller could not produce enough water flow to ignite firing continuously due to H_2O liquid state.

Nomenclature

WEPS	=	Water Electric Propulsion System
SWWEPS	=	Satellite With WEPS
WRS	=	Water Recovery System
ISS	=	International Space Station
ECLSS	=	Environmental Control and Life Support System
JEM	=	Japanese Experiment Module
JEF	=	JEM Exposed Facility
HTV	=	H2B Transfer Vehicle

I. Introduction

SPLIJE L.L.C and Osaka Institute of Technology have been studying for new advanced type of electric propulsion system what we call WEPS (Water Electric Propulsion System). This propulsion system applies "water" as a fuel because water is green, reusable, and ecological. This green propellant eliminates toxic ones (such as hydrazine and nitrogen tetroxide often used), and can keep space environment safer and cleaner. WEPS also is expected to resolve difficulty in perspective of re-fuel or cost saving is significantly important for the future manned space mission. Recent space exploration proves that plenty of water/ice exists on surface or inside asteroid, Moon, Mars and other planets or satellite like Enceladus. If the technology is established to obtain water in-space in near future, bringing propellant from the Earth is no longer required. Thus in-situ resource utilization can be achieved from propellant supply perspective.

[1] President/CEO, nogawa.yuichiro@gmail.com
[2] Professor, Advanced Rocket Laboratory, Department of Mechanical Engineering, hirokazu.tahara@oit.ac.jp

However at this moment, it is difficult to obtain water resource from outside the Earth, therefore we will use waste water resource as a product of Water Recovery System in ISS (see Section II A).

Satellite with WEPS (SWWEPS) is planned to development after WEPS technical feasible assessment is complete. When we assume that SWWEPS launch and deployment opportunity from ISS will be given in early 2020s and also assume WEP development phase is 5 years span. In order to achieve Early 2020's launch, the term of 2017-2020 is very important as starting step for PDR, CDR, and ISS safety review panel which will require all ISS mission. Considering all the above, the latest WEPS development roadmap is shown in Figure 1.

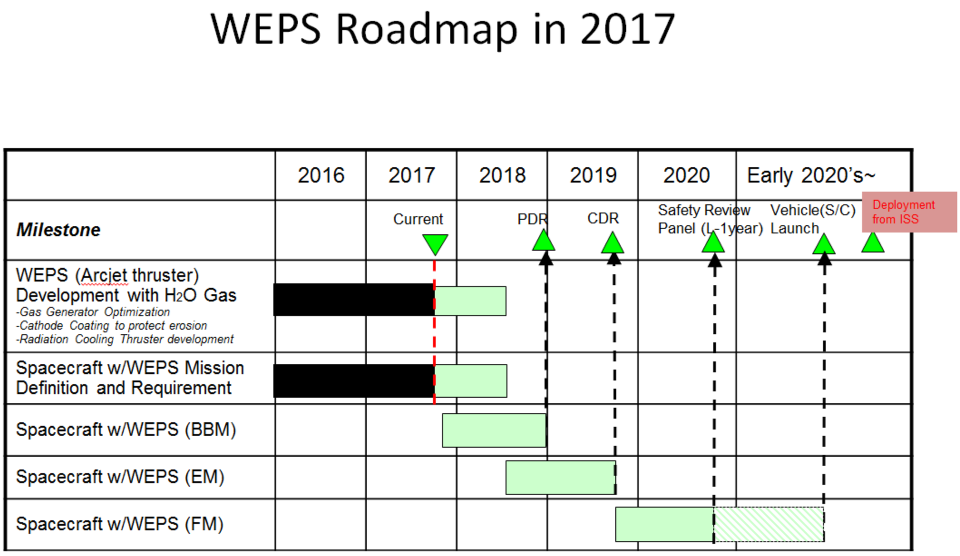

Figure 1. Latest WEPS Road Map[3]

Deployments from ISS have a lot of heritage so far. The idea of precisely and safely launching satellites into orbit from the ISS has become increasingly popular in recent years[6]. Besides CubeSat series, up to ~50kg class satellite was deployed from ISS. It's the hottest spot in ISS. WEPS is relatively large system itself, so we plan to assemble a small size (~50kg class) of SWWEPS. Typical sequence to deploy from ISS is shown in Figure 2. through Figure 4. SWWEPS can be delivered by several launch opportunities such as HTV, Dragon or Cygnus. Around 50kg class can be still within the envelope of typical pressurized internal cargo. After SWWEPS is delivered, ISS crew will fill excess reclaimed waste water into the propellant tank inside the satellite which has been empty. Following the filling with water, crew transfer and attach the satellite to deployer (e.g. called J-SSOD, NRCSD, Cyclops, etc.) put on JEM Airlock slide table. Inner hatch closure, depressurization in the JEM Airlock, Outer hatch closure and extract of slide table are followed and finally ISS Robotics Arm captures the satellite then maneuver to release position and deploy that. We are going to apply a very similar deployment method for SWWEPS as a highly reliable option.

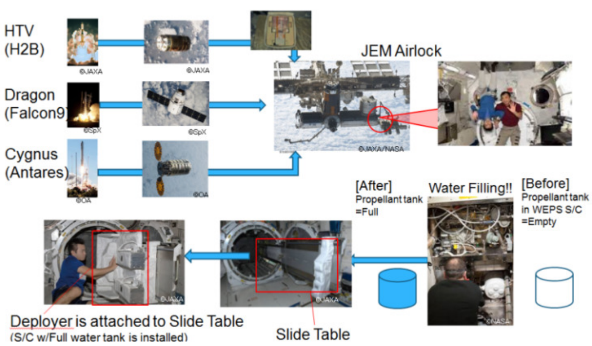

Figure 2. SWWEPS and Deployer Assembly Sequence inside ISS[3]

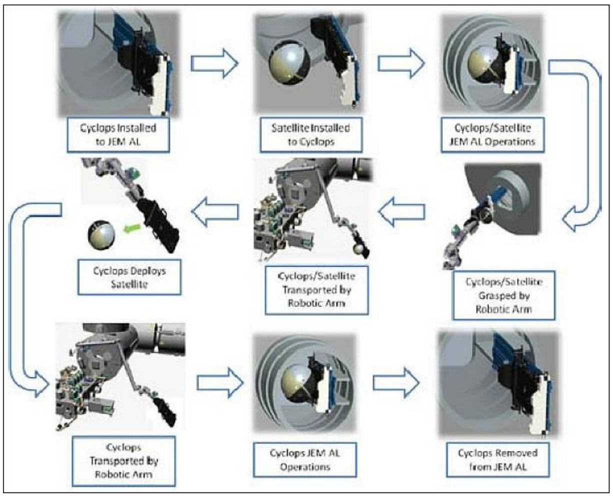

Figure 3. Typical Satellite Deploy Sequence from ISS/JEM (Cyclops operation) [2]

Figure 4. Example of Satellite Deployment from ISS/JEM

II. WEPS design concept and H/W improvement

A. WRS(Water Recovery System) in ISS

It is difficult to obtain water resource from outside the Earth, thus we will use waste water resource as a product of Water Recovery System, which is one of ECLSS (Environment Control and Life Support System) in ISS. WRS provides clean portable water by reclaiming waste water, including water from ISS crew member's urine, cabin humidity condensate, and EVA (extra vehicular activity) waste shown in Figure 5. This reclaimed waste water from WRS can be used for a fuel in WEPS. The water tank in WEPS Spacecraft will be empty as launch configuration and after launch it will be filled with water in space (in this case ISS) by ISS crew manual filling. An objective of this study is to use or refuel water "in-space", assume this filling method in ISS can be applicable in the similar activity in Moon or other planet.

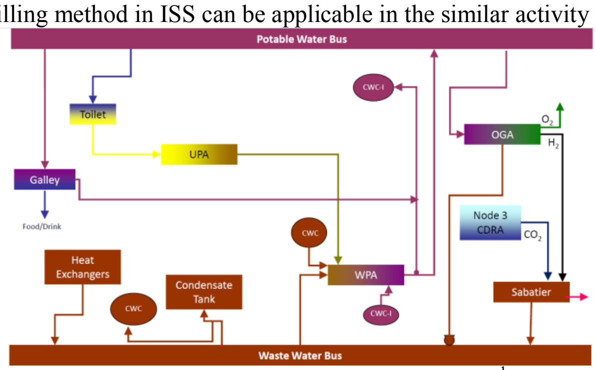

Figure 5. ISS ECLSS WRS overview [1]

B. DC Arc jet design improvement for WEPS

DC Arc jet thruster is a form of electric propulsion for spacecraft, whereby an electrical discharge (arc) is created in a flow of propellant (typically NH_3 or N_2H_4). There many DC Arc jet thrusters currently on orbit and they are working very well, so DC Arc jet is well known as one of the most reliable thrusters. OIT and LLC have been developing a new type of sustainable DC Arc jet thruster to mitigate electrode erosion and to achieve lower power consumption around 1-3kW.

As our developing process, we firstly started with water cooled type thruster, then Anode radiation type (Cathode area is cooled by water but Anode area is cooled by radiation) has been developed so far. Finally we aim to develop full radiation type thruster which is highly mandatory for space environment because we plan not to use water as coolant. 1st version of Anode radiation type DC Arc jet thruster are shown in Figure 5. and Figure 6. in detail. Carbon anode/nozzle, A stainless steel (SUS304: 18% Cr/8% Ni) anode holder, a pure tungsten cathode, and insulator materials made from PBT (Poly Butylene Berephthalate) are used for 1st version. Total length is 147mm, and maximum diameter is 98mm. But this 1st version consists of multi-layer configuration for Anode holder, so precise sealing is very difficult and it prevents the thruster from stable firing. Recent firing test results in firing shutdown in only 10sec due to insulator H/W damage. 2nd version of Anode radiation type has been manufactured several times base on 1st version's lesson and learned. The 2nd version basic design is shown in Figure 7. and Figure 8. in detail. The big modification from 1st version is Anode holder. It consists of single layer insulator and inlet/outlet for water supply line (not for a coolant but a propellant) is allocated outside of Anode holder to secure sealing. Anode holder shape will be also changed from cylinder to hexagonal. A constrictor of a convergent-divergent nozzle throat, as shown in Figure 9., has a diameter of 1.0 mm and a length of 1.0 or 1.5 mm. A divergent nozzle angle is 52 deg and a cylindrical cathode made of pure tungsten has a diameter of 3 mm. The shape of the cathode tip is conical shape. The gap between the electrodes is set to 0 mm.

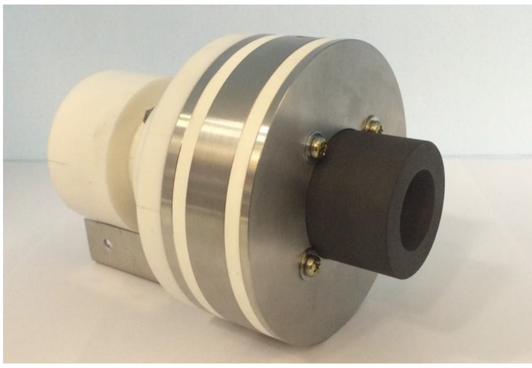

Figure 5. 1st version of Anode radiation type DC Arc jet thruster

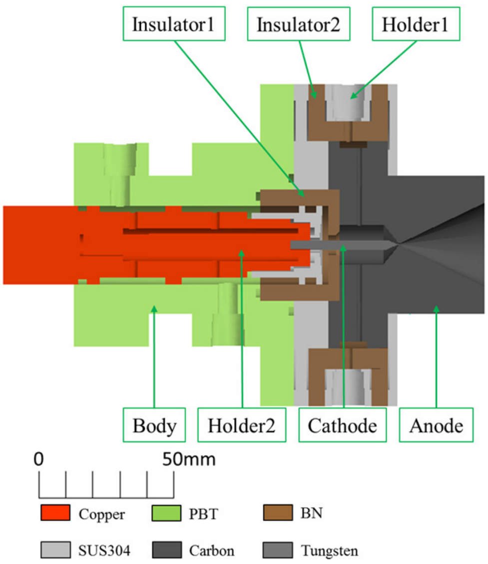

Figure 6. Cross section design for 1st version of Anode radiation type DC Arc jet thruster

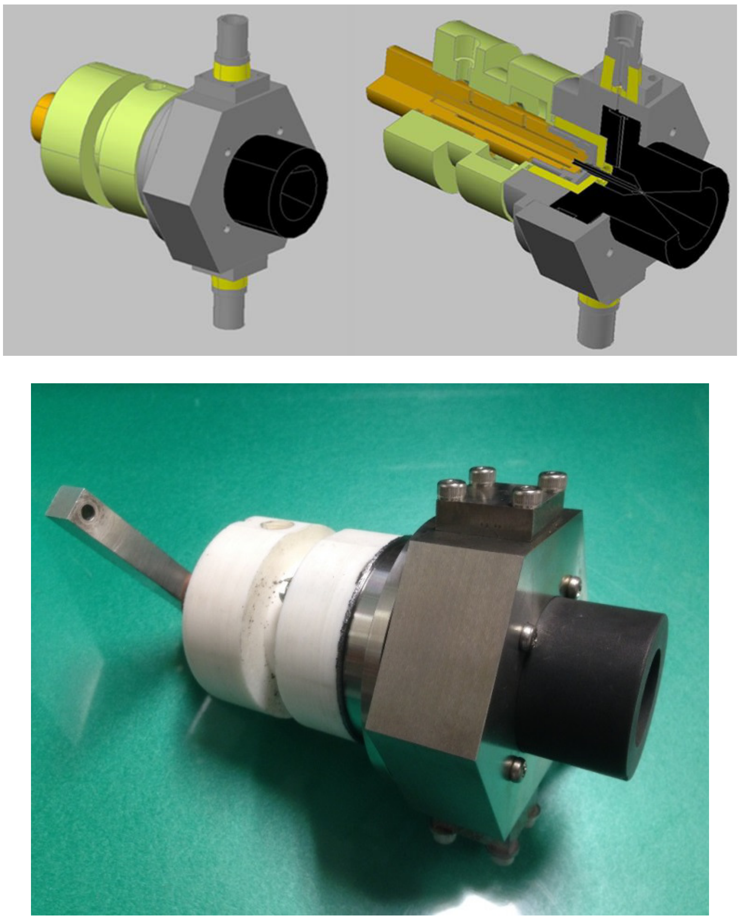

Figure 7. 2nd version of Anode radiation type DC Arc jet thruster

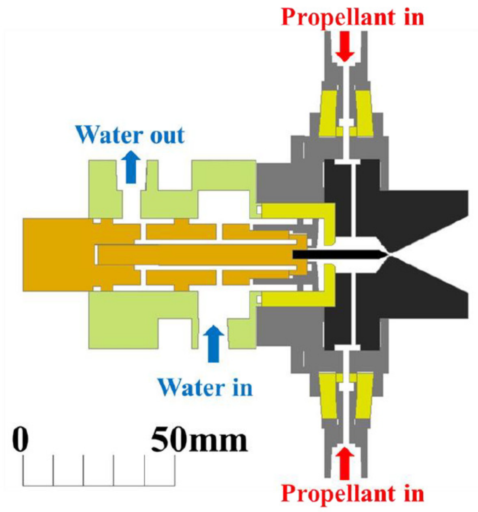

Figure 8. Cross section design for 2nd version of Anode radiation type DC Arc jet thruster

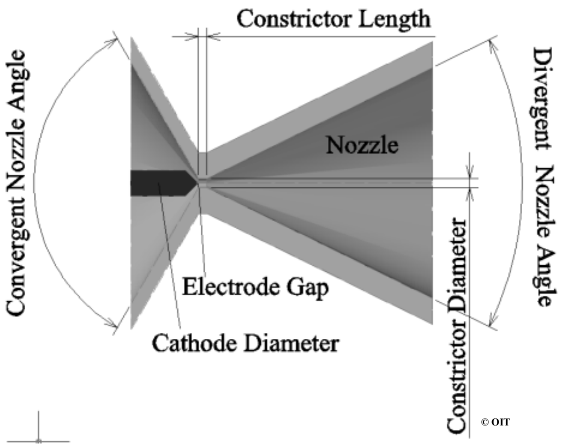

Figure 9. Electrode design

Parameters	number
Cathode diameter	3mm
Constrictor length	1.0mm
Constrictor diameter	1.0mm
Divergent nozzle angle	52deg
Convergent nozzle angle	102deg
Electrode gap	0mm

Table.1 Electrode parameter

C. Gas Generator

According to our experiment results in the past, it is found that water flow by a micro tube pump is not high enough to fire by H_2O only. The usual mass flow controller cannot produce enough water flow to ignite firing continuously due to H_2O liquid state. OIT succeeded to make a prototype of new gas generator using a heat glow plug. Glow plug is one of the car Diesel engine igniter for an internal combustion engine. The new gas generator body is made of copper, as shown in Figure 10. Its cross section overview is also shown in Figure 11.

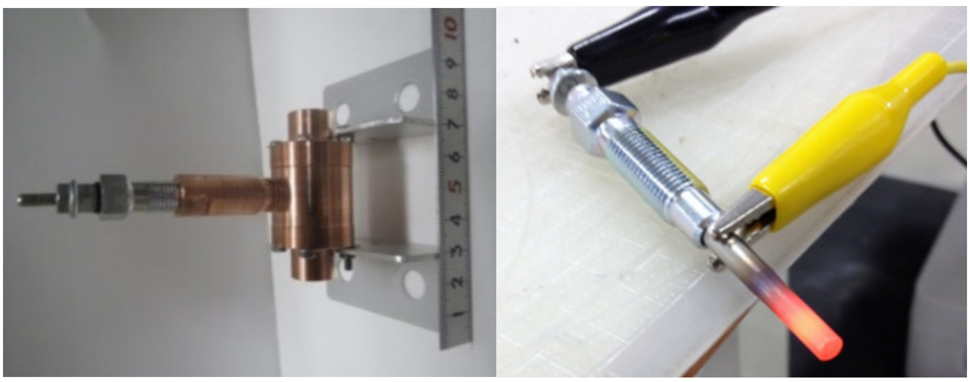
Figure 10. Side view of glow plug(Left), Heated glow plug(Right)

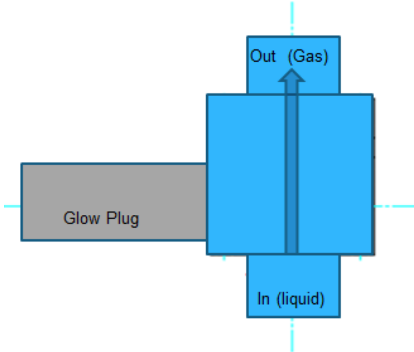

Figure 11. Gas Generator concept overview (cross section)

To check its performance whether water can be kept as gas state, we are measuring Gas Generator temperatures with vacuum configuration (Initial pressure = 6Pa). Input power is 74.6W (input current 8.40A and voltage is 8.88V). The latest trend graph of Gas Generator temperature is shown in Figure 12.
In this experiment, at ~1620secs (1st black solid line) water supply started because a certain period of warming up for gas generator is required. It is estimated that Gas Water gas ejection started from outlet at 1890 sec as stated as 2nd black sold line and confirmed stable and continuous water gas supply was achieved successfully. We are still pursuing more optimized Gas Generator design to keep stable Gas injection into Arcjet thruster. (i.e., direct adjacent interface to inlet of Arcjet thruster)

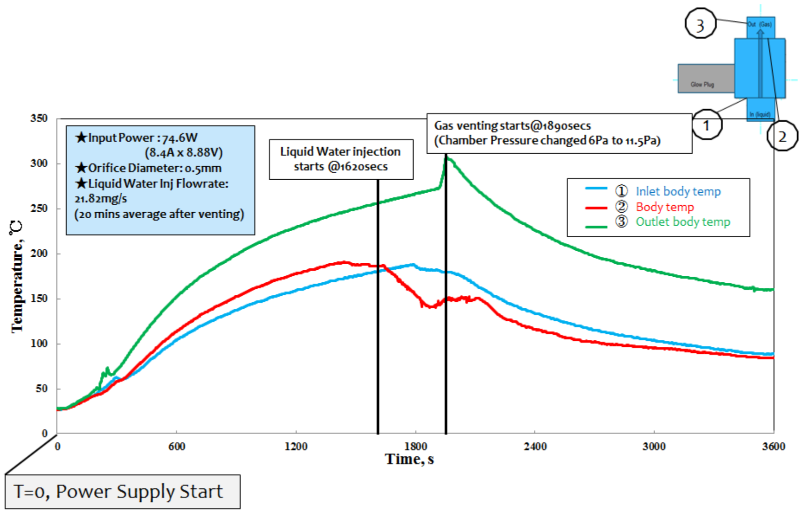

Figure 12. Temperature trend of Gas Generator

III. Validation test results with new Arc jet thruster

A. Experiment Facility

OIT has a variety of facilities to perform electrical propulsion experiments. One of vacuum chambers is used for DC Arc jet experiment, and the photo is shown in Figure 13. and a simplified schematic is also shown in Figure 14. and Figure 15. PWM power supply has been used to perform stable operation with quick response. The vacuum pressure is kept below 1Pa with rotary pump and a mechanical booster (exhaust speed 600m³/h for both). Thrust measurement system we use is a thrust stand with plate springs developed by OIT.

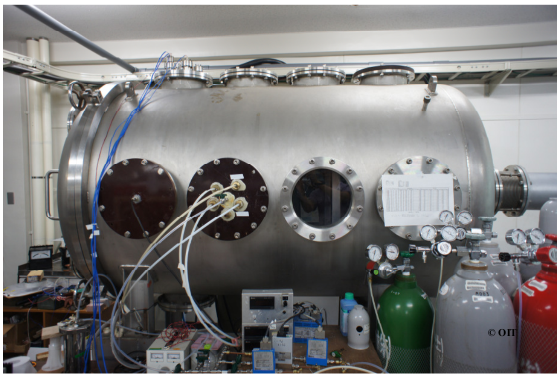

Figure 13. Vacuum chamber (Side View)[3]

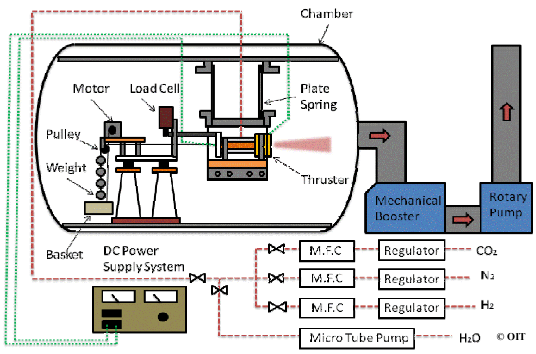

Figure 14. Schematic of experimental equipment. (Except Gas generator)[3]

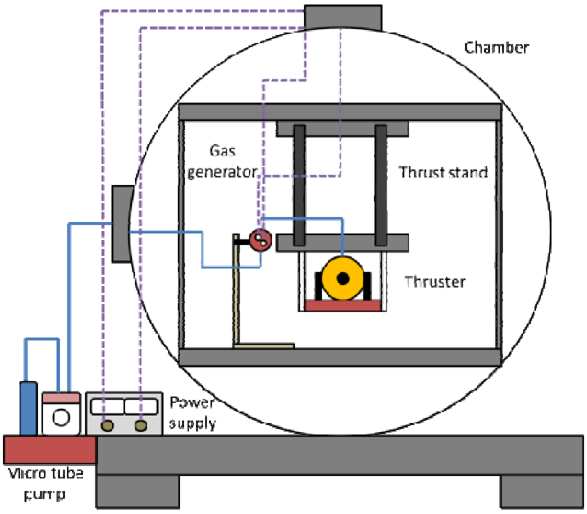

Figure 15. Cross Section of experimental equipment inside Vacuum Chamber (with Gas generator)[3]

B. Firing Test Results

Although an optimization for Gas Generator is still in progress, we got some preliminary data for firing with H_2O Gas only but it should be noted that this firing test starts with N_2 Gas injection only and increasing ratio of H_2O/N_2 then H_2O Gas injection only (N_2 Gas injection stop) in the end. (See Figure 16.) The other note is that this first firing was confirmed by water cooled type DC Arc jet thruster before developing 1st version Anode radiation type thruster. Its firing duration was quite a short (~10secs), but a snapshot could be taken as in Figure 17. As a comparison with 1st version Anode radiation type, snap shot at water cooled type is shown in Figure 18.

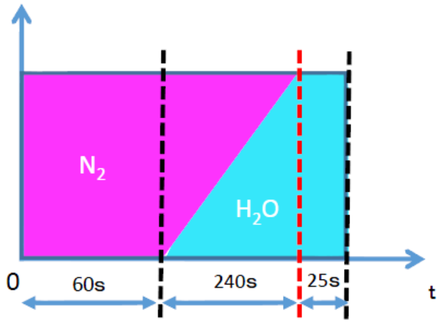

Figure 16. Current typical WEPS Firing Sequence (N_2 Trigger method)

After developing 1st version Anode radiation type thruster, we could slightly extend H_2O only firing duration ~30sec. We still need to apply "N_2 Gas Trigger method" but Gas Generator/thruster designs have changed a little. These may contribute to some improvement for thruster. The recent firing test was performed with input current 19A, input power 38V, and H_2O flowrate 25.2 mg/s. The snapshot at the test is shown in Figure 18. We need to investigate why plume gets weak. We also identify the other key factor is cathode sustainability and that means we need to resolve how the thruster can be sustained from erosion with Oxygen.

Figure 17. H_2O Only WEPS Firing snapshot (1st version Anode radiation type)

Figure 18. H_2O Only WEPS Firing snapshot (Reference: Full Water cooled type)

IV. Conclusion

OIT and Splije LCC are developing WEPS by using "waste water" reclaimed in ISS. This new advanced type of electric propulsion system directly utilizes "water" as a fuel, and would get space environment near Earth or ground facility safer and cleaner. Current our goal is to assemble this WEPS to small size spacecraft (~50kg level), launched and deployed from ISS in early 2020's.

To seek less complicated design for WEPS, an option without H_2/O_2 by water electrolysis is selected. But just replacing from NH_3 or N_2H_4 to water is not enough due to liquid state H_2O. As a resolution, Gas Generator using glow plug has been developed, so quick H_2O gas injection to Arc jet thruster can be achieved firing by H_2O only and it is succeeded for a short period. To extend firing duration and sustainable firing in space, we should consider main two key factors for WEPS Optimization. One is cathode sustainability to prevent electrode (especially cathode) from O_2 erosion and the other is efficient H_2O gas injection to thruster.

References

[1]Jesse Bazley, “ISS Regenerative Life Support: Challenges and Success in the Quest for Long-Term Habitability in Space” 62nd IAC Flight Operations Virtual Forum, United Space Alliance, October 3rd, 2011

[2] Daniel R. Newswander, ”Space Station Integrated Kinetic Launcher for Orbital Payload Systems(SSIKLOPS)-Cyclops” 27th Annual AIAA/USU Conference on Small Satellites, 2013

[3] Y.Nogawa, ” The latest development status for Direct Water Propellant Type DC Arcjet Thruster and Small Satellite Development” APISAT2016, Splije L.L.C, October, 2016