STEP-2021-007

二重振り子式スラストスタンドにおける温度均一板の設計
Design of Temperature Uniform Plates for Dual Pendulum Thrust Stand

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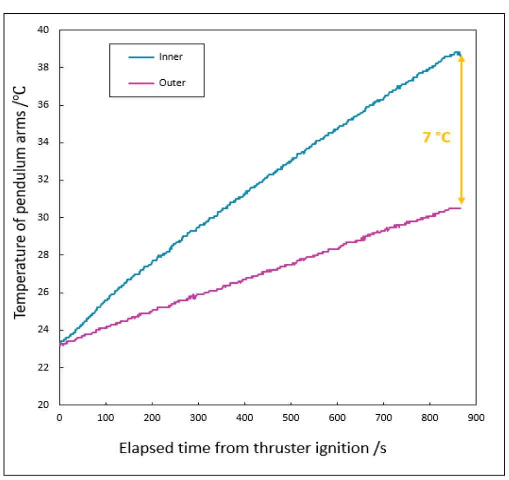
Abstract

The Dual Pendulum Thrust Stand is used for measuring the thrust of the RAIJIN-66 Hall Thruster. Due to the radiant heat of the plume, there is some level of distortion in the pendulum arms, which leads to error during thrust measurement. This relates to the Thermal Drift problem. To solve this Thermal Drift issue, Temperature Uniform Plates have been designed. These plates limit the incoming heat flux and thereby reduce the overall thermal expansion of the pendulum arms. This enables no drift thrust measurement which leads to accurate calculation of other performance parameters and analysis.

1. Introduction

Hall Thrusters are among the most promising Electric propulsions systems for orbit keeping and also for orbit transfer due to their high thrust efficiency when compared to other plasma thrusters with specific impulse of 1500 – 2000 s (1). In order to effectively measure thrust in real time, a dual pendulum thrust stand was developed (2). When the heat entering the inner and the outer pendulum is the same, they are distorted by the same amount and there is no error in thrust measurement. The imbalance of temperature between inner and outer pendulum arms increases with the thruster power, and thermal drift starts to occur even with the dual pendulum stand.



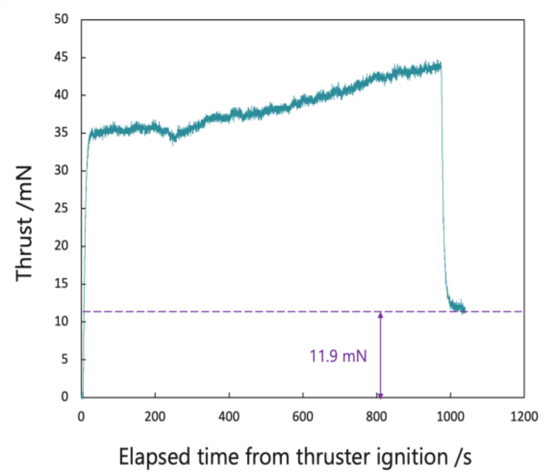


Figure 1: Temperature imbalance (Top), thermal drift during thrust measurement (Bottom)

In order to achieve no drift, thrust measurement, temperature uniform plates have been installed around the pendulum arms to maintain uniform temperature between the inner and outer pendulum arms.

This paper reports the approach of design of temperature uniform plates, where data of heat flux experiments using a pyroelectric detector are used as an input in Ansys FEM software. This is followed by experimentation to verify the simulation and effectiveness of the temperature uniform plates in maintaining uniform temperature.

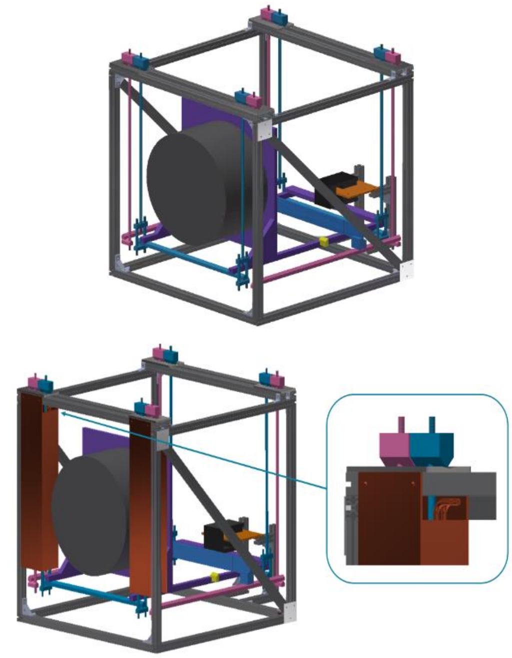


Figure 2 : CAD model of Dual Pendulum Thrust stand: without temperature uniform plates (Top); with temperature uniform plates (Bottom)

2. Design approach and analysis

2.1. Radiation Heat Flux Measurement

To measure heat flux from the thruster, a pyroelectric detector (Gentec QS3-L) was used. The detector when coupled with an operational amplifier circuit provides data in the form of change in voltage, which can be interpreted through a computer with relevant software. In a pyroelectric Detector, due to the incident radiation flux on the pyroelectric element; absorption of radiation flux results in a temperature change within the pyroelectric material. The pyroelectric effect generates charges on the electrodes which is then transformed into a signal for interpretation. In this experiment, the calibration was done using the data provided by the manufacturer (3). The generated charge is given by:

$$dQ = p \cdot A \cdot dT$$

Where, Q is the generated Charge, p is the pyroelectric coefficient, A is the area of the pyroelectric element and T is the temperature.

The operation conditions during the experiment were a discharge voltage of 100 V and a discharge current of 2 A. Additionally, a collimator was used to limit the line of sight during the experiment.

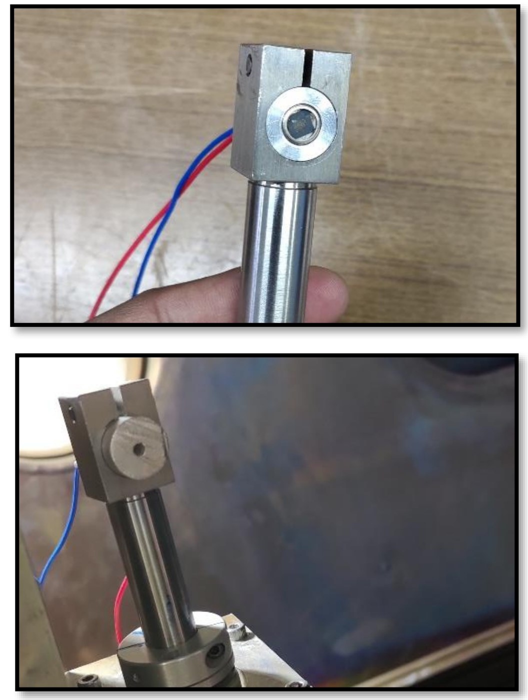


Figure 3: Pyroelectric Detector (Top); Pyroelectric Detector with a collimator (Bottom)

The pyroelectric detector is installed on the transverse system and the measurement begins just behind the thruster and is moved downstream till the detector views the tail of the plume. Figure 4 shows the schematic diagram of the setup during the experiment.

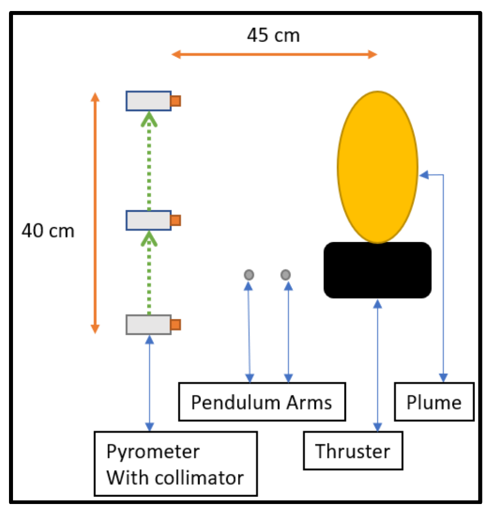


Figure 4: Schematic Diagram of the setup for Radiation Heat Flux Measurement

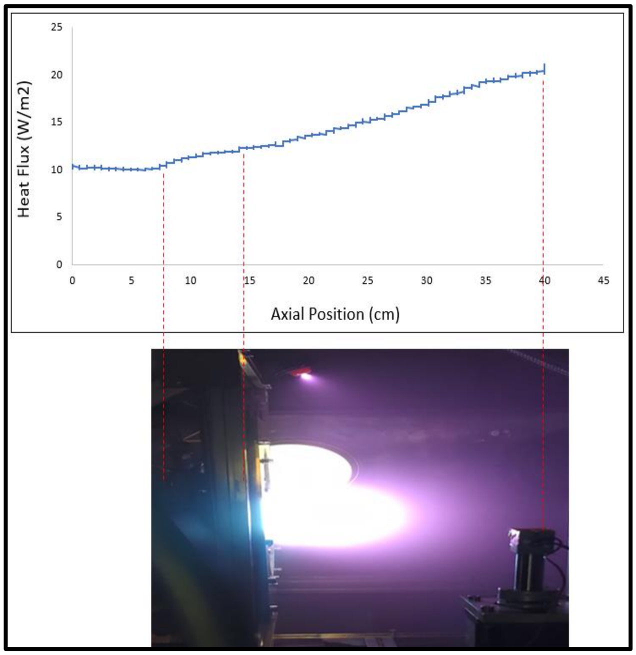


Figure 5: Measured Heat Flux Axial Distribution

Since the input for FEM analysis requires radial distribution data, the heat flux radial distribution was calculated using the heat flux value (~12 W/m^2) at the line of sight at the thruster exit and the distance of the pyroelectric detector from the temperature uniform plates, assuming the radiation power density is uniform in the radial direction in the plume having the diameter of 10 cm.

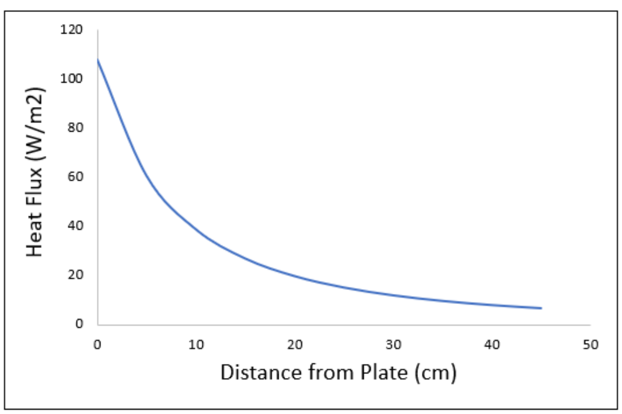


Figure 6: Expected Heat Flux from the plume to the stand

Heat Flux values from Figure 6 were used as input values for FEM analysis using ANSYS as explained in the next subsection

2.2. Finite Element Method Analysis Using ANSYS Transient Thermal

The simulation time scale was set to 15 minutes and the heat flux was set as load, as per the data in Figure 6. The test cases include 3 cases:

1. Application of load directly on Pendulum Arms
2. Application of load on Temperature Uniform Plates with thickness 0.3 mm
3. Application of load on Temperature Uniform Plates with thickness 0.6 mm.

<u>**Case 1:**</u> Application of load directly on Pendulum Arms

Figure 7 shows the temperature contour and temperature time history of the pendulum arms. The existence of temperature of difference between the two arms is clearly visible and needs to be eliminated.

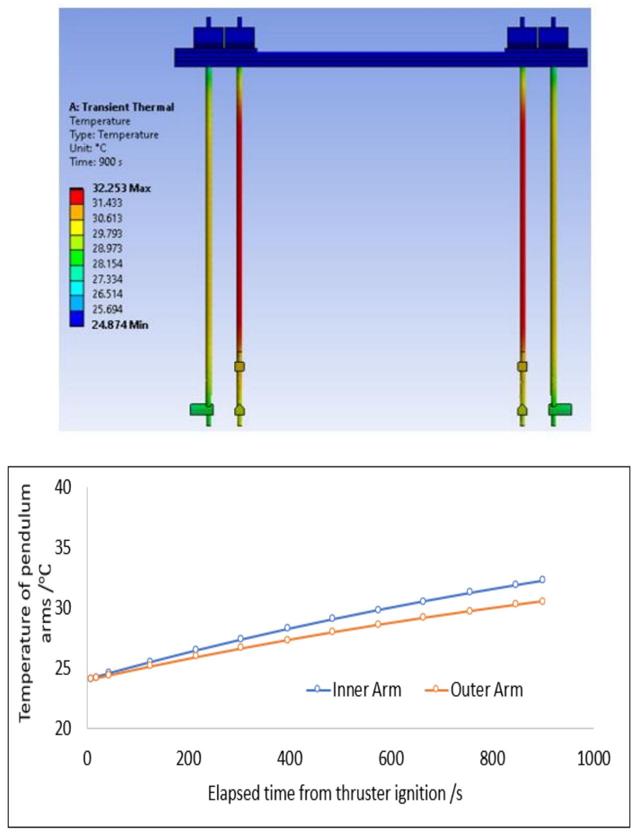


Figure 7: Simulation without Temperature Uniform Plates

Case 2: Application of load on Temperature Uniform Plates with thickness 0.3 mm

Figure 8 shows the temperature contour of the temperature uniform plates and temperature time history of the pendulum arms. As can be seen through the plot, there is significant reduction in temperature difference, thereby verifying the effectiveness of the temperature uniform plates.

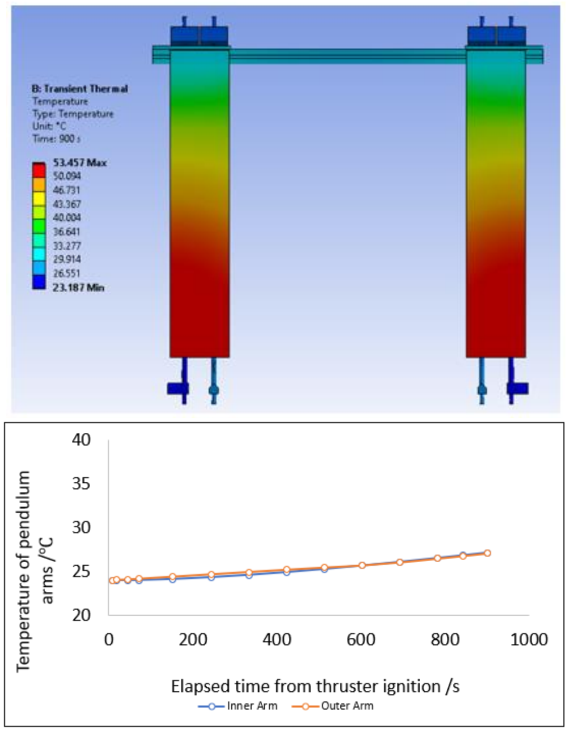


Figure 8: Simulation with Temperature uniform plates of thickness 0.3 mm

Case 3: Application of load on Temperature Uniform Plates with thickness 0.6 mm.

Figure 9 also shows the similar results as that of Case 2. However, there is no significant reduction in temperature difference between the pendulum arms, and therefore give no additional advantage over the 0.3 mm thick plate.

From a manufacturing and installation viewpoint, a 0.3 mm thick plate is better for consideration for temperature uniform plate. Therefore, a 0.3 mm thick plate will be used during actual experimentation.

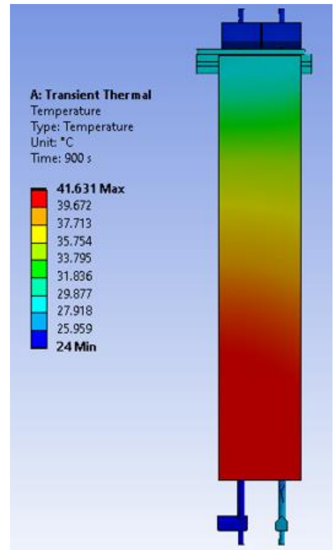


Figure 9: Simulation with Temperature uniform plates of thickness 0.6 mm

3. Result and Discussion

A 0.3 mm temperature uniform plate was installed around the pendulum arms and the temperature time history was measured. The experimental results were very similar to computed results through FEM Analysis

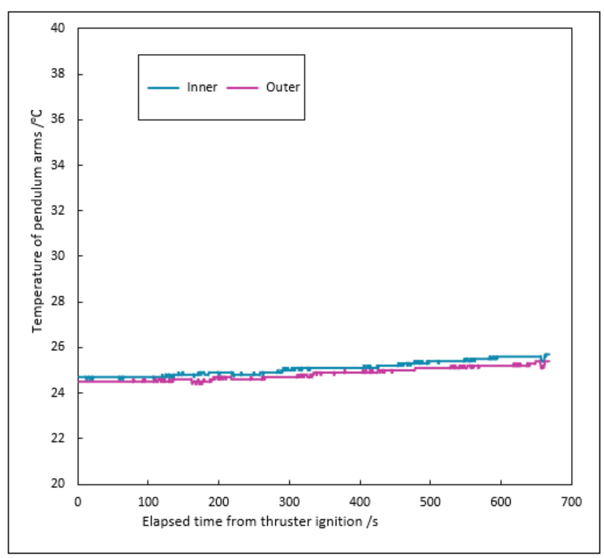


Figure 10: Temperature of pendulum arms after installation of temperature uniform plates.

Thrust measurement were furthermore done as zero drift thrust measurement is the main goal of this work. Figure 11 shows the thrust measurement with thermal drift (top) and the successful elimination of thermal drift and achievement of zero drift thrust measurement (bottom).

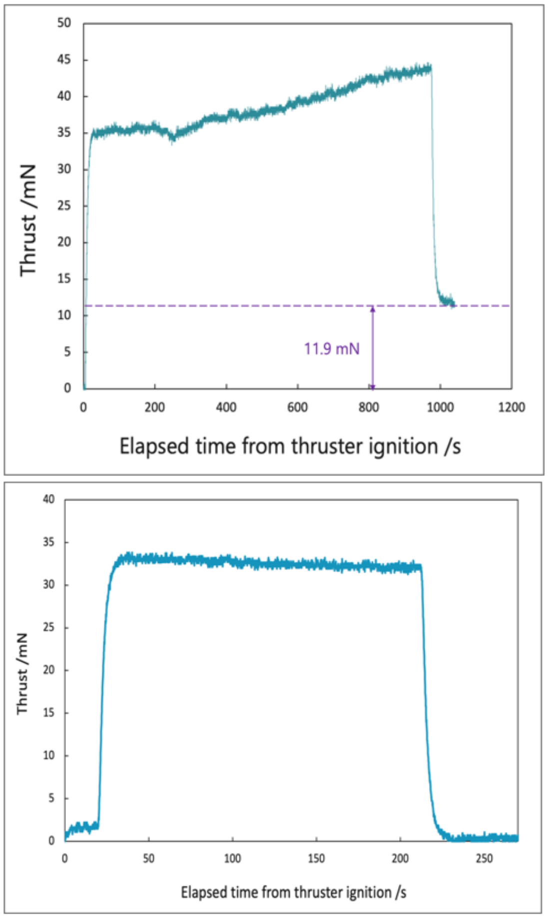


Figure 11: Thrust measurement without temperature uniform plates (top) Thrust measurement with temperature uniform plates (bottom)

4. Conclusion

The 0.3 mm thick plate was sufficient in cancelling the radiative flux imbalance between the inner and outer pendulum arms. From a manufacturing and installation standpoint, the plate should be thin. It was shown through simulation that a thicker plate didn’t have any advantage over the 0.3 mm plate. Zero drift thrust measurement was successfully demonstrated and a longer thruster measurement is to be done in the future, along with an experiment where the relationship between anode temperature and thruster performance will be studied.

5. References

1. Kaufman, Harold R. "Technology of closed-drift thrusters." *AIAA journal* 23, no. 1 (1985): 78-87.
2. Nagao, Naoki, Shigeru Yokota, Kimiya Komurasaki, and Yoshihiro Arakawa. "Development of a Dual Pendulum Thrust Stand for Hall Thrusters." In *43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit*, p. 5298. 2007.
3. Detector Basics, InfraTec