Engineering Notes

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Mercury Flow Meter for Ion Thruster Testing

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Introduction

IN the course of conducting experimental studies of mercury bombardment thrusters, considerable time is consumed in waiting to obtain accurate mercury flow rate information. Mercury flow measurement techniques presently in use involve the measurement of a mass or volume of mercury and they therefore provide integrated flow rate information which implies an average flow rate. It is difficult to determine flow rate trends from such information. These problems could be alleviated if a continuously indicating, accurate flow meter were available. The thermal flow meter described herein, which is based on the concept suggested by Laub,[1] does indicate mercury flow rates continuously over the range of interest for ion thruster testing with acceptable accuracy.

Design and Operation

The basic concept on which this device operates was employed independently by Pye[2,3] and is illustrated in Fig. 1. As liquid mercury passes through the flow tube toward the vaporizer and thruster, it is heated slightly by the fixed power heater. The proximity of the high temperature sensor to this heater and the fact that the temperatures at the two ends of the tube are held at ambient values by the heat sink shown implies a temperature difference between the two sensors shown in the figure. These sensors (thermistors) are connected into a bridge circuit which produces an output proportional to the temperature difference which they sense, and this output can be related to flow rate.

The present flow meter employs a 0.30 mm i.d. Teflon flow tube with a 60 mw resistance heater located 8.4 cm from the entrance to the flow tube and 4.2 cm from its exit. The two 0.11-cm-diam, 10 kΩ glass bead thermistors used to sense temperatures are located 1) at the entrance to the flow tube, and 2) near the heater. The inlet and outlet temperatures are equalized by passing the inlet and outlet flow in close proximity to each other in a high heat capacity mass as suggested by Fig. 1. This entire assembly is enclosed in a vacuum feed-through to effect thermal isolation and hence minimize spurious output. The flow tube length and diameter, the heater location and the thermistor locations were determined from analysis of the one-dimensional heat-transfer problem associated with flow meter operation.[4] The two thermistors are connected into a bridge circuit containing two additional 10 kΩ thermistors and a 4-v battery. These two additional thermistors are connected electrically into opposing legs of the bridge circuit and are located adjacent to the thermistor sensing the temperature of mercury at the entrance to the flow tube. Output voltage from the bridge is displayed on a digital volt meter and a strip chart recorder.

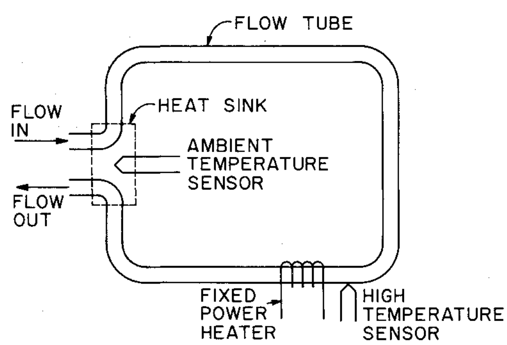
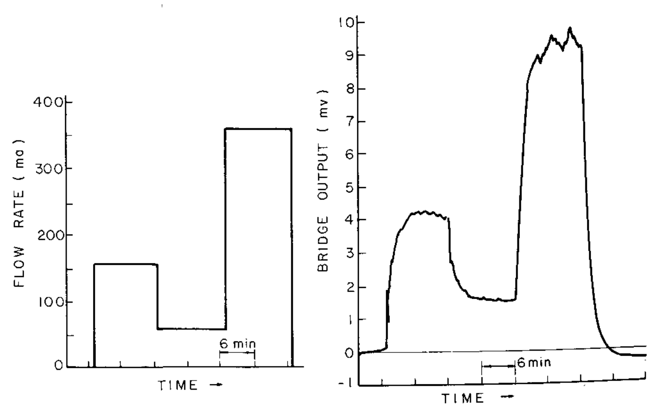


Fig. 1 Thermal flow meter schematic.

Flow Meter Performance

The flow meter has been tested using a small variable speed, positive displacement pump to produce the desired flow rates. Typical flow rate input obtained with this pump and the associated flow meter bridge output obtained on a strip chart recorder are shown in Fig. 2. The flow rate input shown in Fig. 2a is not exactly correct as the pump plunger tends to stick and then jump, producing a jagged flow pattern which is evident in the bridge output data (Fig. 2b), but conventional flow rate measurements show a step function flow pattern, like the one shown, exists on the average. The flow meter is seen to have a time constant, determined primarily by the thermal inertia of the device, which is of the order of a minute. The time constant could be reduced by reducing the length of the flow tube but this would require a corresponding reduction in the diameter of the flow tube to maintain the sensitivity of the instrument, and preliminary tests indicated the feed system would have to be pressurized to facilitate mercury flow through the tube if its diameter were reduced further.

Calibration of the thermal flow meter was accomplished in a thruster feed system by measuring the time required for a mercury meniscus to fall between two scribe marks confining a known volume of mercury in a 0.9-mm-diam bore glass tube while the flow meter output remained essentially constant. The resulting calibration curve for the thermal flow meter is presented as



a) FLOW METER INPUT b) FLOW METER OUTPUT

Fig. 2 Flow meter dynamic performance.

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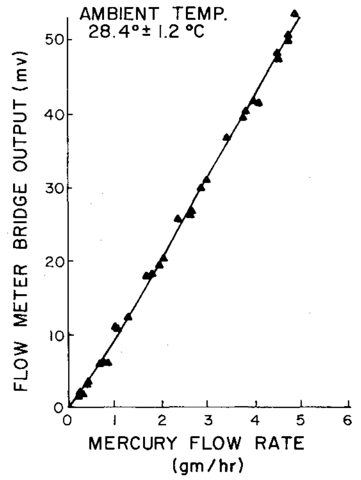

Fig. 3 Flow meter calibration curve.

Fig. 3. It shows a nearly constant sensitivity of about 10 mv/g/hr over a 0.2–5.0 g/hr flow rate range and it appears higher flow rates could be indicated. By increasing the sensitivity of the readout equipment the flow meter appears to perform satisfactorily at low flow rates (<0.3 g/hr). The scatter in the data points of Fig. 3 are considered to be due to variations in ambient temperature and scatter in flow rate measurements obtained from the glass tube.

One drawback with this device is its sensitivity to variations in ambient temperature (about −0.4 mv/°C) which could introduce significant flow rate measurement errors. This could be eliminated by holding the mercury entering the system at a fixed temperature by using a temperature controller as Pye does.[3] Theory[5] suggests however that the use of matched thermistors in the system should also eliminate the drift and since this approach would yield the simplest system, it is being pursued at the present time.

Several months of operating experience with the flow meter on an operating thruster have demonstrated that it is very useful as a tool for indicating flow rate trends. This usefulness is illustrated in Fig. 4 which displays flow meter output as a function of time for flow rate initiation—stabilization—termination cycle. After the flow meter heater had been allowed to stabilize and the bridge circuit had been zeroed, the vaporizer was energized. The figure shows a large negative flow rate associated with expansion of the mercury occurs immediately. This is followed by the establishment of a positive flow rate about 6 min after vaporizer energized, an increase in flow rate, associated with contraction ment which was necessary to achieve the desired flow rate, stablization at a steady flow rate is observed (about 15 min after vaporizer heatup began). When the vaporizer heater is de-engerized, an increase in flow rate, associated with contraction of the mercury as it cools, is observed. Subsequently the output

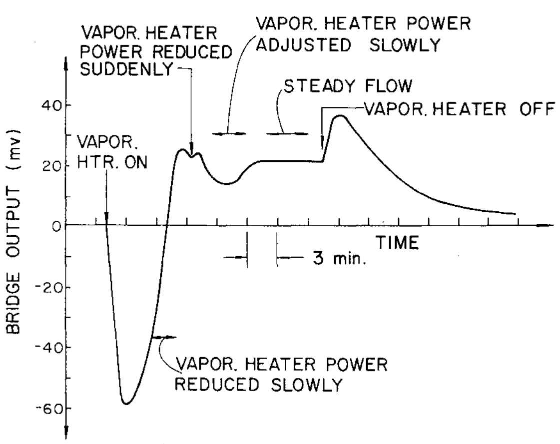

Fig. 4 Typical flow meter output in thruster feed line.

drops to zero exponentially as the flow meter temperatures stabilize back to their no-flow values.

Conclusion

A continuously indicating thermal flow meter has been made which indicates mercury flow rates in the range of interest for ion thruster testing. This device, which employs a small bore Teflon flow tube and thermistor sensors in a bridge circuit has been operated over a flow rate range from zero to 5.0 g/hr, has shown a sensitivity of about 10 mv/g/hr and a time constant of the order of a minute.

References

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Pulsed Plasma Microthruster for Synchronous Meteorological Satellite

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Introduction

MAJOR advances in pulsed plasma microthruster system technology have been made since the LES-6 flight launched 1968.[1,2] One of these latter thrusters accumulated about 8900 hr of thruster operation at synchronous altitude during East-West stationkeeping.

The demonstrated success of the pulsed plasma system suggested possible application of a pulsed plasma propulsion system to perform East-West stationkeeping as well as satellite fine pointing which is realized by spin axis precession control of the synchronous meteorological satellite (SMS). The new system required a 25-μ lb-sec impulse bit capability with these impulse

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