



Development of a Micro-Thruster Impulse Measurement System Using Optical Sensors

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2008. 8







- Introduction
- **4** Traditional Measurement Stands
- Proposed System Design and Measurement Method
- Computer Simulation
- Theory Verification by Test
- **4** Conclusion







- Micro thruster produced extremely low level thrust
 - mN ~ µN level thrust produced
- Conventional measurement method cannot be used
 - > Strain gauge, spring, deflection, etc.
- Bang-bang type thruster often used
 - Does not produce sustained thrust
 - More important to measure total impulse





Laser Interferometry





- Uses pendulum to reduce frictional loss
- Laser interferometer measures distance changes → infer produced thrust
- Impacter' sometimes used to deliver known amount of momentum to system for differential measurement

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- Near frictionless bearing in middle
- Thrust firing create torque and change relative angle of arm
- Angle and angular rate are measured to derive delivered thrust

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- Instruments are bulky and require much calibration
 - Instrument suite tends to be much larger and bulkier than actual test setup
- Stringent calibration required for each test
 - > Test data can vary depending on test condition
 - > Micro-unit measurement requires complex and laborious calibration

System loss can greatly affect measurement data

- Friction loss cannot be avoided
- Misalignment introduces error

Uiscrepancies in physical setup can reduce data accuracy

- > Temperature difference can cause large deviation
- Mass mismatch, or difference in geometry caused during setup can lead to large errors





To design, develop, and prove the concept of a new measurement system that can characterize the minimum bit impulse produced by micro-thrusters







Comparative measurement taken

- > Performance inferred by measuring and comparing two swing times
 - 1st swing without firing thruster, 2nd swing with thruster firing
- > Comparative measurement results in negating most error

Calibration can be reduced

- > Detailed and stringent calibration before each test is not required
- Most of error sources are included in 'control swing'

Minimize sensor suite bulk

- > Associated sensors and electronics are small in size
- > Can be adopted to different applications
- > Does not require extra provisions for sensor suite accommodation



Performance Comparison



Item	Distance Meas. (Laser Interfero.)	Angle Meas. (Rotating Platform)	Time Measurement
Measurement Range (mNs)	0.1 - 10,000	0.0001 - 1	0.1 - 100
Max. Resolution (mNs)	0.01	0.0001	0.01
Error (%)	2	5	4
Comment	 Bulky support equipment Impactor calibration required 	 Large in size (over 1.5m) Strenuous calibration required 	 Simple design and compact No calibration required after initial characterization Refinement needed to improve resolution and accuracy



- ♣ Previous method (displacement measurement) → new method (time measurement)
- **Experimental data showed satisfactory results**

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- 4 1st swing : no thruster firing (control swing)
- 2nd swing : single thruster firing



Determining Initial Displacement



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Control Swing is used to determine initial displacement

> Control swing time gives indication of initial displacement





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∆t vs. Applied Impulse Sim. Result



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Step 1. Initial Displacement



4 Measure control swing time to obtain initial displacement

value



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Step 2. Identify Appropriate Curve



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17



Step 3. Measure Impulse



Take time measurement of impulse-applied swing to calculate impulse applied



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Data Uncertainty



- System random error: standard deviation = ±14µs
- **4** Time difference \rightarrow 2 x swing times : ±28µs
- **4** To have 95% confidence, need to include $2\sigma : \pm 56 \mu s$
- **4** Data mismatch error : 1%
 - Result discrepancy between test result and interpolated theoretical data
- % error associated with system random error (above) of ±56µs: 3%
- **4** Total system error for measurement: 4%





·-·- Init Disp = 0mm

Test Trendline

- Init Disp = 0.1mm

Test Result

4.50E-04 5.00E-04 5.50E-04 6.00E-04

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Cold Gas Thruster Test Result



Calculated theoretical impulse: 372µNs

Impulse measured by system: 367µNs

scatter

Good Match!

Applied Impulse (Ns)

3.00F-04 3.50F-04 4.00F-04

- **4** However, scatter results in large standard deviation: \pm 128 μ Ns
 - > Error due to thruster itself: valve slamming effect, unstable flow, etc.
 - Measured thruster performance range: 239µNs ~ 495µNs

0.587200

0.587100



Conclusion (1/2)



Performance of micro-thruster can be characterized by using proposed measurement system

Time difference between no-firing and thruster firing swings can be measured to calculate applied impulse

Has advantages over previous methods

Reduces calibration steps

> Reduces required setup by simplifying sensor suite

- Performance calculation method devised using computer simulations
- **Experimental data is matched with simulation data**

Good match verifies the proposed new method for measuring applied impulse



Conclusion (2/2)



- Using proposed method, minimum bit impulse of microthruster can be calculated by measuring relative swing time
 - > Swing time measured for no-firing swing
 - > Swing time re-measured with single thrust firing
 - > Difference in time can be used to calculate thruster performance

