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Considerations about the attitude and orbit acqu sition phases led to a maximum power of 24W consumed by the propulsion subsystem.

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THRUST BALANCE FOR A MICRO THRUSTER TEST STAND

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INTRODUCTION

The impulse is an important parameter for the design a d oper satellite orbit and attitude control systems that use reaction jets. I controlling the motion of the satellite, it is necessary to know what given jet will deliver before beginning any maneuver so that it can be accomplished with a minimum consumption of fuel: fuel being the critic that determines the useful life of the satellite.

One of the manners used to determine the impulse of a thruste experimentally measure the thrust and integrate it over a certain time However, in satellite control systems the jets develop a low thrust on of 0.5 to 20.0N and commonly operate in a pulsed mode with cycle times 50ms. This low thrust and short cycle time complicates the measurement interference from the mechanical dynamic response characteristics of t balance.

Here, this problem is discussed by presenting a dynamic analy actual performance of a thrust balance intended for use in the range (100N and with pulse cycle times of 50ms. In what follows, the balance described, a mathematical analysis of its dynamic behavior is complet results are compared with some experimental measurements.

THE BALANCE

Figure 1 shows the general features of the thrust balance. T thruster under test is attached to a table which is limited to move o direction of thrust by means of two flexures. The table butts against a piezoeletric force transducer and is held in place by means of a compression spring/screw thread device. The transducer is connected to a charge amplifier which in turn is hooked to some recording device. In the experiments discussed here, the signal was recorded with a storage oscilloscope.

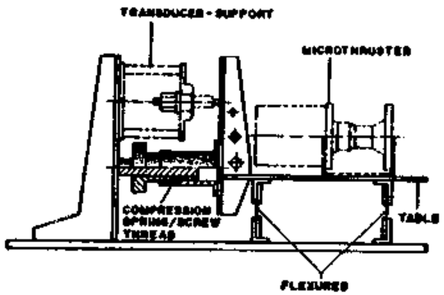

Figure 1. Thrust Balance.

With the objective of being able to control mechanical damping, the table is also fitted with a magnetic damper. The damper was positioned at more than one location with respect to the table during the tests, and will be discussed in a later paper.

DYNAMIC CHARACTERISTICS

The measurement system can be viewed as in Figure 2. In that schema, the original thrust force signal F(t) is transformed to a displacement signal X(t) by the table.

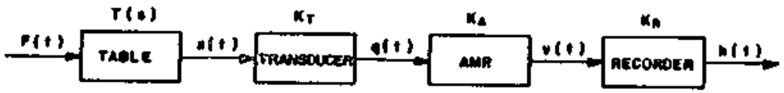

Figure 2. Schematic representation of the system.

The displacement is then transferred to a electrical charge signal q(t), then v(t) after passing through the amplifier, and finally, to, a displacement h(t) on a graph. Each of the transformations involves a transfer function, which depends

upon the nature of the device employed, that modifies the incoming sign

Limiting the analysis to the table, X(t) can be found from

$$X(t) = \int_0^t F(t - \tau)\, t(\tau)\, d\tau$$

where t(t) is the inverse La place transform of the transfer function T the table which in this case is shown to be

$$T(s) = \frac{W_n^2}{S^2 + 2\,\zeta\, W_n\, S + W_n^2}$$

where

$W_n = \sqrt{K/M}$ [rad/s]

$\zeta = c/2MW_n$ [-]

K = equivalent spring constant of all table supports [N/m]

M = mass of the table [kg]

c = damping constant [N.s/m]

To simulate the pulsed mode operation of the micro thruster, F considered to be a square wave with an amplitude equal to the magnitude thrust A and a period T equal to twice the pulse duration time. During time of the thruster $0 \le t \le T/2$ the displacement is given by

$$X(t) = A\,[1 - e^{-\zeta W_n t}\,(\cos W_d t + \frac{\zeta}{\sqrt{1 - \zeta^2}}\ \text{sen}\ W_d t)]$$

where

$$W_d = W_n \sqrt{1 - \zeta^2}$$

During the off time $T/2 \le t \le T$

$$X(t) = A_T\, e^{-\zeta W_n t}\, \sin(W_d t + \theta)$$

where

$$A_T = \frac{A\left[1 - \frac{e^{-0.05\zeta W_n}}{1-\zeta^2}\sin(0.05W_d + \phi)\right]}{e^{-0.05\zeta W_n}\sin(0.05W_d + \theta)}$$

$$\theta = -0.05W_d \cdot \tan^{-1}\left(\frac{\zeta}{\sqrt{1-\zeta^2}} + \frac{e^{-0.05\zeta W_n}}{\sqrt{1-\zeta^2}} \cdot \frac{\left[\frac{\zeta}{\sqrt{1-\zeta^2}} \cdot \sin(0.05W_d+\phi).\cos(0.05W_d+\phi)\right]}{\left[1 - \frac{e^{-0.05\zeta W_n}}{\sqrt{1-\zeta^2}}\sin(0.05W_d+\phi)\right]}\right)$$

$$\phi = \sin^{-1}\sqrt{1-\zeta^2}$$

Table 1 lists the characteristic values of the measurement system. In Figure 3 is the idealized displacement response of the table utilizing these values to a increase in level of 6N.

Table 1

Characteristics of the thrust balance

Table mass	0.650kg
Table moment of inertia	$91.7\text{x}10^{3}$ kg.m^2
Rigidity of flexures	$22.7\text{x}10^{3}$ N/m
Rigidity of spring/thread mechanism	$3.27\text{x}10^{3}$ N/m
Natural frequency	591 rad/s
Maximum table displacement	$0.44\text{x}10^{-3}$ m
Time constant	$2.4\text{x}10^{-3}$ s

TESTS

The balance was mounted on a massive concrete block as shown in Figure 4. A thrust level of 6N was simulated by suspending a weight from the table and a step change to zero was effected by cutting the chord.

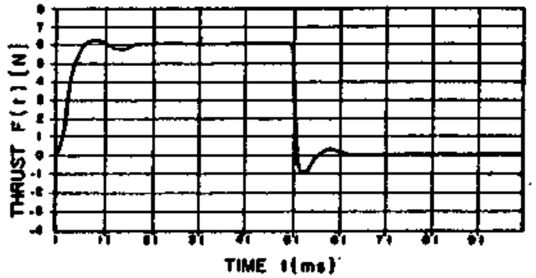

Figure 3. Response of table displacement to step increase of thrust from 0 to 6N.

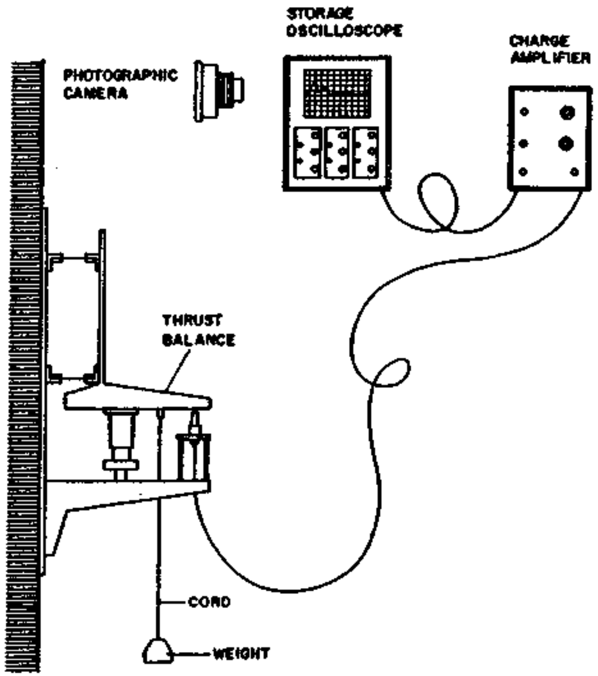

Figure 4. Test set up for finding the dynamic response of the thrust balance.

Figure 5 shows a sample of typical results in which it can be seen that the system doesn't behave as predicted by the mathematical model. In the Figure , it is easy to see that

$$Ln \frac{A_1}{A_2} \neq Ln \frac{A_2}{A_3} \neq \ldots Ln \frac{A_{n-1}}{A_n}$$

However, there is the following behavior

$$Ln \frac{A_1}{A_2} = Ln \frac{A_3}{A_4}$$

$$Ln \frac{A_2}{A_3} = Ln \frac{A_4}{A_5}$$

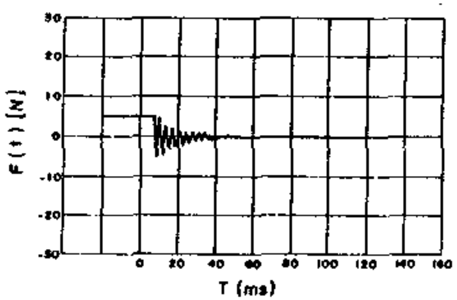

Figure 5. Balance dynamic response to a thrust level of 6N.

This result was believed to be due to a low rigidity in the transducer support and the parts were stiffened. Figure 6 shows the results after the modification and it can been seen that the math model provides a reasonable prediction of the table behavior.

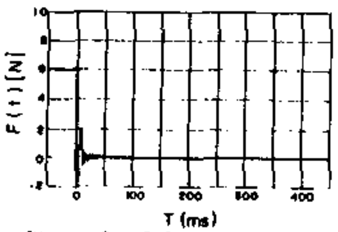

Figure 6. Balance response.

Based on these results, it is felt that the present balance introduce any real distortion into the thrust signal for the conditic it was designed. In fact, it appears that pulses down to 20ms may be measured.

CONCLUSIONS

The results shown in Figs. 3, 5 and 6 demonstrate that the mathematical model employed in the analysis provides a reasonable pre- of the system behavior and the feasibility of the system concept to tl purpose. The dependence of the system dynamic response characteristic geometrical parameters is shown; the transducer and its mounting devi determine the mechanical damping,and the spring/thread mechanism does on the system equivalent stiffness. The measurement system can be vie mass-spring-damper system with an adequate damping coefficient within to 0.8 ideal values range.

The development will be continued after some modifications in in the original design through the accuracy evaluation, calibration me and accessories definition.