Dynamic Testing of Propulsion Modules

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Autoliv

Introduction

The goal of our senior design project was to design a dynamic tablet testing device for Autoliv that actuates at a minimum of 1 m/s and can measure force and position with a sensing rate of ≥100 kHz throughout a collision with the a pyrotechnic, gas generant tablet. The output data from our device will be analyzed by the Autoliv inflator development team and used to better model the mechanical behavior of the gas generant tablets during the ignition cycle of inflators. These improvements will help Autoliv ensure that its inflator systems remain within their safety specifications for the housing internal pressure.

Table 1. Design Metrics

Design Metric	Target	Achieved
Minimum "Linear Actuator" Speed	1 [m/s]	1.15 [m/s] Average over 10 Tests
Force Sensing Rate	100 [kHz]	> 200 [kHz]
Position Sensing Rate	100 [kHz]	Equal to Data Acquisition Rate (essentially infinite resolution)
Force Sensing Accuracy	+/- 1 % [N]	+/- 2.75 % [N]
Position Sensing Accuracy	+/- 0.2 [mm]	+/- 0.275 [mm]
Compatible With Autoliv Instrumentation	Binary Metric	BNC Connectors & Remote Firing Button
Safe To Operate	Binary Metric	Inoperable Without Enclosure Closed
Key	Performance Specification	Design Constraint

Solution

Our design team's solution to this problem is a DC motor powered, rack and pinion actuation system. This system is given structural rigidity using 30 mm aluminum extrusions and is enclosed using acrylic panels for safety. To measure the position a string potentiometer is affixed to the actuation assembly so that the position can be measured directly. To measure force, a FlexiForce A301 piezoresistive sensor is affixed to the tablet striking surface of the actuation assembly. All of the control circuitry is housed in a central control box which also houses the user facing BNC ports for data collection and remote triggering.

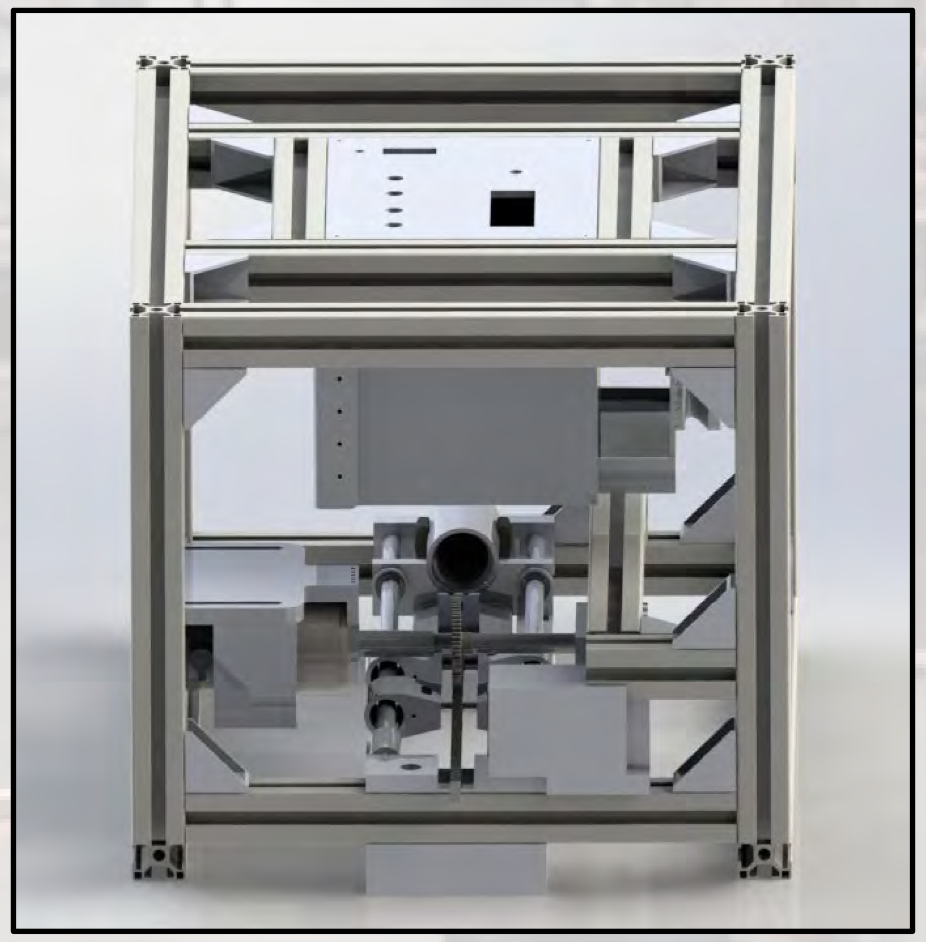

Figure 1. Final CAD Rendering of Device

Analysis

Motor speed calculations were carried out to ensure the selected motor meets the 1 m/s velocity constraint. A pinion gear of 1.25" radius was selected and the target velocity is 1 m/s so from equation 1, the required motor velocity was ~300 rpm as seen in Table 2.

$$\omega = \frac{v}{r} \cdot \frac{60}{2\pi} \quad (1)$$

Table 2. Motor Speed Calculations

Quantity	Value	Units
v	1	m/s
r	1.25 [0.03175]	in [m]
w	300.76	rpm
Key	Known Value	Calculated Value

The forces acting on the motor will be the force enacted by the tension in the string potentiometer and the force required to accelerate the actuation assembly at the desired acceleration. Applying equations two and three yields the required motor torque as 26.5 oz-in as shown in Table 3.

$$F_t = F_{pot} + m a_{max} \quad (2)$$

$$T = r \cdot (F_{pot} + m a_{max}) \quad (3)$$

Table 3. Motor Torque Calculations

Quantity	Value	Units
r	1.25	inches
F_{pot}	1.9	Newtons
m	406	grams
a_{max}	9.84	meters/second^2
T	0.187 [26.5]	Newton-meters [oz-in]
Key	Known Value	Calculated Value

Conclusion

Overall this design was able to meet all of the design metrics that were laid at at the beginning of this project by Autoliv. The target performance specifications were from the very onset intended to function as targets only, not metrics of success, so this design's proximity to those targets is a success. The sensing system's sampling rate has been validated using a Measurement Computing, NIST certified DAQ. Going forward, Autoliv has expressed that they may incorporate additional sensing systems (that are well outside of the financial scope of our design team) if they deem it necessary. The data collection and post processing will be done by Autoliv engineers using live pyrotechnic tablets, as we were provided inert tablets to do our design validation testing. This project presented our team with an opportunity to better develop the following skills: part and assembly design, electrical circuit design, software design, data analysis, spectral analysis, and physical user interface design.

Results

The string potentiometer used for the position sensing system was calibrated using electronic calipers. The effective range of the calibration equation is from 0 to 180 mm and over that range, the calibration results in less than 0.275 mm of absolute error as seen in Figure 2. The FlexiForce A301 piezoresistive sensor used for the force sensing system was calibrated using a digital dynamometer. The effective range of the calibration equation is from 0 to 180 N and over that range, the calibration equation results in less than 2.75% error as seen in Figure 3.

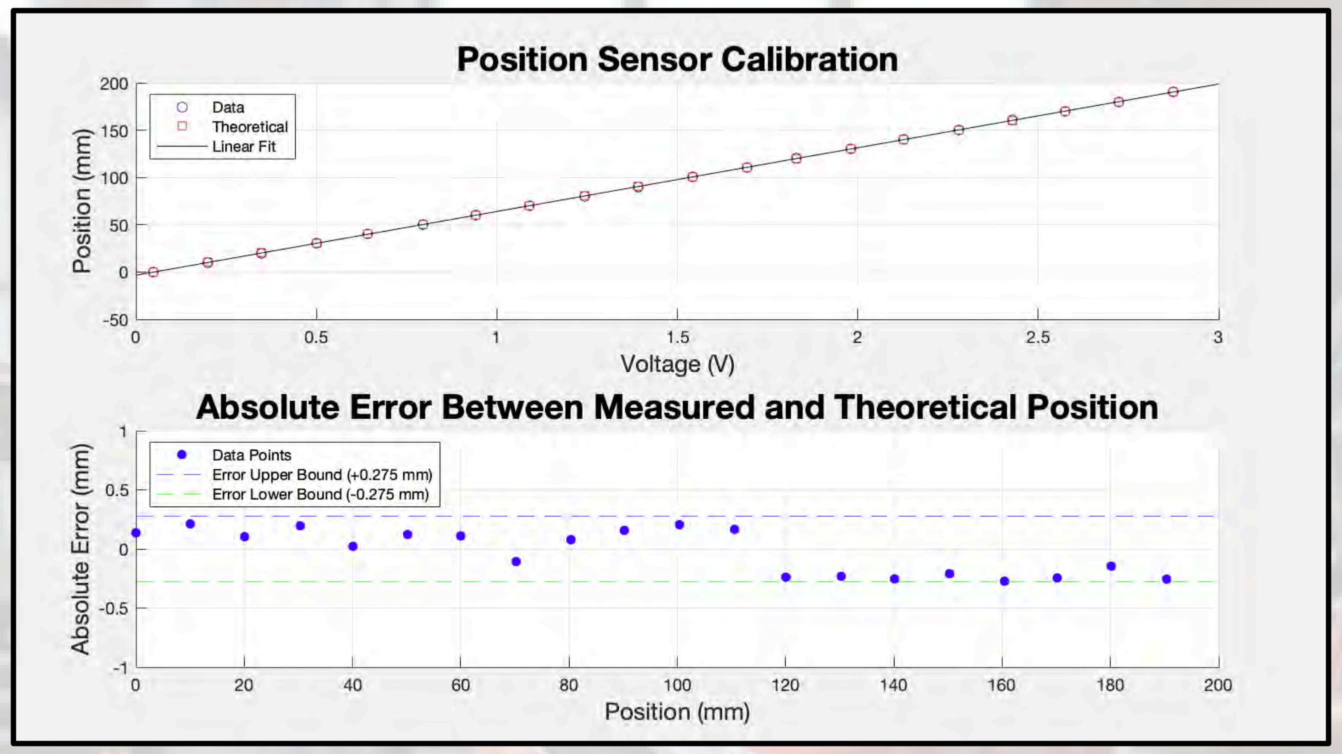

Figure 2. Absolute Error Between Measured and Theoretical Position

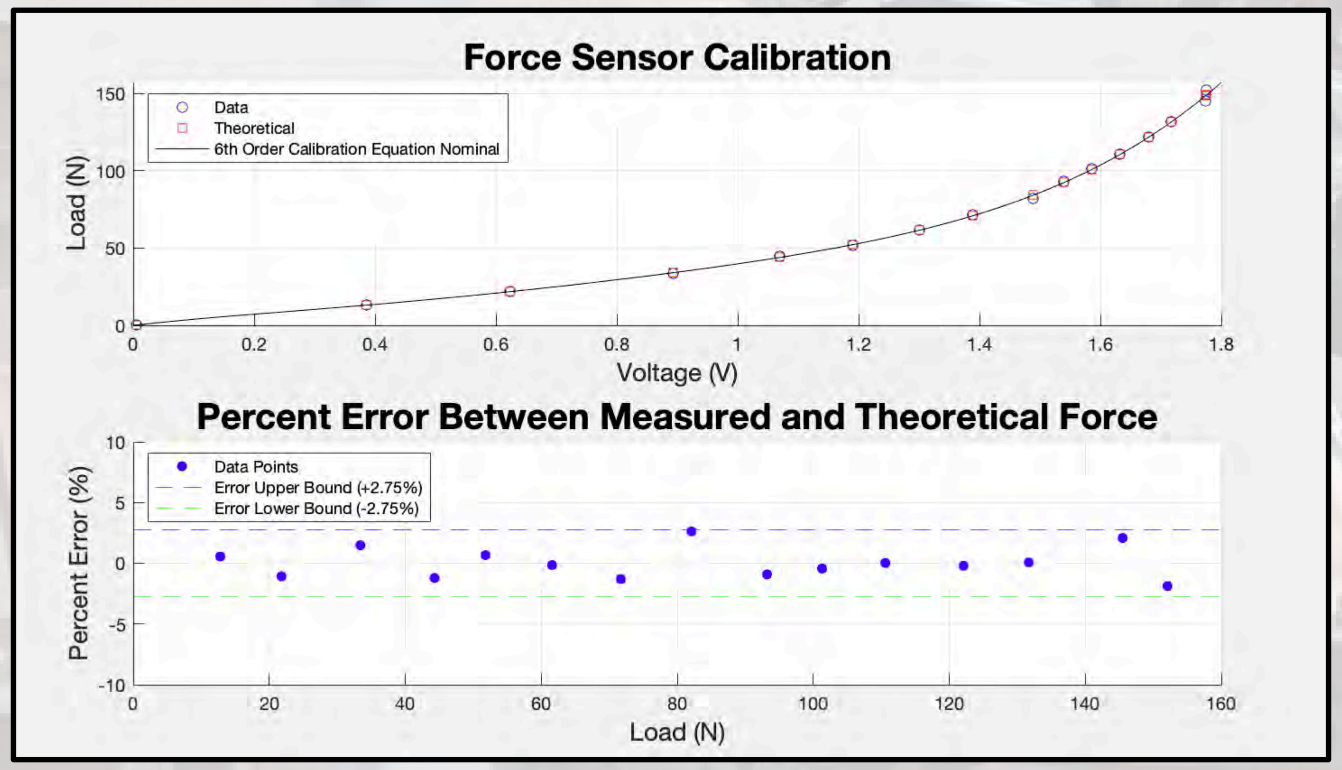

Figure 3. Percent Error Between Measured and Theoretical Load

The actuation velocity was tested in a series of ten tests and the average maximum velocity reached was 1.15 m/s with all of the tests surpassing the design metric of 1 m/s.

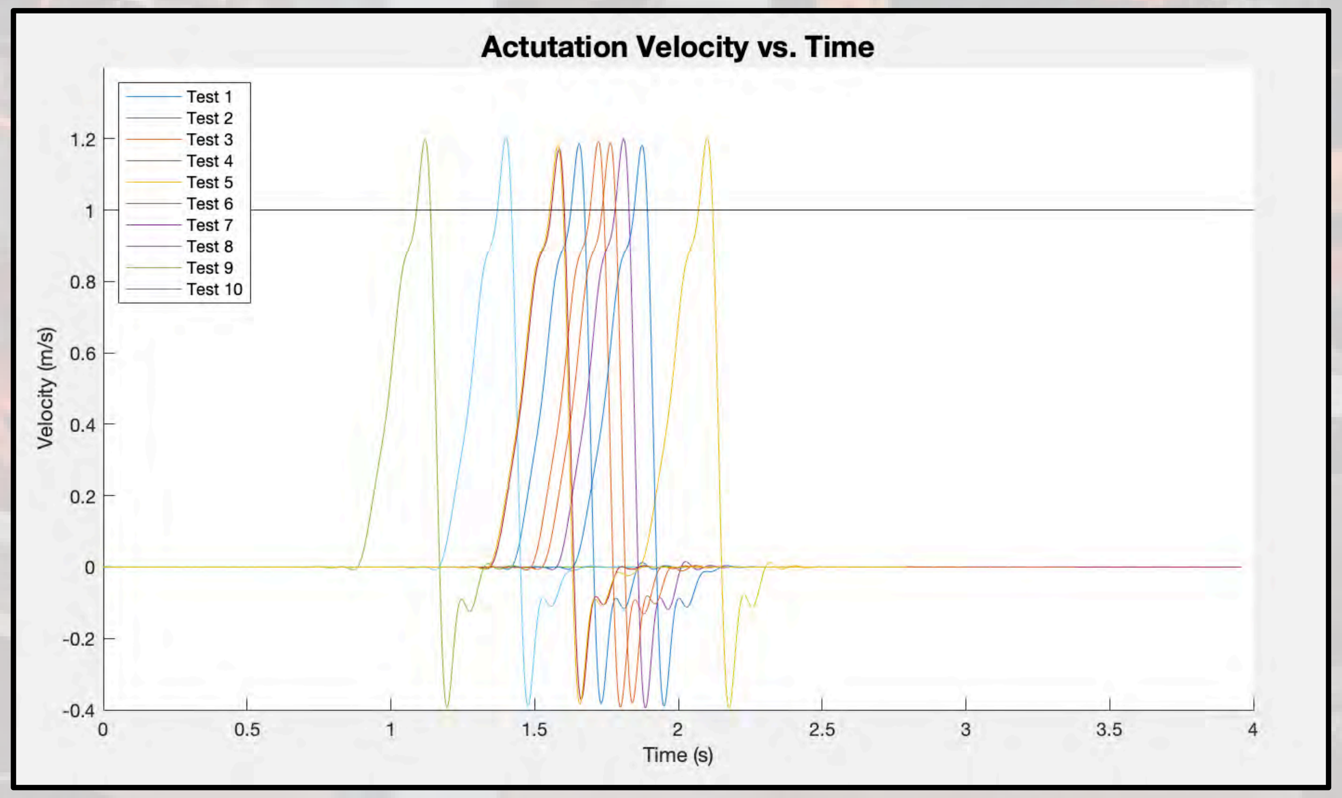

Figure 4. Actuation Velocity vs. Time