Data Acquisition System Documentation

Thrust and Pressure Measurement System for Aerotech Solid Rocket Motors

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1. System Overview

This DAQ system was developed to accurately record thrust and chamber pressure data from Aerotech solid rocket motors during static fire tests. The system captures static thrust and pressure data from both a load cell and a pressure transducer, conditions the signals, and stores the data for post-processing and analysis.

2. Hardware Components

The following components were used in the system:

Hardware List

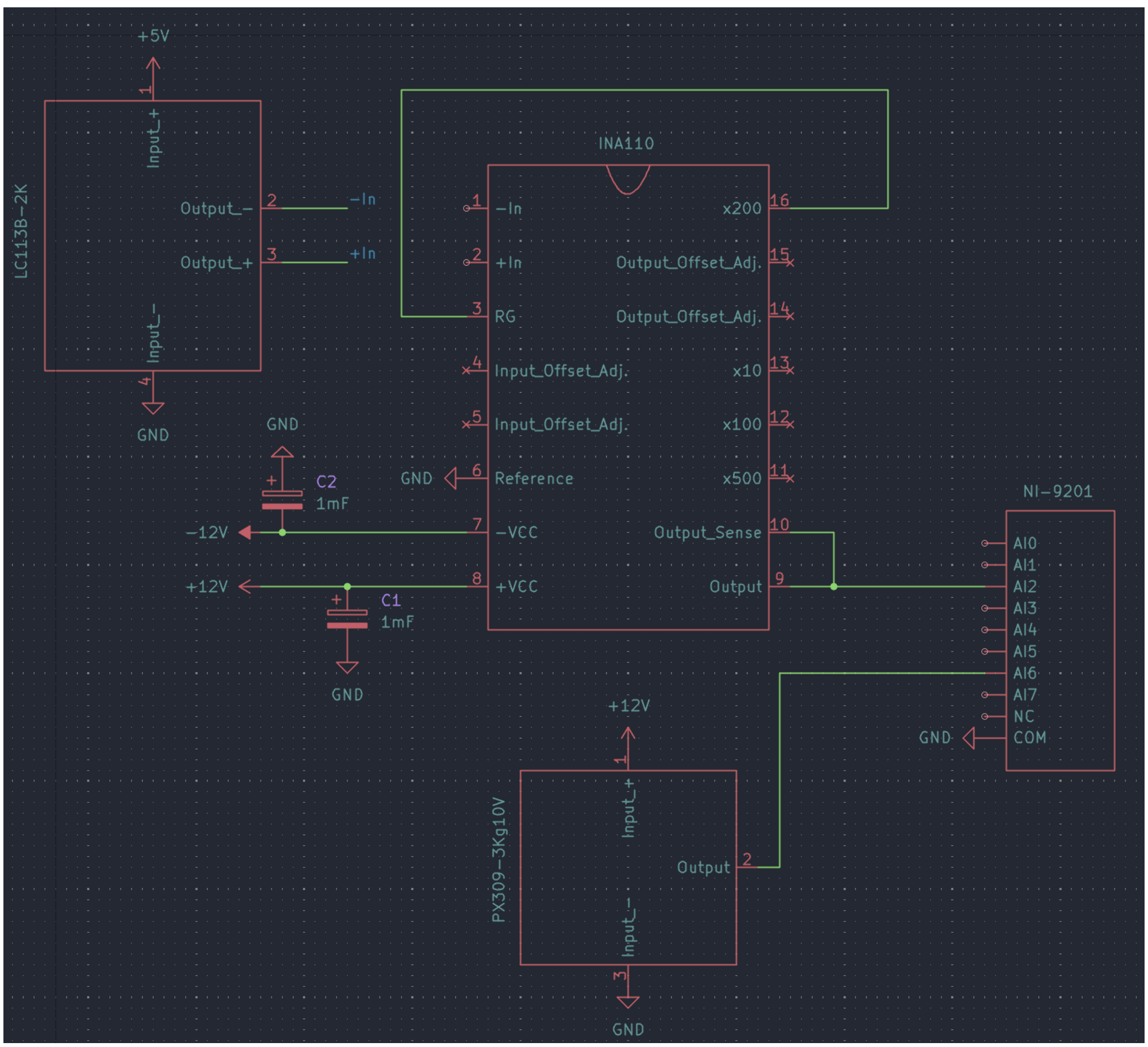
- **NI cDAQ-9174** – Chassis for data acquisition modules
- **NI 9201** – 12-bit Analog Input Module (used to read sensor voltages)
- **NI 9482** – Electromechanical Relay Module
- **DR-ODC5** – Solid-state relay (used for ignition)
- **PS-1S400EP** – Power Supply Unit
- **Computer Supply Breakout Board** – Provides regulated voltage
- **INA110** – Instrumentation Amplifier (for load cell signal conditioning)
- **LC113B-2K Omega S-type Load Cell** – Measures thrust (lbf)
- **PX309-3KG10V Omega Pressure Transducer** – Measures chamber pressure (psi)
- **1 μF Tantalum Capacitors** – Used for filtering power supply noise
- **General wiring, connectors, and test stand**

3. Software

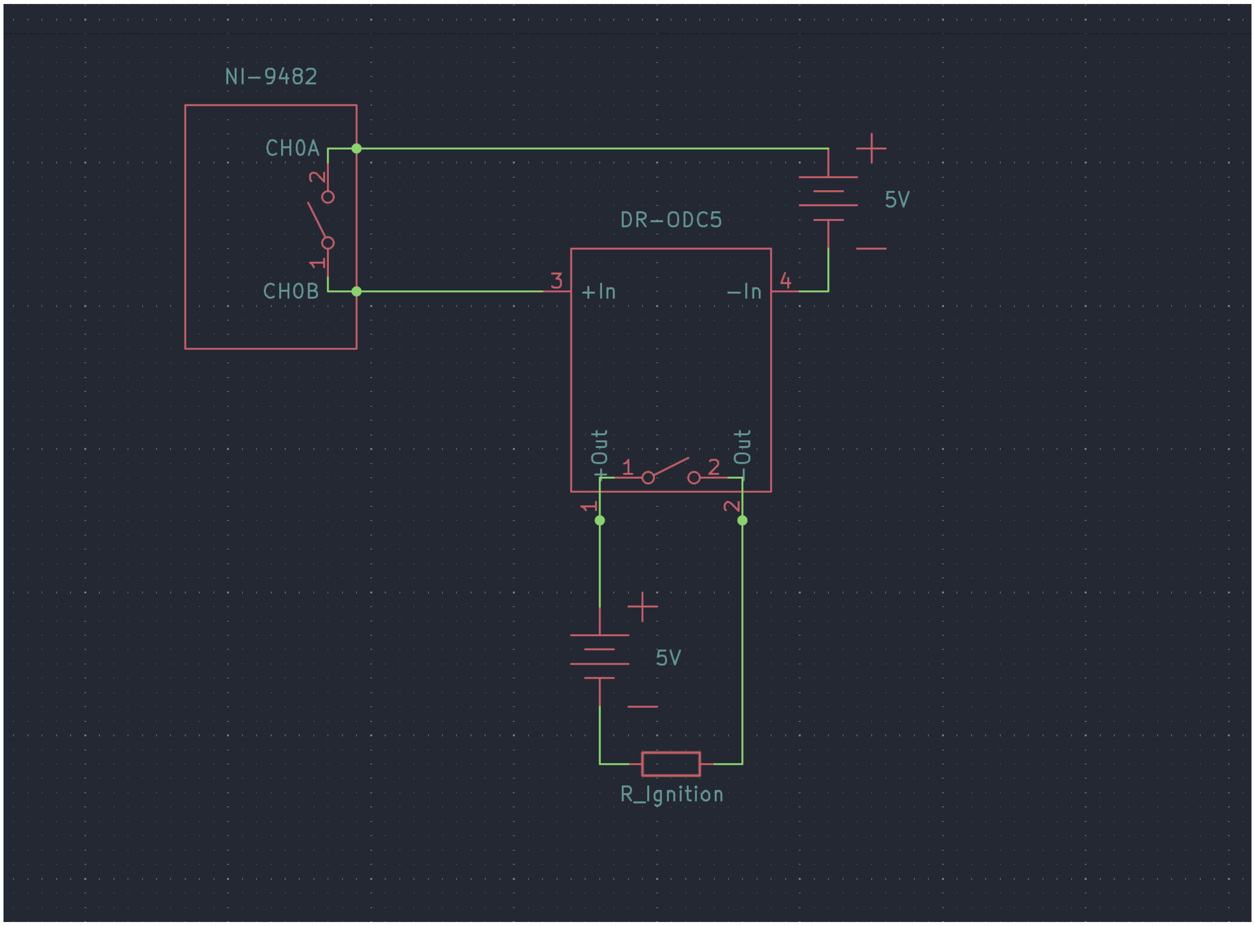
- **NI LabVIEW** – Used for real-time data acquisition, relay control, and data logging.
- **Microsoft Excel and Python** – Used for data filtering and post-processing.

4. Circuitry

Load Cell and Pressure Transducer Circuit



Ignition Circuitry



5. System Configuration

Channel Configuration

COM: Connected to common ground

AI2 (NI 9201): Amplified load cell voltage

AI6 (NI 9201): Raw pressure transducer voltage

CH0a & CH0b (NI 9482): 5V relay voltage for ignition

Sampling Rates & Rationale

- **B**: Bandwidth
- ***Fs***: Sampling frequency
- **N**: Number of samples

Pressure Transducer (PX309-3KGV):

Sampling Rate (fs): 2000 Hz

Reason For Sample Rate: According to the transducer's datasheet, the PX309's response time is <1 ms. A 2,000 Hz sample rate satisfies the requirement to meet the Nyquist Theorem under the assumption that the highest frequency within the data set will be less than or equal to 350 Hz.

$$B \approx \frac{0.35}{Response\ Time} = \frac{0.35}{0.001\ s} = 350\ Hz$$

$$Fs > 2B;\ 3276.8\ Hz > 700\ Hz$$

<u>Load Cell (LC113B-2K):</u>

Sampling Rate (fs): 2,000 Hz

Reason For Sampling Rate: The LC113B-2K load cell datasheet does not specify an exact response time; however, based on typical performance of similar S-type load cells, the response time is estimated to be in the range of 2–5 milliseconds. A 2,000 Hz sample rate satisfies the requirement to meet the Nyquist Theorem under the assumption that the highest frequency within the data set will be less than or equal to 175 Hz.

$$B \approx \frac{0.35}{Response\ Time} = \frac{0.35}{0.002\ s} = 175\ Hz$$

$$Fs > 2B;\ 1638.4\ Hz > 350\ Hz$$

6. Operation Workflow

1. **System Startup:**
    - Power on the CDAQ and power supply
    - Connect CDAQ usb to Rugged Laptop
    - Open LabVIEW DAQ VI and open Main.vi
2. **Data Acquisition Sequence:**
    - **T = 0-10 s:** 10-second countdown.
    - **T = 10 s:** Data acquisition begins.
    - **T = 12 s:** Ignition.
    - **T = 30 s:** Data acquisition stops.
3. **Data Logging:**
    - Four Excel files are generated after the 30-second test:
        1. Pressure Voltage (Raw)
        2. Pressure (PSI)
        3. Load Cell Voltage (Raw)
        4. Thrust (Lbf)
4. **Post-Processing:**
    - Apply a **Moving Average Filter** in Excel to smooth data.
    - Graph and analyze thrust and pressure profiles.

7. Calibration

Load Cell Calibration:

To ensure accurate thrust measurements, the load cell was calibrated using a known mass. The calibration process involved the following steps:

1. **Baseline Measurement:** The load cell was initialized with no applied load, and the corresponding voltage output was recorded as the zero-load reference point.

2. **Known Load Application:** A calibrated mass of **2Kg** was carefully applied to the load cell. The voltage output corresponding to this known load was recorded.

3. **Linear Calibration Curve Development:** With two data points, the zero-load voltage and the 18 lbs load voltage, a linear relationship between voltage output and applied force was established. This linear equation enables the conversion of voltage readings into thrust measurements in pounds-force (lbf). The calibration equation takes the form:

$$Force(lb) = m * Voltage\,(V) + b$$

where m is the slope and b is the y-intercept, determined from the calibration data.

4. **Implementation in LabVIEW:** The derived linear equation was programmed into the LabVIEW software to allow real-time conversion of voltage readings to thrust values during data acquisition.

Pressure Transducer Calibration:

To ensure accurate pressure measurements, the PX309-3KG10V pressure transducer was calibrated against known pressure sources using the following procedure:

1. **Manufacturer's Specifications:**

    - The PX309-3KG10V pressure transducer is rated to output **0 to 10 VDC** corresponding to a pressure range of **0 to 3000 psi**, when powered with an excitation voltage between **9 and 30 VDC**. This results in a theoretical sensitivity of **0.00333 V/psi (3.33 mV/psi)**.

2. **Baseline Measurement:**
   - The transducer output voltage was measured at **0 psi (ambient atmospheric pressure)**. The voltage reading was recorded as **0.019 V**.
3. **Known Pressure Application:**
   - A pressure of **100 psi** was applied using the pressure lines at the National Center for Physical Acoustics (NCPA).
   - The transducer output voltage at this pressure was measured to be **0.360 V**.
4. **Sensitivity Calculation:**
   - Based on the measured voltage readings, the sensitivity was determined using the following formula: Sensitivity = (0.360 V - 0.019) / 100 psi = 3.41 mV/psi.
   - This measured sensitivity closely matches the theoretical value specified by the manufacturer, validating the sensor's performance.
5. **Linear Conversion Equation:**
   - A linear equation was established to convert voltage readings to pressure values in psi: Pressure (psi) = (Measured (V) - 0.019 V) / (0.00341 V/psi)

6. **Implementation in LabVIEW:**
   - This conversion equation was implemented in the LabVIEW data acquisition system, allowing for real-time conversion of voltage measurements to pressure readings during motor tests.

By performing this calibration, the accuracy and reliability of the pressure measurements were validated for the specific DAQ setup and test conditions.

8. Safety

- Always verify the relay function prior to the test.
- Keep safe distance during ignition.
- Never Load the motor or igniter with the power supply on.
- Ensure mechanical fail-safe pin is inserted

DAQ System Setup

Resources

1. Omega Engineering. (n.d.). *LC103B series—High accuracy, stainless steel, S-beam load cells*. Omega. https://mx.omega.com/pptst_eng/LC103B.html

2. Omega Engineering. (n.d.). *PX309 series—General purpose, stainless steel pressure transducers* (Data sheet). Omega. https://assets.omega.com/pdf/test-and-measurement-equipment/pressure/pressure-transducers/PX309.pdf

3. National Instruments. (n.d.). *NI cDAQ-9174 chassis specifications*. NI. https://www.ni.com/docs/en-US/bundle/cdaq-9174-specs/page/specs.html

4. National Instruments. (n.d.). *NI 9201 analog input module specifications*. NI. https://www.ni.com/docs/en-US/bundle/ni-9201-specs/page/specs.html

5. National Instruments. (n.d.). *NI 9482 electromechanical relay module specifications*. NI. https://www.ni.com/docs/en-US/bundle/ni-9482-sbrio-9482-specs/resource/ni-9482-sbrio-9482-specs.pdf

6. Sensata Technologies. (n.d.). *DR series output modules datasheet*. Sensata. https://www.sensata.com/sites/default/files/a/sensata-dr-series-output-modules-datasheet.pdf

7. Texas Instruments. (n.d.). *INA110 precision instrumentation amplifier datasheet*. TI. https://www.ti.com/lit/ds/symlink/ina110.pdf

8. T-Win. (n.d.). *PS-1S400EP 400W power supply specifications*. Computer World Pro. https://www.computer-world.pro/t-win-ps-1s400ep-400w-p-97811.html

9. GeeekPi. (n.d.). *ATX breakout adapter terminal block power board*. Amazon. https://www.amazon.com/GeeekPi-Breakout-Adapter-Terminal-Computer/dp/B08MC389FQ

Test Plan & Checklist (Day of Burn)

Pre-Test:

- Confirm all cables and power supply are secured
- Confirm analog inputs and common are secure and connected
- Tighten all fasteners
- Ensure load cell is fastened and secure
- Plug in DAQ and Power supply
- Connect usb from DAQ to computer
- Ensure both channels are at desired sample rate and sample number
- Open Main.vi and confirm code runs correctly and saves data to excel
- CONFIRM THAT RELAY MODULE IS OFF AFTER TEST
- Check each data file for expected values at zero psi and lbs
- CLOSE ALL EXCEL FILES

Test:

- Ensure fail-safe pin is inserted
- Strap down and secure test stand
- Grease pressure transducer and fasten to threaded rod
- Load motors in combustion chamber and mount to threaded rod
- Apply the combustion chamber brackets
- Connect ignitor fuse to ignition terminals
- Insert igniter into loaded combustion chamber securely
- Confirm test site is clear
- Run Main.vi

Post-Test:

- Confirm data collection
- Clean Up test site and combustion chamber the day after
- Filter and graph data