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SOLID ROCKET MOTOR TEST STAND V.1

PROJECT REPORT

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SPARK TECH

SOLID ROCKET MOTOR TEST STAND

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***Abstract*— In this project report, the design, assembly, and testing of a solid rocket motor test stand are described. The creation of a dependable and secure facility for solid rocket motor performance testing was the goal of this project. The report gives an overview of the materials, equipment, and data acquisition systems used in the test stand and lists the outcomes of various static firing tests that were carried out on it.**

***Keywords*—**

1. Rocket motor testing
2. Static firing tests
3. Test stand design
4. Data acquisition systems
5. Performance evaluation

I. INTRODUCTION

For testing and evaluating the performance of solid rocket motors in model rockets, a solid motor model rocket test stand is a specialised facility. The goal of this project is to create a test stand that is effective, simple to use, and provides reliable data for performance evaluation. To measure thrust, burning rate, and pressure during static firing tests, the test stand ensures the rocket motor's safe and dependable operation. The solid rocket motor is an important part of the propulsion system of model rockets, which are a well-liked hobby and educational tool.

II. METHODOLOGY

Test stand body: The solid model rocket test stand was designed and constructed using aluminium as the primary material for ease of transportation and fabrication. The base of the test stand, which holds the rocket motor, was made using aluminium composite panel (ACP) due to its lightweight and high strength properties. A PVC pipe mount was attached to the ACP base to hold the model rocket motor. The PVC mount was attached to the ACP base using epoxy for a strong hold and to avoid vibration. The body of the test stand was constructed by attaching the aluminium panels using aluminium rivets to ensure durability and stability.

Electronics: The electronics system of the solid model rocket test stand consisted of two custom-built circuits - one for the countdown and ignition system, and another for data logging. The entire system was powered by a lithium-ion battery connected to an LM2596S DC-DC Buck Converter Power Supply step-down module for stable and efficient power supply. LED strips were also attached to the test stand for better visibility.

The details of the first electronic circuit board (Board 1) are as follows: The microcontroller used was an Arduino Nano, which was connected to a seven-segment display for displaying the countdown. For the ignition system, an IRF540N n-channel MOSFET was used as a switch to close the circuit, allowing high current to pass through a nickel-chromium wire, which became red hot and ignited the fuel. The power supply for the nickel-chromium wire was provided by an SMPS power supply of 16V and 30A.

The details of the second electronic circuit board are as follows (Board 2): The microcontroller used was an Arduino Nano, but the same board can be used for esp32 wroom board, which was connected to a 20kg load cell via an HX711 dual-channel 24-bit precision A/D weight pressure sensor module. An SD card module was also connected to the microcontroller using SPI protocol communication for data logging from the HX711 module. (*Board 2 was designed specifically for Test 2, but prior to that, the circuit was prototyped on a solderless breadboard for Test 1.)

Software: The test stand consists of three programs that are used for calibrating load cell and collecting data from it. The three programs are as follows:

Board 1 Program:

The Board 1 program starts a countdown from 99 seconds on a seven-segment display using the "SevSeg.h" library. Once the countdown is over, the digital pin 13 is made high for 3 seconds for heating of nickel-chromium wire.

```
int i=99;
unsigned long previoustime=0;
unsigned long currenttime;
```

Enter the countdown seconds (10-99)

```
if(i == -2)
{
    digitalWrite(13,HIGH);
    delay(3000);
    digitalWrite(13,LOW);
}
```

Enter time interval for short circuit of Nichrome wire (10-99)

Board 2 Program:

The Board 2 program uses multiple libraries including "SD.h", "HX711_ADC.h", "SPI.h", and "Wire.h". The SD card CS pin is connected to Arduino D10 pin, and for HX711, DOUT is connected to D5, and SCK pin is connected to D6. The program has a baud rate of 9600, and the calibration value should be written in the "calibrationValue" section as mentioned in the program. The program starts up the load cell and starts to read the load cell value in grams. Finally, it writes the data to the SD card while simultaneously reading the data.

```
#define SD_CS (10)

const int HX711_dout = 5;
const int HX711_sck = 6;
```

Enter the SD card Chip Select pin address

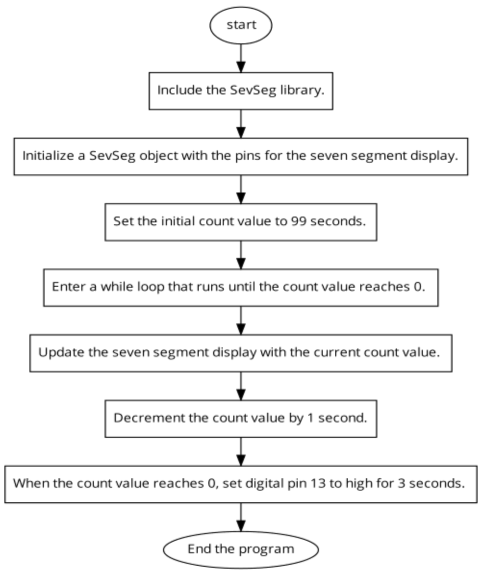
```
float calibrationValue;
calibrationValue = 96.32;
```

Enter calibration value obtained fron calibration program

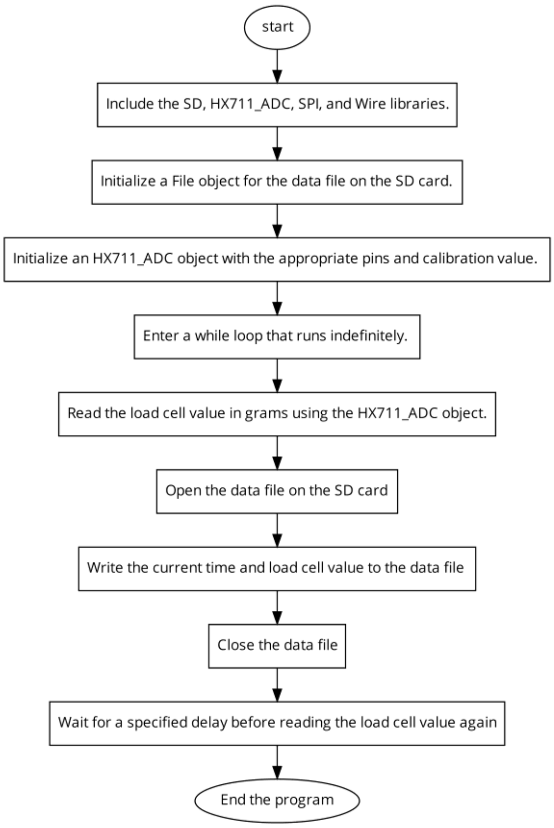
Calibration Program:

The Calibration Program is a sample program provided with the HX711 library. It is used to calculate the calibration value of the load cell by reading the average of multiple readings and adjusting it based on a known weight. The calibration value can then be used in other programs to get accurate load cell readings.

Board 1 Flowchart:



Board 2 Flowchart:



1. TEST STAND IMAGES:

Fig 1.1
This image shows the body of the solid rocket test stand, with a PVC pipe attached to hold the ACP.

Fig 1.2
The image displays the back side view of the test stand, with a chamber located at the bottom chamber is intended for electronic bay.

2. CIRCUIT BOARD IMAGES:

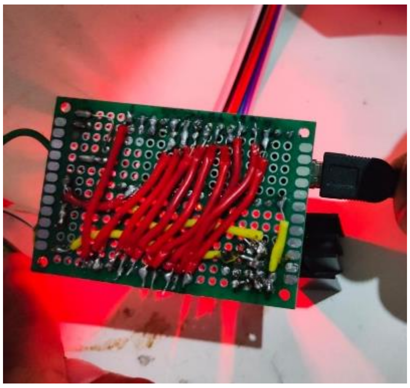


Fig 2.1
This refers to the connections made on the back of perfboard for Board 1 as shown in the above image.

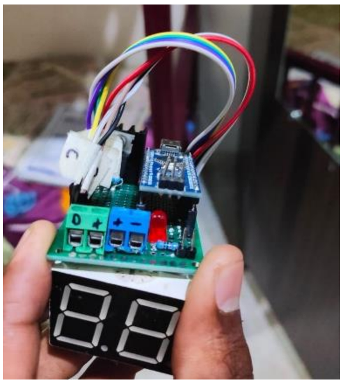


Fig 2.2
The above image shows the connection of Board 1, where the custom circuit board is connected to a seven-segment display.

Fig 2.3
This image is related to the connection of board 2, where the SD card module is attached to it.

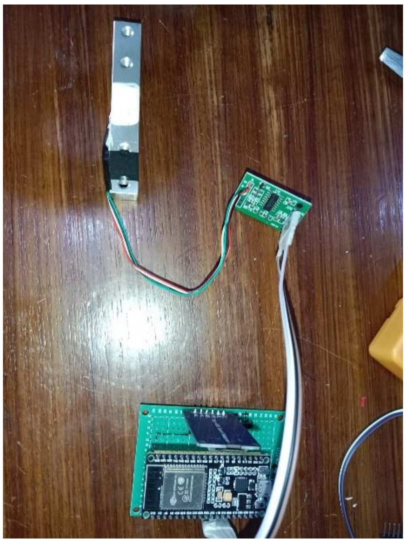


Fig 2.4
This image displays the connection between board 2, the load cell, and the HX711 module.

III. RESULTS

Test 1 *(March 8th, 2023)* was unsuccessful due to the failure of the custom-built motor. The motor, which was made using a PVC pipe, caught fire during the test, resulting in the loss of all recorded data. The fuel used in this test was rocket candy, which is a mixture of 65% potassium nitrate and 35% sugar.

Fig 3.1.1
The image displays the setup and arrangement of the test stand (test 1).

Fig 3.1.2
The image displays the entire setup of the test stand with the rocket motor securely placed within the PVC outer housing pipe.

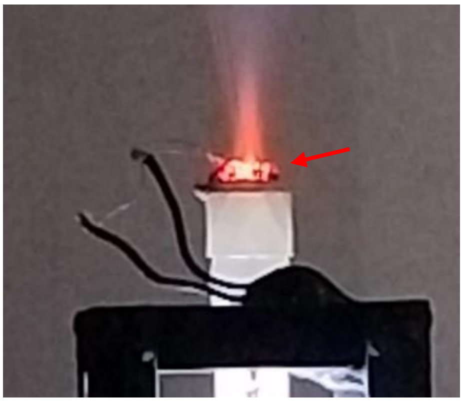


Fig 3.1.3
This image depicts the melting of the motor body and the resulting melted plastic protruding out of the nozzle.

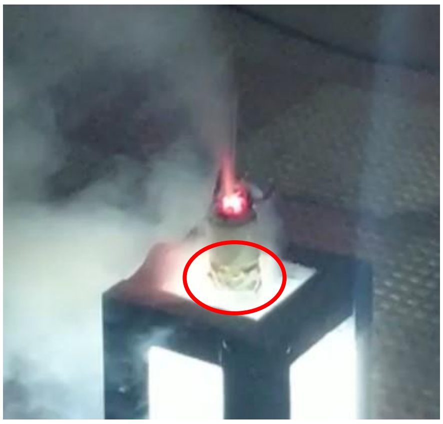


Fig 3.1.4
This image depicts the melted plastic around the neck of the nozzle due to overheating.

Fig 3.1.5
This image depicts the fire caused by the melting of the nozzle neck.

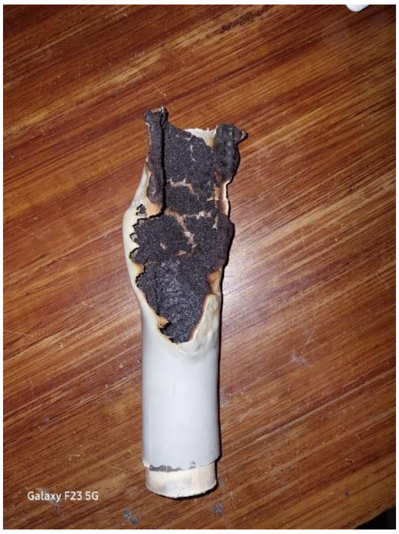


Fig 3.1.6
This image depicts the melted PVC body of the motor that has adhered to the outer PVC housing, along with some burnt rocket fuel.

Test 2 *(April 7th, 2023)* was partially successful. We replaced the PVC pipe with an iron curtain pipe (A tube with a length of 12 inches and a diameter of 1 inch) as the motor body to withstand the heat. However, during the test, we made a mistake in the nozzle throat diameter simulation, which resulted in an explosion of the rocket motor.

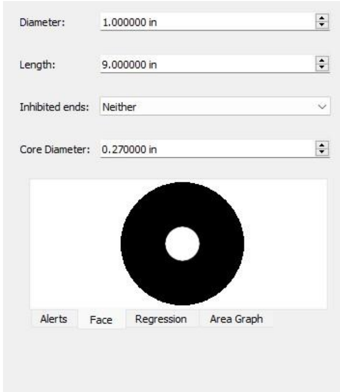


Fig 3.2.1
This image shows the grain structure of the solid propellant inside the motor body.

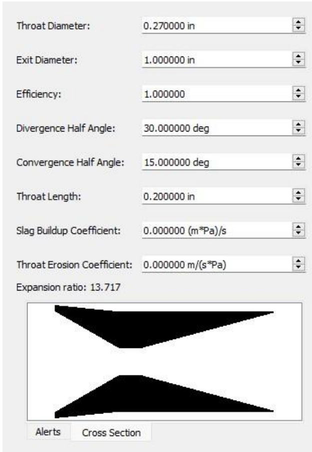


Fig 3.2.2
This image shows the construction details of the nozzle.

Fig 3.2.3
This image displays the new motor body made of iron curtain with the nozzle attached at the top.

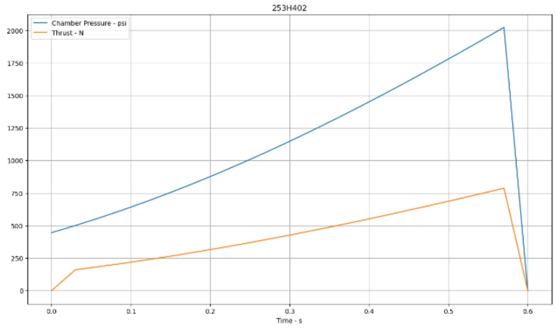


Fig 3.2.4
This image shows the motor simulation using OpenMotor software.

Fig 3.2.5
This image shows the fuel burning prior to the explosion.

Fig 3.2.6
This image shows the pattern of explosion, which occurred due to high chamber pressure, reaching nearly 400-2000 psi, as per the simulation data.

Fig 3.2.7
This image depicts the damage caused by the explosion to the load cell, ACP, and electronic bay.

Fig 3.2.8
This image shows the damage that occurred to the aluminium body, which has a cover damage and is bent.

Fig 3.2.9
This image shows the condition of the iron motor body after the explosion.

IV. DATA ANALYSIS

The data from ***Test 2*** of the rocket motor can be analysed as follows:

- The total burn time of the motor was 1.02 seconds, after which an explosion occurred, resulting in a total test time of 1.8 seconds.
- The maximum thrust recorded during the test was 19196.41 grams, which is approximately 188.28 newtons.
- The mass of the solid rocket motor, including the propellant and the iron motor body, was 239.6 grams.
- The mass of the propellant used in the test was 170 grams.

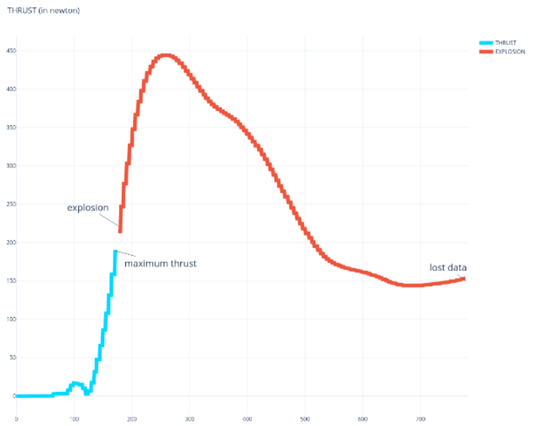


Fig 4.1

The image displayed above shows the thrust graph of test 2 in Newton. However, the data was not successfully recorded to the SD card due to the vibrations caused by the explosion. The blue line on the graph represents the recorded thrust, while the red line represents the thrust during the explosion. (It should be noted that the thrust value during the explosion may have been inaccurately recorded as the load cell was designed to measure up to 20 kg but recorded a thrust of 45 kg.)

V. DISCUSSION

The solid rocket motor test stand is designed to perform each step autonomously, including ignition triggered after the countdown and data recording to the SD card. This means that once the switch is turned on, the operator has 99 seconds to safely retreat to a bunker while the test is conducted. After the test, the data can be collected from the SD card and analysed accordingly. The only issue encountered was with the custom-built motor, and there were no problems with the electronics or stand.

In the discussion, we can suggest several upgrades to the solid rocket motor test stand that can enhance its capabilities. For instance, integrating an RTC (real-time clock) can provide more precise data with respect to time, while increasing the load cell capacity to 50-200kg can allow testing of larger rocket motors. The addition of wireless communication systems like ESP Now can further improve safety measures, enabling real-time plotting of graphs and faster data acquisition, while reducing manual work associated with SD card methods. These upgrades can lead to faster and more reliable testing, enhancing the accuracy and efficiency of the test stand.

VI. CONCLUSION

In conclusion, the solid rocket motor test stand proved to be a reliable and efficient tool for testing solid rocket motors. The stand was able to autonomously perform every step of the testing process, from ignition triggering to data recording. While there were issues with the custom-built motor, the electronics and stand themselves functioned without any problems.

Overall, the solid rocket motor test stand was a success in its ability to provide valuable data for motor performance analysis. By continuing to improve and upgrade the stand, it will become an even more effective tool for testing solid rocket motors in the future.

VII. REFERENCES

1. The graph was plotted using Plotly. Link*: https://plotly.com/
2. The simulation graph was plotted using OpenMotor software. Link*: https://github.com/reilleya/openMotor
3. HX711_ADC library documentation*: https://github.com/bogde/HX711
4. IRF540N datasheet*: https://robu.in/product/irf540n
5. load cell datasheet*: https://robu.in/product/weighing

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