Desktop "High Striker"

Team 18: Los Alamos National Laboratory

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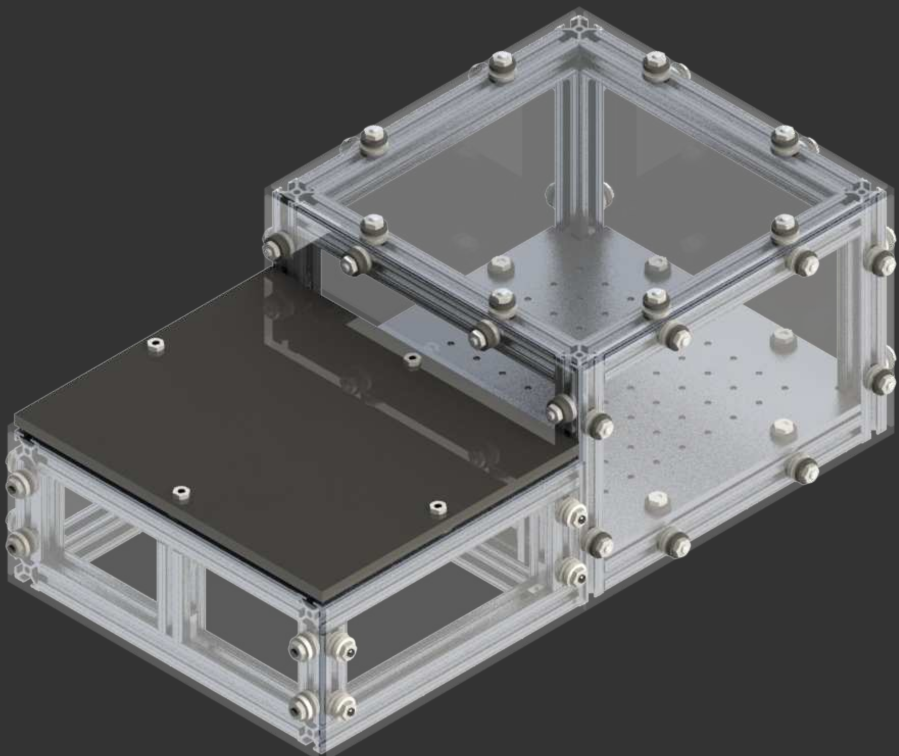
Director: Dr. Gerard Carroll



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Project Overview

As the Desktop High Striker project name eludes, the system must mimic a High Striker carnival game and requires a visual output to be displayed after an impact to signal how hard the user is able to strike the system. The Desktop High Striker measures a high speed and force impact utilizing a piezoelectric transducer (PVDF), a laser diode officially known as a Vertical Cavity Surface Emitting Laser (VCSEL), and an optical measurement system (OMS). The input to the fixture mimics any impact similar to a blast shock and is measured by the piezoelectric transducer and conveyed through the VCSEL and OMS with an oscilloscope. The data is then read through a script in MATLAB and plotted. Through testing with a vertical drop tower, a calibration curve and information on the PVDF's general behavior and degradation rate can be determined and utilized to characterize the PVDF sensor.

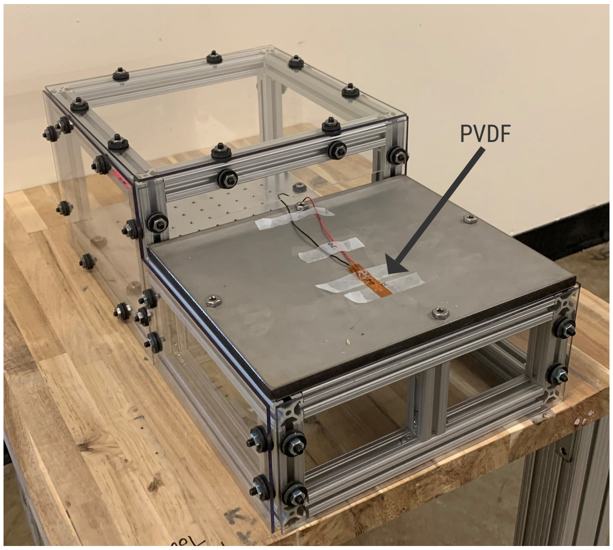


Fig. 1: Full Assembly of High Striker test fixture with PVDF attached to the top of the Strike Plate.

Through discussion with Los Alamos National Laboratory (LANL), project requirements were developed pertaining to the High Striker system's physical footprint, performance, and general function. They state that the High Striker test fixture must measure no larger than 2ft. x 2ft. x 2ft. and weigh no more than 50 pounds. The most important requirement in place aims to identify a relationship between the momentum input (through physical impact) and the initial peak voltage output of the optical measurement system. Additionally, the PVDF sensor degradation occurring over repeated impacts needs to be detailed, and the minimum required input to excite the VCSEL must be identified. In order to generate consistent and comparable data, a method of creating a known force is also critical.

Critical Project Components

PVDF Gauge: Generates a voltage in response to its piezoelectric material experience physical deformation in its cross-sectional area.

Fig. 2

Fig. 3

VCSEL: A laser diode, which can receive a signal input and produce a corresponding optical output.

OMS: A device that is used to measure the optical output at the tail end of the VCSEL, and display it as a voltage to be read through an oscilloscope.

Fig. 4

Design Iterations

Through brainstorming and research, the team produced numerous Desktop High Striker design options that would measure an impact. Even after the design was ultimately selected, changes to this design were made as testing was done and improvements were realized. The brainstorming, research, and testing that went into each design iteration taught the team something, and brought the team closer to achieving the projects goals. This section covers the teams two main designs - the mechanical vibration design being the one that the team ultimately pursued.

Piston-Cylinder

The piston-cylinder design intended to use a circular strike plate attached to a pneumatic cylinder as the mechanism for inputting an impact to the system. In the design, a strike from a hammer would compress the pneumatic cylinder and thus increase the pressure within the cylinder. The PVDF gauge would be situated inside the pneumatic chamber and the increased pressure/stress would excite the PVDF gauge. This design was not selected because of the complications with fabrication and amount of maintenance required to maintain pressure throughout the cylindrical chamber. Running the wiring through the chamber would create additional complications. Another reason for not selecting this design was the difficulty of accessing the chamber for switching sensors. The team decided against the piston-cylinder design because the uniform pressure made by the chamber did not excite the PVDF properly in preliminary testing. This was due to slow changes to the stress of the system. This design taught the team that PVDFs need to be excited by sharp, fast impulses.

Fig. 5: Initial CAD model of piston-cylinder design.

Mechanical Vibration

The mechanical vibration design utilizes the vibrations created in the steel strike plate from an impact to excite the PVDF. The PVDF is mounted to the underside of the strike plate to avoid direct impact and to reduce the amount of degradation the gauge will experience through multiple strikes. The mechanical vibration design, after some basic analysis, proved to be the most robust design with minimal maintenance needed. This design was more robust as there was less of a chance of failure with a plate attached directly to the frame, than at the piston rod of the Piston-Cylinder design. This design also protects the PVDF and extends the amount of times each PVDF can be used which is crucial to gathering more testing data to better characterize the sensor. With the PVDF attached on the bottom of the strike plate, the electronic wiring can be hidden and can directly run through the backside of the main housing into the rear housing. Additionally, the design allows the most ease when switching between PVDFs. With only the removal of the strike plate needed, replacing the PVDFs takes minimal time. Due to these reasons, the mechanical vibration design was selected to proceed into prototyping.

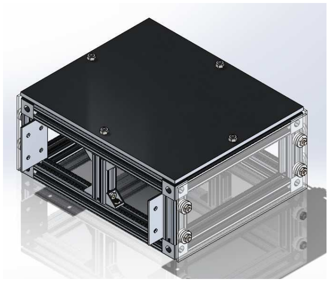


Fig. 6: Initial CAD model of the main housing with the strike plate attached (dark square on top of frame).

Project Design

The design for the test fixture was modeled off of the design for a carnival "High Striker" game and was intended to be a scaled down version to fit on a desktop.

While working within the constraints of the design requirements set forth by the client, the team decided on the Mechanical Vibration design to fabricate and use for the testing phase. After some initial testing, the team found that the PVDF sensors were more robust than initially assumed. The team found that the sensors required a greater deformation than a vibration from the strike plate, and could withstand these type of impacts more frequently than initially expected.

The design was altered slightly to achieve an identifiable output from the PVDF. Instead of placing the PVDFs below the strike plate to record vibration, the sensors would be impacted directly on top of the plate. This direct impact allowed the team to obtain a signal that contains a sharp peak voltage when the system is impacted.

Another portion of the overall project design was the drop tower attachment. The team used this drop tower attachment that was built by the previous year's High Striker team. The attachment allows the drop tower to interface with the system. Additionally, it centralizes the physical impact to the PVDF.

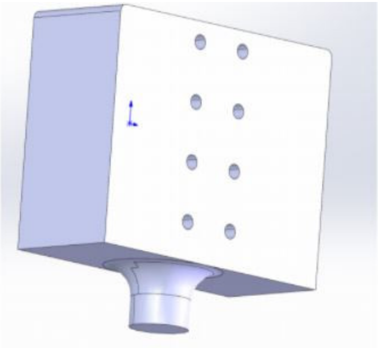


Fig. 7: Drop Tower Attachment

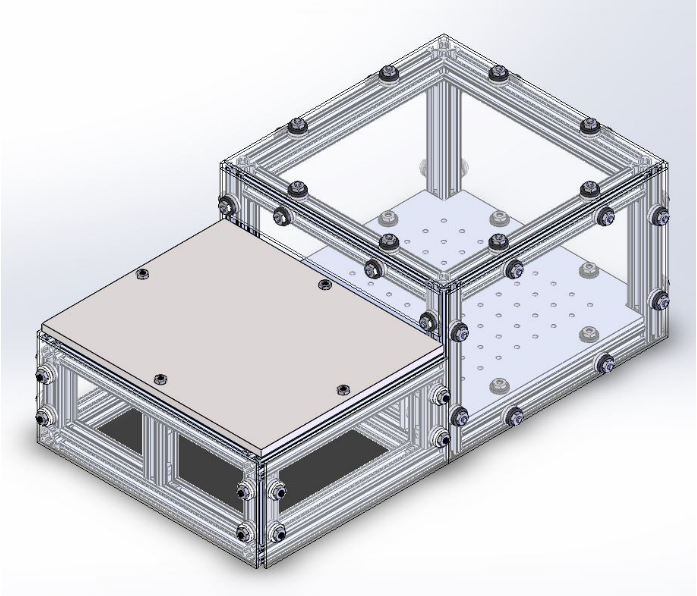


Fig. 8: Final High Striker Design CAD model

The design seen in figure 8 is a modular structure, made with 1in. 80/20 extruded beams covered with protective polycarbonate sheeting. These sheets help protect the electronics that are housed within the design from outside impacts or debris that could harm the system. The transparent feature of the polycarbonate sheets would also allow the average user to view and enjoy the experience of using the High Striker system.

The housing is meant to minimize any strains or stresses to the structure to ensure that it is robust for testing. The strike plate seen in figure 8 is made from 304 stainless steel and, as mentioned previously, acts as the impact surface. Each fastener is coupled with a rubber gasket which will absorb the impact energy. Additionally, the short height of the beams was designed to decrease the strain on the extrusions.

The housing also has an aluminum "pegboard" (multi-holed plate in the larger rear structure). This pegboard allows for multiple electronic components to be securely attached to the structure in a variety of configurations.

System Integration & Functionality

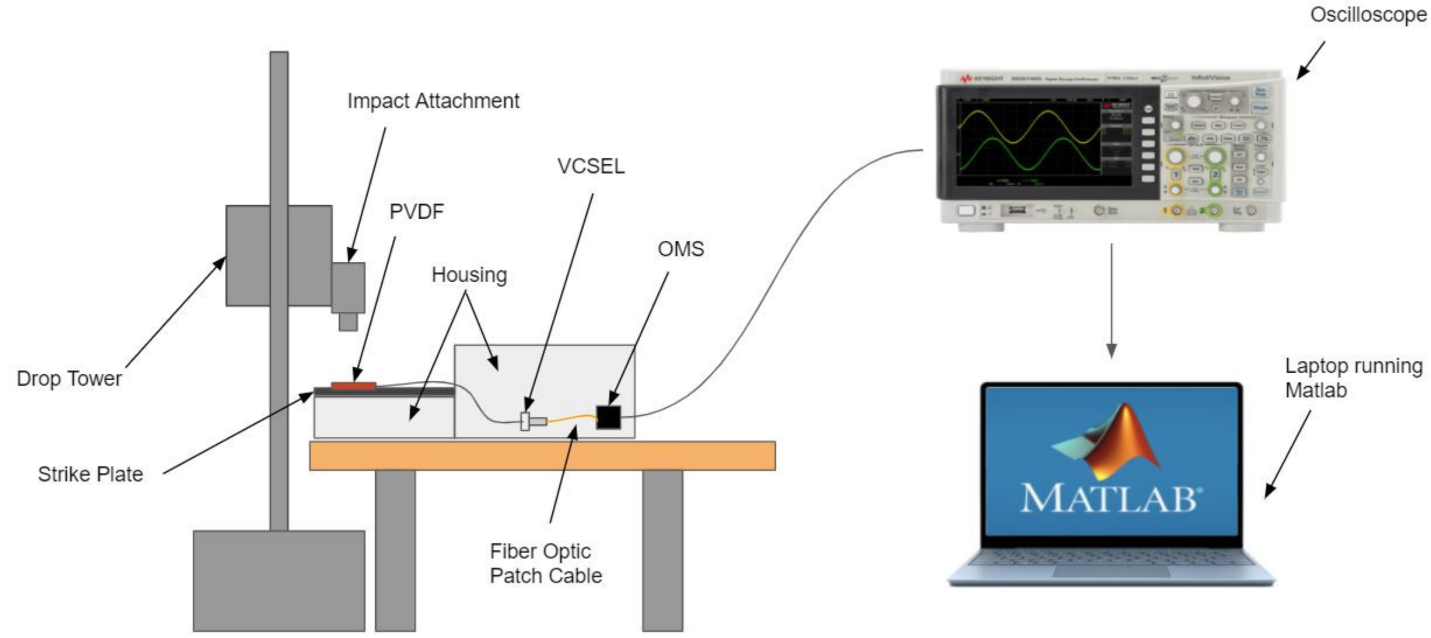


Fig. 9: Display of the housing/component assembly and the setup utilized for testing.

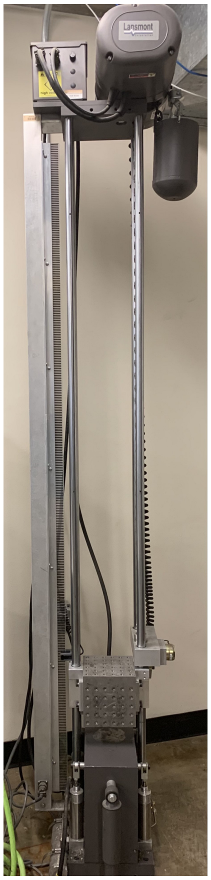


Fig. 10: Drop Tower

The display seen in figure 9 labels the entire assembled system used for testing of the Desktop High Striker, including the CU Boulder Idea Forge's pre-existing Lansmont drop tower test equipment seen in figure 10. The electronics system composed of the PVDF, VCSEL, and optical measurement system which were connected directly between each component without the use of any other intermediary circuitry. This configuration is consistent with the application used by LANL. The use of the Lansmont drop tower test equipment in the system served as the method for delivering a known, quantifiable impact to the High Striker system.

The display above also provides a visual of the sequence of operations which starts with the initial impact and ends with the data analysis. After the initial impact is delivered to the strike plate using the drop tower, the resulting strain experienced by the PVDF causes it to produce a voltage signal that is sent to the VCSEL. The VCSEL uses that input to produce an optical output that can be recorded by the optical measurement system. The optical measurement system then delivers an output in the form of a voltage, and is read through an oscilloscope.

Software was developed to automatically generate the visual characterization for each impact immediately after the drop, but it was not integrated with the oscilloscope that was used in the final design. As a result, the data was manually saved and brought into MATLAB to be analyzed.

Testing Summary

The testing operations in context to the High Striker test fixture were designed to verify the project requirements were met regarding performance and behavior. The first section of testing performed used the Lansmont drop tower pictured in figure 11 to deliver impacts across a range of different heights. The intention of doing so was to create a characterization between the momentum of each drop and the resulting initial peak voltage output of the system. To achieve consistency and account for influencing factors, a new PVDF was installed on the strike plate for each session of the characterization testing.

To determine the PVDF degradation behavior over repeated impacts, the drop tower was also utilized. In this test, a momentum magnitude in the middle of the developed drop range, 12 inches, was delivered to the system 20 times on a new PVDF. This was performed four times to identify output trends as the sensors experienced a large number of impacts.

In the impact testing conducted with the High Striker fixture, the VCSEL was not successfully integrated with the PVDF. Possible causes for this are detailed further in the data analysis section. As a result, the VCSEL was tested independently using a function generator. Four different voltage magnitudes were input to it, each at three different pulse widths to analyze its activation threshold and varying performance.

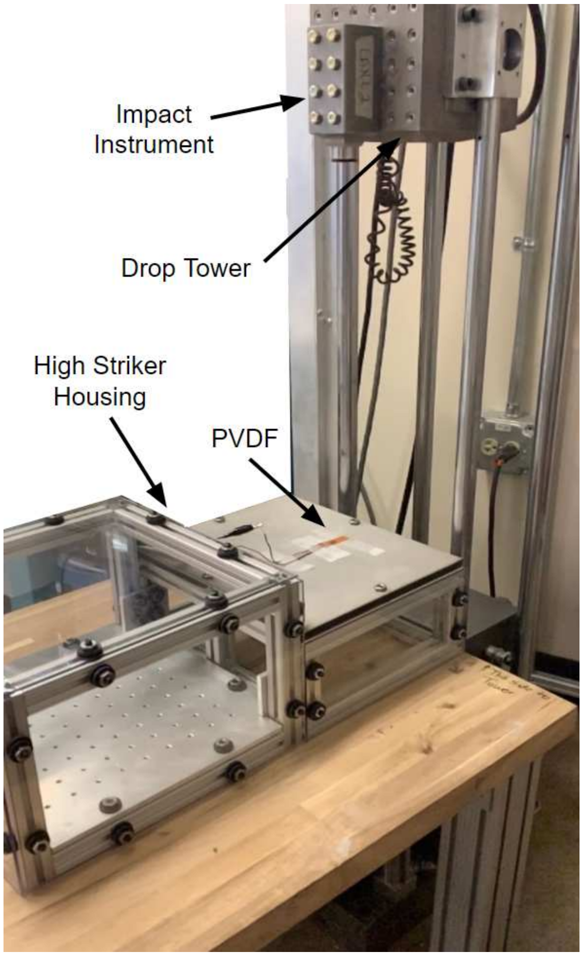


Fig. 11: The testing configuration with the drop tower, impact instrument, and High Striker test fixture.

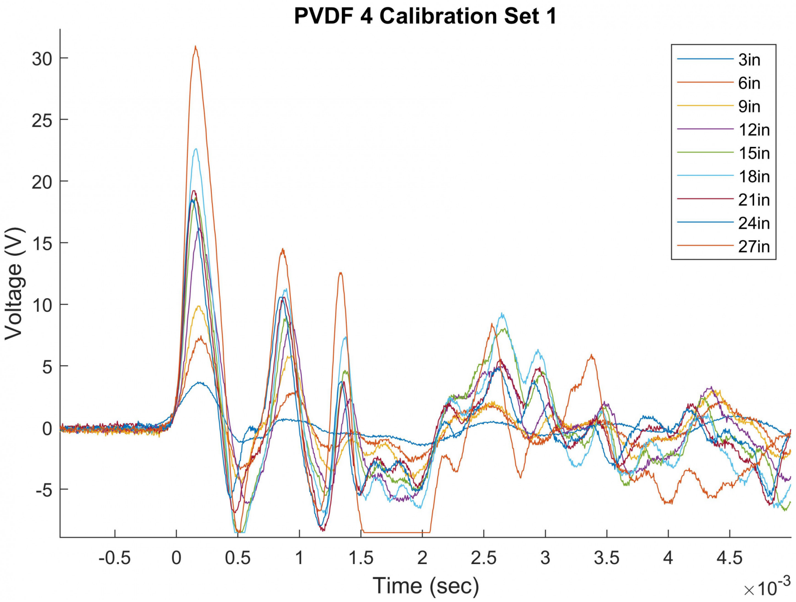


Fig. 12: Raw output of the PVDF gauge recorded by the oscilloscope. Each curve is produced from a single drop at one of the varying heights tested.

The PVDF output in response to drops from varying heights between 3 and 27 inches revealed valuable insight to both the team and the client. Seen to the left in figure 12 is the PVDF output at the 10 different drop heights, or momentum inputs, for a single characterization test session.

The PVDF gauges produced noticeably different initial peak voltages across differing heights, but they also displayed a very similar output profile across the entire recorded time scale. The following sections in this document detail a more comprehensive testing analysis.

Data Analysis

VCSEL & OMS

Throughout testing of the desktop High Striker, the team attempted to integrate the VCSEL and OMS system with the PVDF gauges. During this integration troubleshooting process, data was collected and analyzed from the VCSEL-OMS in an attempt understand the devices and their integration. While integration was never successful, data that was collected allowed the team to draw conclusions about the VCSEL-OMS system and provide these conclusions and data to LANL.

The most important data that was collected was data acquired by testing the VCSEL-OMS with a function generator. We used the function generator to output pulses similar in both voltage magnitude and pulse width to the outputs from the PVDF gauges.

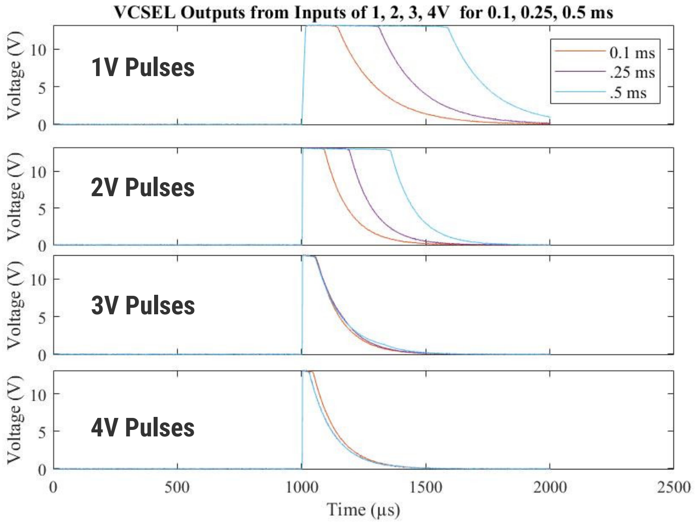


Fig. 13: VCSEL-OMS outputs from function generator inputs of 1, 2, 3, & 4V with pulse widths of 0.1, 0.25, & 0.5 ms.

It was found that VCSELs often break from function generator inputs greater than 5V. Furthermore, while the VCSEL was excited as expected with the function generator, when connected to the PVDF and receiving similar inputs the VCSEL was never excited even during extensive trouble shooting. This led the team and client to believe that the selected VCSEL may not be the best device for the team's desktop application because of differences in the scale of impact magnitude from a blast as opposed to a hammer strike.

Degradation

A crucial part of understanding the PVDF gauges was to determine the number of strikes that cause degradation. This was completed by creating drop tower impacts from a singular height (12in.) and measuring the peak voltage. The peak voltage indicated the largest input to the system. If the voltages are irregular in behavior in comparison to each other, then degradation can be determined to start at that point. The outputs and average peak voltages of the two PVDF gauges used are shown in figure 14. The blue, red and purple data is for one PVDF and the green is another PVDF. The red data is higher than average and the purple is highly inconsistent. The green data is inconsistent, but still has a similar starting average as the first PVDF.

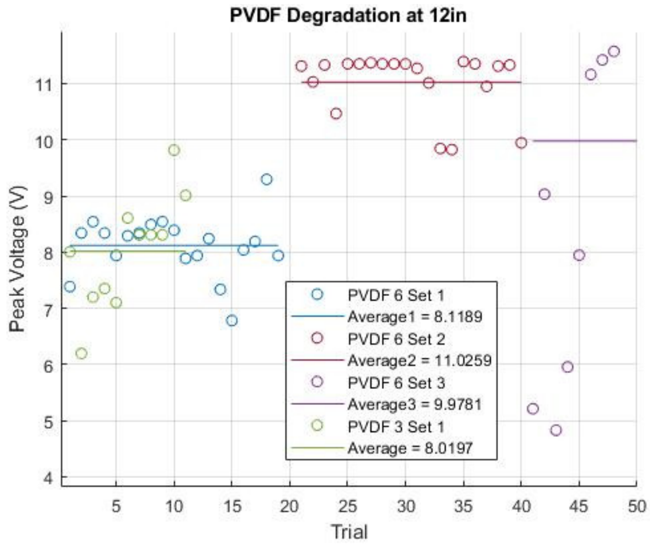


Fig. 14: Compiled data of drops for the PVDFs. The averages per each testing set is also given. The trial number is based on the number of degradation hits that the sensor had seen.

From this data, it can be concluded that the PVDF gauges are consistent and accurate for under twenty medium hits. After this point there is either a change in the average voltage (red data) or irregular data (purple data) that can be viewed as degradation.

Data Analysis

Calibration

A calibration curve of the PVDF gauges was created to use as a reference for smaller impacts. This was completed by measuring drops from the drop tower at predetermined heights and using the peak voltages to create a relationship between the inputs and outputs. Each set signifies a full PVDF iteration of testing from 3in to 27in. In figure 16, the peak voltages for each PVDF set is plotted against the height they were dropped at. There are some instances where a PVDF gauge is used multiple times. A positive linear curve (black) was then fit to the data to show the combined relation of all of the data.

The data shows a clear indication that the linear fit is the correct curve type for the data as there is no major curvatures in the data. Different models such as an exponential, square root, and logarithmic equations were also tested, but there was no indication that these models worked better than the linear fit. Despite the trend seen in the data, the goodness of fit (figure 15) signifies that the model is not an accurate representation of the data as a good model will have an SSE of zero, indicating that the randomness of the data is fully represented by the model, and an adjusted R-square value of 1, indicating that variance is accounted for. The data is highly varied between each of the individual PVDFs as well as the outputs per each height. There are few cases in which a similar voltage is reached between the data sets for the specific height. This indicates that the PVDF gauges are not consistent relative to each other at impacts within this height range. It is also possible that the housing system moved after each larger impact which would impact the consistency of the set up; however, there would be clear indications that the housing shifted in the data such as clear signs of degradation or outliers.

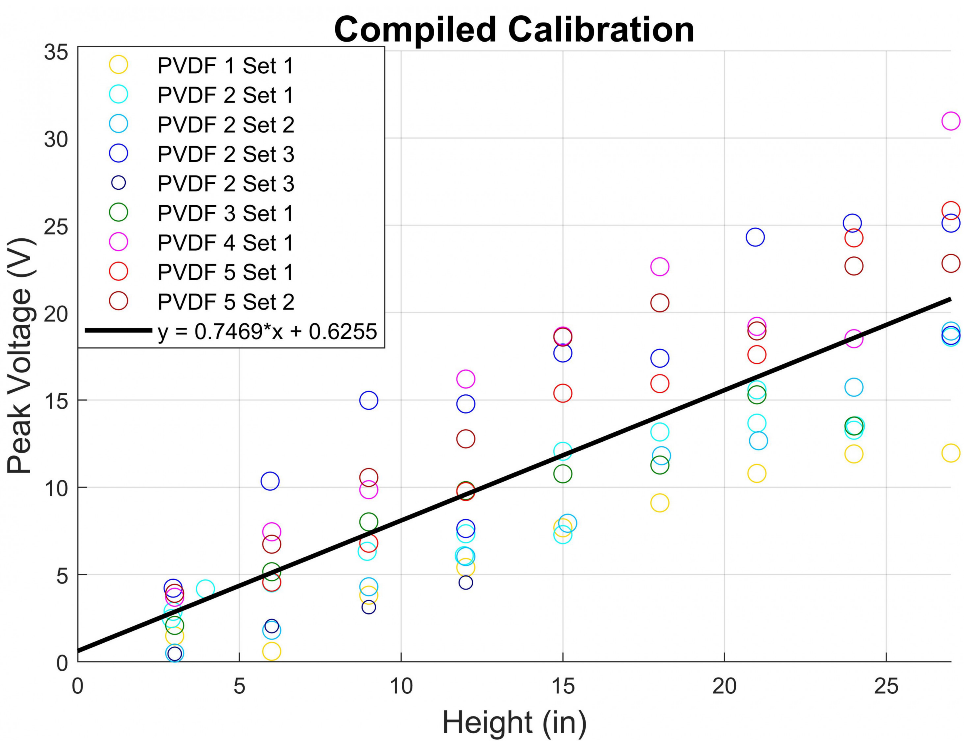


Fig. 16: Calibration plot of all the PVDFs used in calibration testing. Similar colors indicate the same PVDF. The black line is the linear curve fit of the data to use as a model or reference to check for accuracy and consistency.

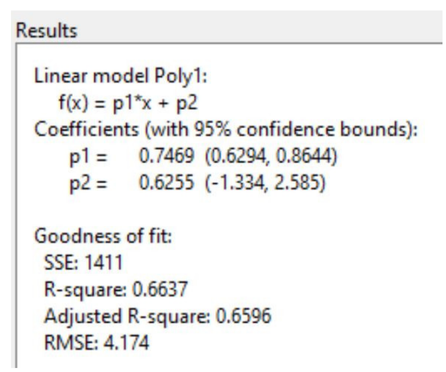


Fig. 15: Curve fit logistics of the compiled calibration data (see left). The goodness of fit parameters give a measure to how accurate the model represents the data.

Final Results and Conclusions

The Desktop High Striker test fixture was a research and development project. Throughout the past year, Team 18 navigated the research, design, fabrication, and testing processes necessary to achieve the team's goals to create a viable test fixture for LANL. The design was determined after an intensive down selection process that included a preliminary testing and fabrication phase. The design is an easy to use and durable test fixture that allows the team to acquire data in order to understand sensor degradation, calibration, and functionality through post-testing analysis.

The team's design met the goals of being within the project's size and weight constraints, being robust enough to withstand 100+ strikes, and characterizing shock impulses using PVDF gauges. There were some challenges and roadblocks that the team faced during the project. The team did not integrate the VCSEL-OMS system with the PVDFs; however, analysis was done in order to explore the integration difficulties. As discussed in the data analysis section, testing indicated that a VCSEL may not be the correct device for this project's application with PVDFs. The inability to integrate the VCSEL-OMS caused other difficulties. These difficulties ultimately meant that the team was unable to automate the data collection system or implement a visual output for the system.

Overall, Team 18 is proud of their achievements and understands that in research and development projects the goals are often changing and that understanding why components do not work is valuable information. Despite the challenges and roadblocks encountered during the project, the final design and data were indispensable outcomes of the project that are highly valuable to Los Alamos National Laboratory.

Looking Forward

In further development of the High Striker, the team identified several modifications and achievements necessary to better the system for continued research and development. The first of which was solving the integration between the VCSEL-OMS and PVDF. The successful integration between these components will allow for performance conclusions that more accurately identify the collective behavior of the exact system which LANL is using in their application. That implementation will also allow for a visual output that reflects the impact magnitude delivered to the system for user experience.

In the design of the project, it may be necessary to modify the mechanical design to eliminate the need for maintenance of the modular frame. Stronger corner connectors would be implemented to keep the frame from vibrating loose. Additionally, a form of fastener or thread adhesive may be used on the internal set screws to hold the frame and connections together.

If these system improvements are able to be implemented moving forward, the benefits from the improved system would build well upon the valuable insight that has already been obtained for LANL over the past year.

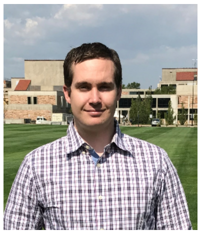
Meet the Team

Bryan Wong - Project Manager

As the project manager, Bryan is responsible for creating a timeline and schedule for the project. Bryan motivated the team throughout the project and made sure deadlines were met with great quality work. He worked closely with every member of the team and supported other roles. Bryan had a major contribution to the design and CAD modeling for the project. Bryan hopes to pursue a career focused in design and manufacturing in the industry.

Sarah Woronoff - Communications & Logistics Manager

As the logistics manager, Sarah is in charge of communications between the client and the team as well as supporting other roles to meet deadlines. She incorporated multiple portions of the project together and ensured that other roles had the resources they required to complete their sections. She will continue her career in engineering as a Systems Integration and Test Engineer at L3Harris.



Jacob Jones - CAD & Manufacturing Engineer

As the CAD engineer, Jacob is in charge of finalizing and approving changes to project designs, and analyzing the structure of the project. As the manufacturing engineer, Jacob is in charge of working closely with the various manufactures that aided in the fabrication of different parts in the design. He was a part of different sections of the project and aided where possible with other team members. He plans to pursue different options in design and manufacturing in the engineering field.

Michael Rizzo - Systems & Test Engineer

As the test and systems engineer, Michael is responsible for the development of the test plan and execution, as well as the overall system integration to be used in the testing application. Michael dealt a great deal with coordinating the use of the drop tower, and helping with its operation in the testing procedures. He wishes to pursue product design and testing, specifically within the outdoor industry.

Nils Johnson - Financial Manager

As the financial manager, Nils is in charge of ensuring the team is within their budget as well as purchasing of the projects components. Nils also spent lots of time working on testing and trouble shooting the PVDFs and VCSEL-OMS. Nils hopes to continue his engineering career in the field of renewable energy.

Acknowledgements

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