May 10, 2018

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Dear Dr. Guven,

Please find the attached final design report entitled "The Design and Creation of a Fracture Toughness Testing Apparatus." The report analyzes the design, project process and manufactured device. The scope of work and added features of the device are examined in detail. It is with pride and pleasure that we present this report and the testing apparatus to the Virginia Commonwealth University College of Engineering.

Sincerely,

Abdullah Almarri

Stephanie Fulenwider

Arnaud Debraine

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THE DESIGN AND CREATION OF A FRACTURE TOUGHNESS TESTING APPARATUS

MECHANICAL AND NUCLEAR ENGINEERING

College of Engineering

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May 2018

Contents

List of Figures

List of Tables

Chapter 1

Executive Summary

Analysis of material properties is one of the fundamentals of engineering design from the nano level to mega structures. The purpose of this project was to design and manufacture an Izod testing machine used for research by the school. This particular design allows the end user to analyze detailed data about ceramics and polymers. This machine interprets the total energy required to break the analyzed specimen. At a minimum, the device needed to capture initial and final heights reached by the pendulum arm and to return this data in a downloadable form.

The team designed and fabricated a functional American Society of Testing and Materials (ASTM) compliant, fully automated impact tester. The main body consists of a rigid steel post bolted to a fixed base. Movement of a support arm is actuated by a precision stepper motor that releases the pendulum arm at the appropriate height, with an electromagnet. Through custom developed software, the entire system is fully controlled by a touchscreen attached to the base of the machine or a connected laptop. An encoder measures the position of the pendulum through the swing while an accelerometer measures the change in acceleration through the specimen fracture. The system is controlled by an Arduino board which sends the data to a Raspberry Pi or a laptop to transform, visualize and save the data.

The modular design adheres to the ASTM D256 – $10^{\varepsilon 1}$ standard governing Izod Impact Resistance Testing of Plastics. The hammer and the vice fixture were designed to be interchangeable so that the apparatus can be utilized as a Charpy impact testing machine if desired. The potential energy can be adjusted by changing the plates attached to the sides of the pendulum body, increasing or decreasing the total weight of the pendulum. Open source coding languages were used for programming the machine to ensure ease of further adjustment in the future.

Chapter 2

Background

While the examination of materials through their properties is a relatively old process, fracture testing has only been around since the beginning of the 20th century. The original impact test was created by S. B. Russell and Georges Charpy around 1900. Charpy continued the evolution of the test and was given credit for its standardization.

Soon after 1900, an impact test was developed in England by Edwin Gilbert Izod to analyze why a steel shot barrel burst. Placed in a cantilever position, he released a hammer to strike the specimen. Subsequent inventors have improved the design and purpose of the test, but named it Izod for the specimen and notch placement. With the development of metallurgy and microanalysis, existing tests have been modified to deliver more specific information. With computer controlled sensors and analysis, scientists and engineers can analyze subtle differences between samples of slightly modified materials. Starting with the formation of ASTM in 1898, standards assist engineers in analysis by eliminating geometric-induced variations. As computers have shrunk in size, precision sensors can collect exponentially more data, thus increasing accuracy. The price and availability of these sensors and most of the computer parts make this fracture toughness machine possible to manufacture for personal use. As the Charpy and Izod testing machines have evolved, some manufacturers have created machines that utilize either the Charpy, the Izod or both. Since the request was for the testing of ceramics and polymers following ASTM standards, the Izod test is the natural choice.

Figure 2.1: Izod's Impact Tester

Chapter 3

Design Objectives

The original scope of work proposed for this project was to produce an impact test apparatus complete with a sensor to measure the initial height of the pendulum and the final height after fracturing the test specimen with a software to capture and store this data for future analysis. Impact testers are used in the material sciences field to study a materials ability to absorb energy prior to yielding. This information is necessary for engineers when selecting materials for their designs. The project team decided to instrument the apparatus further by adding a DC motor to automate the pendulum arm motion, electromagnet to allow a free release of the pendulum and an accelerometer to measure the force acting on the specimen at impact in g's. The added sensors will provide better repeatability between tests and give more information for additional material property characterization.

The electromagnet will enhance the release of the pendulum, decoupling it from the DC motor drive system. This will eliminate any added energy losses associated with friction in the motor, gear train, support arm bearings or friction caused by a standard mechanical release mechanism. The accelerometer will provide the g force applied to the test specimens surface at the moment of impact. This data point will allow the machines program to calculate the Fracture Toughness of the material based on the users input for pendulum mass along with the specimens width and depth.

Chapter 4

Design Criteria and Constraints

Table 4.1: Design Criteria and Constraints

Design Criteria	Constraints
Apparatus Size	Benchtop Model
Accurate Test Results	Machining Tolerances
Minimal Energy Loss	Windage and Friction
Automatic Operation	Control Systems
Pendulum Mass	Motor Selection
Modular Design	Interchangeable Components
Enhanced Capabilities	Sensor Selection Within Budget
Cost Structure	Commercially Competitive
Man Power	Availability
Project Time-line	Budget Extension Approval
Material Selection	Standard Sizes
Engineering Disciplines	Mechanical Engineering

Izod testing machines can be purchased in multiple sizes depending on the material selection of interest. This specific apparatus was designed for plastics and brittle materials, requiring a lower energy input in the range of 2J to 21J. This apparatus in part will be for laboratory use at the university, meaning it will have a small footprint to fit on one of the available benchtops. By reducing the size of the machine, material selection became more important to generate the necessary robustness of the machine with smaller components. Additionally, components associated with the impact such as the pendulum body and shaft were considered when assessing the system for vibration. Theoretically the more slender the pendulum shaft is then the longer the resonance time would be, affecting the energy loss value during the test.

For the data generated through testing on this machine to have value, the tests must be repeatable and accurate meeting the specifications outlined in the ASTM standard $D256-10^{\varepsilon 1}$ Test Methods for determining the Izod Pendulum Impact Resistance of Plastics (**Appendix D**). The ASTM has specifications regarding the machine, test specimen clamping fixture along with the specimen size and allowable notch which is used to concentrate the stress and minimize elastic deformation. This document states the machine shall consist of a massive base, mounted vise, rigid frame and bearings with a pendulum style hammer made of hardened steel. The striker of the hammer must be cylindrical with a radius of 0.031 in +/- 0.008 in where the line of contact must be located at the center of the pendulum within +/- 0.1 in. Length of the pendulum arm shall be between 12.8 in to 16.0 in with a vertical free fall of the hammer to be 24 in +/- 0.1 in, producing 2.7 J to 21.7 J of energy which is stated to be sufficient when testing most plastics. Though there may be ranges associated for each criterion listed, the total system together is constrained solely by the energy produced. The overall length, width and depth of the specimen shall be 2.50 in +/- 0.08 in, 0.118 in to 0.500 in and 0.500 in +/- 0.008 in respectively. The V notch on the specimen must be 1.25 in +/- 0.04 in from the upper edge of the specimen. The specimen shall be clamped down in such a manner that the centerline of the notch must be bisected by the top plane of the vise within 0.005 in, making placement difficult when taking the large tolerances allowed on the outer dimensions of the specimen. To meet this specification a jig was produced positioning the specimen in the allowable locational tolerance. When the pendulum arm is released, the hammer should make initial contact with the specimen at 0.87 +/- 0.002 in above the top surface of the vise. This will be critical when designing the vise as the length of the pendulum arm and height of the hammer will be key inputs. The ASTM standard also states that the apparatus shall be designed in a manner to minimize energy losses through windage, friction, vibrations and inertia. This put additional criteria on the design for the forward facing surfaces of the pendulum and the machines bearing selection.

Full automation was established as a required design input during the initial project brief with the customer. The device should have no manual input when lifting the arm to its desired height or in the actuation of the pendulums free release. This criteria will have a direct impact on the design as the required sensors and actuators to create the necessary system will need to be positioned in a manner that they provide the most accurate data but also do not impede on the motion of the pendulum. Additionally, the motor selection will be required to have a holding torque as an option along with the resolution to accurately repeat the release position of the pendulum. A DC motor was selected as AC motors do not have the capability to generate a holding torque. The pendulum mass was also a constraint in the motor selection as it needed to generate enough torque to lift the heaviest weight at 8 lbs. These added actuators required additional programming for automated operation and data collection.

The final concept was designed with modularity in mind. The Charpy test method is another pendulum style impact test. The differences between the Charpy and Izod methods are that the Charpy test specimen is fixtured for a three point bend test and the Izod uses cantilever beam positioning and the impacting head for Charpy is wedge shaped instead of a hammer style with a bull nose for impacting. Both the pendulum body and vise are bolt on components and could be easily swapped out to change between these two test methods. The program language used for this device is Python which is free and open sourced allowing it to be easily modified or updated where most commercially available impact testers will have a proprietary software language.

Fabrication was another big constraint towards the completion of this project. Some parts will require a high degree of precision and are better suited to be produced on CNC and EDM machines. The VCU machine shop was considered, but the hourly rate of $65.00 was higher than what was found at a few other shops in the greater Richmond area. After sending out two separate design packages for quoting purposes, one for the double support pendulum concept and the second for the single support pendulum concept, the quotes came back around $2900.00 on average. The cost for time and material was well over the total available budget forcing the design team to rethink its approach for fabrication.

Time and manpower were two more constraints on this project. All the team members have other responsibilities reducing their available time. It becomes difficult to schedule fully attended meetings for design input and review or to test sensors due to people's full-time jobs, families, classes and personal matters. Coupled with the fact that the machining services due to budgetary reasons and programming needed to be completed by individuals on the team significantly reduced people's availability making the necessary manpower to handle portions of this project difficult to maintain. Experience, specifically in electronics and manufacturing was another constraint on this project. Most of the team members have limited to no experience with tolerances, clearances and fits when it comes to mechanical engineering design nor have had extensive exposure to software coding. These were critical to ensure the testing apparatus met the ASTM specifications as previously detailed in this section. This team is comprised of four members currently in the School of Mechanical Engineering and needed to learn functions of Electrical Engineering and Computer Science in their efforts to make this project successful.

The main constraint on this project was the available budget. Considering all of the design inputs and adding the material and machining services required to fabricate parts, the minimal budget supplied by the university has had a limiting effect on the design process. Electronics can be relatively cheap but for the required accuracy and resolution necessary for our machine to be competitive with commercially available models, more expensive sensors were needed. The added instrumentation with regards to automation not only needed to be purchased but the additional actuators required more mechanical components to incorporate them into the final design.

Chapter 5

Design Specifications and Prototype

5.1 Design Concept

The apparatus has been designed to meet the minimum requirements set by ASTM D256 – $10^{\varepsilon 1}$ Standard Test Method for Determining the Izod Pendulum Impact Resistance of Plastics (see **Appendix D**). Two concepts were designed in CAD, one with two support pillars to promote symmetry in the apparatus and the second using a single support pillar in an effort to reduce costs associated with raw materials and machining services. After receiving quotes for the two designs, the second of which having a single support was selected due to the cheaper fabrication cost. This design will free up funds that can be applied to additional customer requests, including an accelerometer to provide instant graphs that will show real time results of the impact force over time. Other customer requests are to have an automated machine that will be push button operated with multiple settings for different initial energy inputs. The initial energy inputs will be provided by using interchangeable plates that will alter the effective weight of the pendulum. The testing machine must be calibrated with all three plate variations to provide accurate test results for various types of plastic and brittle materials.

5.2 Tolerances

This design required tight tolerances associated with areas such as bearing journals, length of the pendulum arm and the height of the bearings centerline from the base plate. The bearing journals required press fits while the pendulum arm length and bearing location directly affected the striking position of the hammer on the test specimen which is set by the

ASTM as being 0.870 in +/- 0.002 in. The ASTM also outlines ranges for the starting angle and length of the pendulum shaft as being between 60° to 30° above 90° and 12.8 in -16 in respectively, however the starting position of the hammer must be such that it produces a vertical height of fall meeting 24 in +/-0.1 in. There was critical geometric tolerancing applied to the flatness of the base plate, parallelness between the centerline of the bearing pockets and mounting surface of the pillar, and perpendicularity between the mounting surface and sidewall of the pillar maintaining pendulum position with the test specimen. Welding of the support pillar to a mountable base plate was part of the design for the purpose of adding rigidity and resistance to deflection. The initial vise selected for this project was scrapped as most precision tool makers vises have a notched clamping surface to be used as a positioning aid. The surface required, needed to be flat and planar with the opposing clamping surface to generate maximum rigidity while minimizing interference with crack propagation. Having a smooth continuous surface will apply an evenly distributed force along the cross section of the test specimen allowing the notch to properly perform its purpose. Therefore a new vise was designed and fabricated for this project.

5.3 Design Process

5.3.1 Stepper Motor Choice

The team started looking into an electric motor as this will be the main drive input for an automated system. We started by researching AC and DC motors to rotate the pendulum into its release position. After assessing the process that the apparatus would go through for one cycle, a holding torque was required as the pendulum would need to move out of the way and pause allowing the technician to load the test specimen then move into the final release position pausing long enough for the program to capture the position prior to releasing. AC motors do not provide a holding torque which moved our focus over to DC stepper motors. Two main constraints in using the stepper motor was the total number of steps the motor is capable of and the torque the motor could generate. As previously discussed, the ASTM outlines dimensions and tolerances around the pendulums height of free fall making the arc distance traveled between steps critical. After calculating what the allowable tolerance was in degrees, we established that a stepper motor with a maximum step of 0.18° would produce a step meeting the 24 in +/- 0.1 in allowable tolerance at the maximum arm length. The second point of interest in the motor selection was the required torque to lift the hammer into position. We calculated the weight mass of the pendulum needed to be in excess of 8 lbs to generate the maximum required energy to propagate fracture according the ASTM document. The mass coupled with an arm length of 13 in meant we needed to generate 120 in-lbf of torque to rotate the arm into position. The stepper motor we selected has a planetary gear box as part of the drive system creating a 100:1 ratio giving it a step size of 0.018°, however the design still did not meet the minimum torque requirement. Therefore, a 4:1 ratio gear train was added to attain the necessary lifting and holding torque. Another constraint on the stepper motor choice process was the available budget. Therefore, the team researched available stepper motors that would meet the required specifications at the lowest cost. The chosen stepper motor operates in a sufficient manner. However, the motor is operating in a range nearing it's maximum limit to complete the necessary output commands. With a larger budget, a stepper motor with an operating range larger than the required lifting and holding torque could be chosen to insure better efficiency and longer part life.

5.3.2 Encoder Choice

The next sensor on the list was the encoder. We needed to find an encoder that had the resolution to see enough points in one rotation to capture the initial and final pendulum heights accurately enough to generate data that could be used for research. We selected an encoder with 2500 PPR (points per revolution) to take care of this and with it being a quadrature encoder then the total number of points is 10,000. Another driver for the encoder that the team had to design around was the total number of steps in the stepper motor needing to be evenly divisible by the PPR of the encoder. This was critical for calculation purposes because if it wasn't evenly divisible then the encoder could be between points when the stepper was not in the starting position. The team was able to keep cost down by selecting an incremental encoder versus an absolute as we are more concerned in the delta between points of interest instead of absolute position. To prove our design considerations, we created a MATLAB code (see **Appendix C**) to look at the stepper and encoder iterating every 0.1 in for the allowable range in arm length. We showed that at the designed pendulum arm length we will be at 74% of the available torque with a 99.99% alignment between the encoder and stepper motors position at the calculated 56° above 90°.

5.3.3 Design Analysis

After the initial cost analysis, the single support design was selected to move forward with. In an effort to be thorough in our vetting of the proper design, the team ran an analysis on the design. We loaded the apparatus assembly into Ansys, constraining the base of the assembly and support pillar. To simulate the maximum force the test apparatus would experience we applied a force normal to the base of the largest weighted side plates. The force was calculated by multiplying the maximum calculated acceleration the pendulum would be experiencing by the largest side plates that would be use during testing. That maximum force was then multiplied by 3 to incorporate a safety factor on the structure of the apparatus. This generated negligible stresses on the pillar, bearings, support shaft and pendulum shaft. The Von Misses stress analysis showed stresses in the range of 1.15×10^{-6} to 8.49×10^{-6} in the pendulum arm, body and weighted side plates, again negligible.

5.3.4 Software Programming

The design team started on the electrical design by selecting an Arduino micro-controller to operate and collect data from the different actuators and sensors. To better understand how to write the C/C++ code in the Arduino IDE, we bought a selection of cheap sensors to conduct tests using simple routines. Two test circuits were built for the necessary testing, one circuit for the encoder and an accelerometer, and the second circuit for the electro-magnet and a stepper motor. Once the machine was built, a final circuit was designed that included all actuators and sensors.

The device is entirely operated through a software interface. Two versions of said software were designed, one for a touchscreen fixed to the machine base and one for a Laptop or Desktop computer. The software produces an enumerated and dated text file for each test run. Additionally, the user can specify the name of the file and its saving directory along with customizing its content through a series of input text boxes on the interface. An example of an output text file along with the a more in depth description of the interface can be seen in **Appendix D**.

The device is operated through four routines (RUN, LOADING, RESET, and CALIBRATION) accessed by the press of a button on the software interface. The RUN routine lifts the hammer to the initial height of 610mm, drops the hammer and records the position of the hammer every 0.036 degrees along with the acceleration of the hammer every millisecond for very first swing of the hammer. the LOADING routine lifts the hammer 30 degrees to allow the user to place a specimen in the vice and if pressed again will bring the hammer back to the zero position. The RUN routine can start from the zero position or the loading position. The RESET routine brings the hammer back down to the zero position after the RUN routine was performed and will be unresponsive if the lifting arm is already at the zero position. The RESET routine is automatically run when the software is closed and the arm is still at the initial drop height. The CALIBRATION routine functions in two steps. The first step move the arm 10 degrees and lets the hammer stabilize itself. Once the hammer is stabilized at the lowest point, the CALIBRATION button is pressed again to perform the second step. The current position of the hammer is set as zero followed by the arm coming down and connecting itself to the hammer and returning itself to the zero position. This allows the user to calibrate the machine prior to performing a series of tests and ensure that the zero position is at the lowest point in the swing. The accuracy of this procedure is +/- 0.018 degrees.

Three major codes were written. The first one for the Arduino micro-controller written in C/C++ based arduino language that encompasses the routine behind each button presses. Another one written in Python for the communication between the Arduino and the computer used to operate the machine through the opening and closing of a COM port at each button press, it saves and decodes the raw data and sent by the Arduino saves it in specific lists. Finally the user interface software written in Python that contains the buttons, that transforms and visualizes the data received upon pressing a button. For more details, the codes are listed in **Appendix G**

5.3.5 Accelerometer

Accelerometers have three types of applications, measuring motion and vibration or shock. Our team was interested in measuring shock events due to the impact of the hammer upon the specimen. The first accelerometer the design team tested was a capacitive MEMS accelerometer. This was inexpensive and came in a ARDUINO kit with several other sensors. We affixed this sensor to the prototype pendulum arm and started generating plots of acceleration over time. However, the team quickly learned from the output that the speed of the accelerometer was not fast enough, losing critical data during the actual test. This type of accelerometer is used to measure motion, which is defined as slow changes in position or velocity and are used to measure sustained accelerations. We needed readings in the microseconds and the MEMS sensor was not sufficient for this task. The attention turned to either piezoresistive or piezoelectric accelerometers for the required hertz to gather the data. Through research we found piezoresistive accelerometers typically have a very low sensitivity which make them less useful for accurate vibration testing. Additionally, these accelerometers are sensitive to temperature variation so a temperature compensation will be required. Although these are extremely good for measuring high amplitude and frequency ranges we did not choose this style due to its common use for automotive impacts or weapons testing meaning the shock event will occur over a much longer time period. The piezoelectric accelerometer is the most widely used accelerometer for test and measurement applications. They are the first choice for most vibration measurements due to their wide frequency response, good sensitivity, and easy installation. Additionally, they are available in different sensitivities, weights, sizes and shapes making them easy to procure and swap out. They also have very low noise levels which makes them a good choice for both shock and vibration testing of all types.

5.3.6 Control System

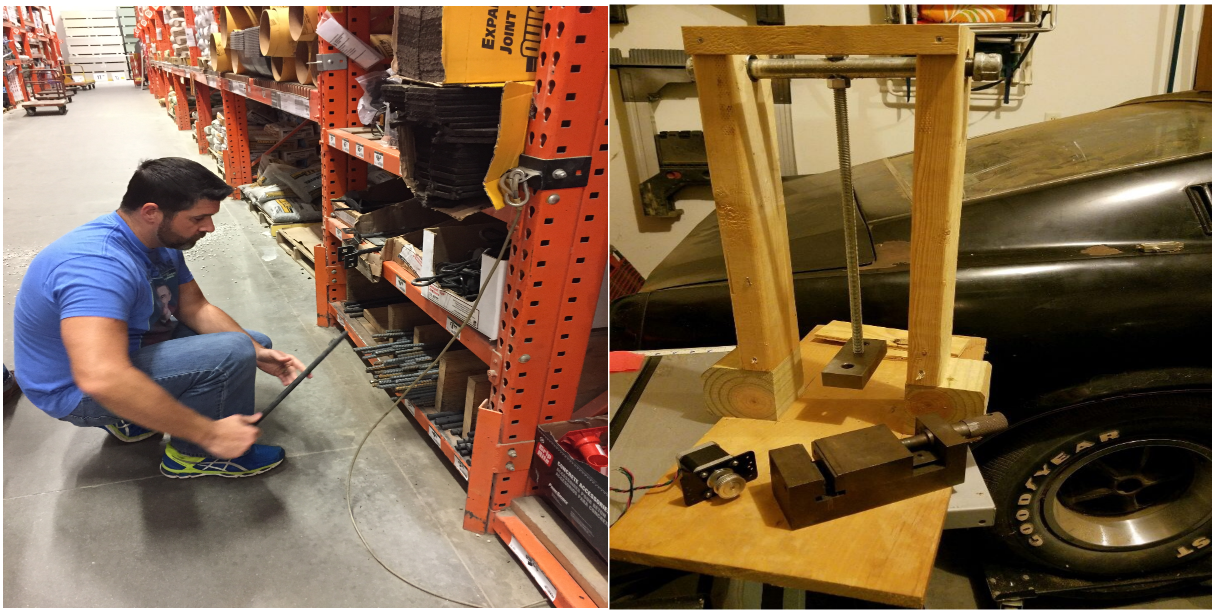
During the early programming stages, it became apparent that the Arduino would not be able to transform the raw data acquired through the sensors into useful information. The design team decided to use a Raspberry Pi along with the Arduino to broaden the capabilities of the system, using the Arduino to control the sensors and actuators while using the Raspberry Pi to transform the data for use in calculating the results as defined by the ASTM. The Raspberry Pi will also be utilized as a user interface and to display the results in a user-friendly manner.

5.3.7 Drawings

A full set of mechanical drawings were generated for this design. These were compiled into a design package and sent out to local shops for quoting purposes. Geometric tolerancing was used to ensure perpendicularity and paralellness between surfaces along with circularity and concentricity of bearing pockets in the support arm shaft. The complete set of drawings with the bill of materials can be seen in **Appendix E**.

5.3.8 MockUp Apparatus

Originally, the team realized that we needed a mockup of the apparatus as a visual representation of the size and to understand how the DC motor and encoder would function with respect to the rotational motion of the pendulum. The team designed a quick prototype using basic materials procured from a local Home Depot store and constructed the mockup apparatus in one of the team members garages. Additionally, we were able to borrow a stepper motor from a colleague to practice writing code in C/C++. The team quickly learned that the stepper motor would not be the critical component for writing the control program turning our attention to the encoder. Additionally, this mockup did not provide accurate rotational movements due using pipes for rotational joints instead of bearings.



(a) Trip to Home Depot   **(b)** Initial Prototype

Figure 5.1: Mockup Apparatus

The vise as seen in the above picture humbly performed the job of securing a specimen for test purposes, but ultimately we had to design and fabricate a vise for this project to adhere to the ASTM standards.

5.3.9 Prototype

Once it was determined that the mockup would not be sufficient for testing purposes, the team quickly designed a new prototype for 3D printing. The new design was scaled down considerably but the team was only interested in reading shaft position and acceleration so the need to fracture specimens was not necessary. This prototype was used with an Arduino kit, complete with accelerometer, gyroscope, magnetometer, small encoder and toggle switch to learn how to program in C/C++ for the micro-controller. By this time in the design process we were able to incorporate the actual apparatus encoder into the prototype to test accuracy and resolution of the data captured by the Arduino. The pendulum had two bosses extruded on the outer surface for affixing and testing the MEMS 6 axis accelerometer. This would lead to better understanding of an accelerometers accuracy and resolution, as in how many data points it generates and if that would be sufficient when trying to read an impact in the time range of 20 microseconds.

Chapter 6

Codes and Standards

As prospective engineers, one the most important set of codes that we are obligated to adhere to is the Engineering Fundamental Canons. The applicable Fundamental Canons state that engineers shall hold paramount the safety of the public, perform services in the areas of our expertise, act for each client as faithful agents or trustees, avoid deceptive acts, and conduct themselves honorably, responsibly, ethically, and lawfully while working on a project. As a design team, these codes were valued and always considered throughout the duration of the design project. as can be seen in the codes and standards section, the operators health was thought of in great detail. In order to ensure members performed tasks in their areas of expertise the team separated the work according to experience and expertise allowing certain team members to take lead on certain project deliverables. As faithful agents of our client, the design team met regularly with our advisor informing him of any set backs or design changes that removed or altered inputs to the final machine based on technology or budgetary constraints.

Another set of standards that this project was designed in compliance with are the ASTM standards for Izod impact testing of plastic. This impact tester meets all the ASTM specifications for an Izod Impact testing machine making the data generated both reliable and usable. This ASTM standard discusses the physical requirements the apparatus had to meet. In addition, the standard discusses all the tolerances that are acceptable for any physical dimensions and energy loss allowable in the system. The test specimen dimensions and how the specimen is to be fixtured are also discussed in the ASTM standard. Therefore, the design was directly guided by this document.

Safety is a very important aspect to each and every design. The designed apparatus is to be used in a laboratory on a university campus. This means that the test apparatus will be operated by multiple people consisting of Research Engineers, students or technicians with access to these laboratories. Additionally, one must keep the toss of the broken specimen in mind as there will be other people in the general area that will be exposed to any dangers associated with flying debris. Therefore, OSHA safety regulations come into action here. The workplace safety regulations are one of the codes that were looked at. The machine shall be designed with safety features that ensure that there would be no potential hazards that would make the workplace dangerous. In addition, these safety features shall also promote the well being and the safety of the operator.

Chapter 7

Design Considerations

7.1 Manufacturability

As Mechanical Engineering students, the team had access to the machine shop in the Innovation Lab at VCU. However, the availability of equipment and tools that could be used to manufacture and assemble the apparatus were limited making the facilities available for use during the manufacturing process another design driving factor. The 3D design of the model had to accommodate the availability of the technologies that could be utilized in the building of the machine. Manual machines were used to fabricate the different parts such as a conventional mill and a conventional lathe. The utilization of larger automated manufacturing machines, such as a CNC mill or CNC lathe, would make the manufacturing process of the same parts faster with a higher degree of repeatability.

The apparatus was designed to be modular having interchangeable components such as the hammer, the vice and the added weights. The design of the testing apparatus was done knowing that the Charpy and Izod Pendulum test methods were similar . The Izod hammer and vice are not permanently fixed and therefore can be replaced to ones that follow the Charpy ASTM standard (D6110-10), and with minor modifications to the software the device will be able to perform both tests adequately. Following a similar technique, the weights were also designed to be interchangeable rather than permanently fixed to allow for an easier change in the initial potential energy of the system. The significant difference between the Charpy and Izod tests are that the test specimen is constrained for either a three point bend impact test or a cantilever beam impact test respectively. The software's inputs for the specimen sizes and weights were designed for the Izod tests and the aforementioned hammer, switching these inputs to appropriate Charpy inputs will allow the software to operate the machine adequately without any back end changes. Additionally, the system being coded entirely in Python and Arduino C based language allows for customization.

The availability of materials was a driving factor in the design process of the apparatus. Material selection was determined by its availability as this would allow greater freedom when sourcing suppliers. Therefore, the majority of the parts on the apparatus assembly were designed using Hot Rolled Steel and Aluminum as these materials are common and would be carried by most US suppliers. Another consideration taken into account for the design was the size of the components. Material suppliers carry sheet, rod and bar stock in many uniform thicknesses and diameters. Therefore, each part was designed to be produced from readily available inventory eliminating the need for a special order to be placed with a mill. Additionally, large quantities can be bought at relatively low cost as seen in the prior design considerations.

7.2 Engineering Economics

The original scope of work was to design, build and deliver an impact test apparatus that incorporated a sensor to measure the pendulums initial height and final height after fracturing the test specimen and software to capture the data for further analysis. Upon researching which impact test method to use, the team became interested in trying to design a test apparatus that could be marketed for commercial sale. The Izod Impact Test Method was selected for the project and these test apparatuses can be found online at Alibaba with a price starting in the range of $4,000.00 - $5,000.00 that will digitally measure and display the impact energy. After seeing some of the prices associated with new test apparatuses, the design team decided to add additional instrumentation with a DC motor to automate the pendulum support arm control, electromagnet to create a clean free release of the pendulum and an accelerometer to measure the impact force in g's. The added improvements would increase the machines capability by automating the pendulum and output fracture toughness with the impact energy. Impact testers from reputable companies do not publish the cost of these machines and are available only through a quote. However, the team received a quote for a midrange instrumented impact apparatus with the same range of joules from Tinius Olsen, which is a reputable manufacturer of lab and testing equipment for a cost of $18,000.00. Starting the design process the team looked at two separate concepts, the first being symmetrical with two support pillars and the second using one support pillar in an effort to reduce material cost and the total number of parts. After fully designing both in CAD and generating prints the two seperate design packages were sent out to different machine shops for quoting. The quotes came back between $2800.00 and $3,000.00 with the single support pillar being the cheaper design. With an initial budget of $2,250.00 the team was forced to adjust how the machine was to be manufactured. We completed most of the machining services ourselves reducing the cost to just the raw materials which was $1201.79. This allowed greater flexibility with our sensors and electronics selection. After researching accelerometers, it was determined that a piezoelectric model would be required at a total cost of $767.80 including the power supply and cable. This left $280.41 in the budget to purchase the remaining electronics and sensors. After getting an encoder and cable donated we were able to purchase the remaining components for a total project cost of $2213.47 which is below the schools budget and well below the middle tier impact tester. Realistically if the design team did not get welding services, minimum machine shop services and the encoder and cable donated, the total cost of the machine would have been closer to $3675.00. Additionally if we add in the machining services of which we will take as being the difference between the $2,800.00 quote and our material cost then the machine would have cost close to $5,000.00. This is still far below the cost of the quoted impact tester found online with comparable functionality and capability. If this were to be commercially produced then the cost of goods to manufacture could be reduced even lower by harnessing the synergies of having one facility complete all the machining and welding services. Larger quantities could also help to reduce the cost when ordering materials and in machining services. In applying these two concepts for commercial production the overall cost of the machine would fall far below the $18,000.00 quote while still allowing the start up to be profitable depending on the market demands

7.3 Political Issues

Supporting American companies and American workers is a popular political issue. Since our project was funded with money from the university, this issue had a direct impact. Any purchase through a school index account must go through the eVA program. This program favors purchasing items from listed vendors who have gone through the eVA vendor process. The purpose of the program is to give business to Virginia companies and those run by historically disadvantaged populations. While this is an admirable stance, going through this system meant extra processing time if a non-eVA vendor was needed.

Generally, our team supported American vendors by choosing prefabricated parts from known American-affiliated companies. In trying to save some money, hardware for the enclosure was outsourced to a foreign company with unknown quality control. The hardware did not fit, causing us to reorder parts from a known American company to ensure functionality. It was a good lesson that spending more on a quality item saves time and money in the long run.

In working with the eVA program, our team got a lesson that Amazon is behemoth company that is difficult to avoid. Because of tax issues and the crushing effect Amazon has had on small businesses, school policy dictated that ordering from Amazon should only be considered if the pre-approved eVA list of suppliers has been exhausted. This proved to be challenging as one component was ordered through an approved eVA vendor only to find out the supplier purchased the component from Amazon and marked the price up by 26 percent. Most companies cannot leverage their shipping costs, so parts had to be ordered well in advance without the benefit of "two-day free delivery" as offered by Amazon. In general, the eVA process forced the team to plan ahead and work within a bureaucratic system, which is good practice for the corporate world.

7.4 Health and Safety Considerations

The Izod impact machine was designed and fabricated as an automated system. However, an operator or technician is still needed to operate the apparatus. Therefore, safety of the operator was considered during the design process. The loading of the specimen into the vice is a task to be manually completed. One of the functions that the apparatus GUI offers is a 'Loading' option, which lifts the pendulum to a 30 degree angle from the zero position. This provides access to the vise, allowing the operator to load the specimen. The "Loading" angle was set at 30 degrees to ensure that even if power to the apparatus were to be lost, the pendulum would not be of significant height to harm the operator if the electro magnets circuit is broken causing it to prematurely release the pendulum while the operator is in the machines path.

Another safety feature added to the impact tester was the safety enclosure. The safety enclosure is made with plexi-glass and uses an extruded aluminum 80/20 configuration for the frame. The enclosure sets around the machine with enough clearance for the apparatus to operate within a free environment. A door was added to the enclosure for ease of access to the machine when it was not being operated and uses a lockable latch ensuring the pinch points or areas of operation will not be accessible during testing. The enclosure serves as a barrier that protects the operator's hands from coming into the path of the machine while it is running. In addition, the safety enclosure makes the environment around the machine safe as it acts as a barrier limiting how far the toss of the fractured specimen may travel.

Chapter 8

Contemporary Issues

Homeland security is a very critical and sensitive issue. There is always a need for the enhancement and development of technologies that help prevent acts against this nation, limiting the damages to human life and property. Engineering plays a leading role in the development of new technologies that can help in making a safer place for everyone. The Izod impact testing machine can be used to analyze materials with unknown mechanical properties such as fracture toughness and impact resistance. These properties will help design engineers develop new materials enhancing existing technologies such as the bullet proof vest or ballistic glass.

Chapter 9

Cost Analysis

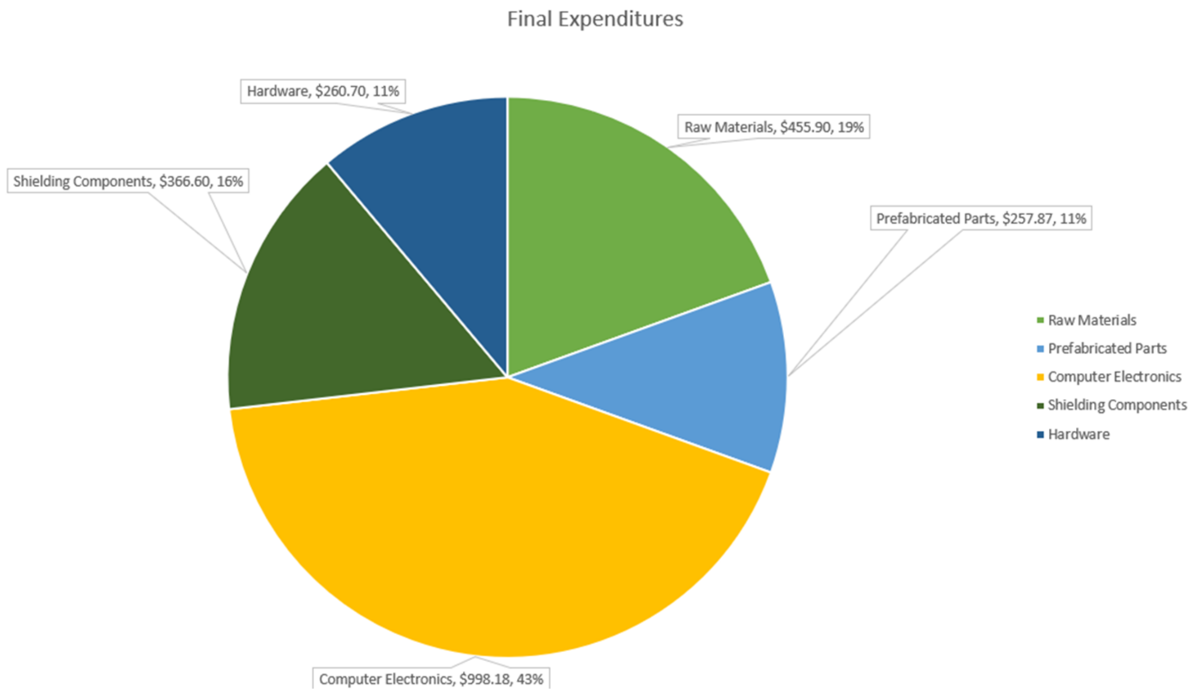


Table 9.1: Pie Chart of Final Expenditures

The original budget was $750. During the design process, the team decided that additional money was needed to complete the project. The team presented the design proposal to the Steering Committee requesting an additional $1500. The team moved forward with the additional funds, totalling $2250.

Five categories comprised the total expenditure amount of $2339.25. Raw materials of steel and aluminum comprised 19% of the budget. Team members fabricated most of the needed parts, saving money. The material for and fabrication of the hammer, pendulum body, pendulum shaft and electromagnet housing were donated. Bearings and gears were part of the prefabricated parts ordered. Comprised of plexiglass and extruded aluminum track, the shielding enclosure consumed 16% of the budget. Hardware came in at 11%. At almost $1000, computer electronics took up 43% of funding. The generosity of Altria saved us $873 on a donated encoder. A piezoelectric accelerometer provided by Dr. Mossi allowed the team to test out the impactor to ensure the correct level accelerometer was purchased. Dytran provided us with two different accelerometers for free. This enabled the team to choose the final accelerometer with confidence. **Appendix B** contains the complete budgetary details including part specification, vendor, and affiliated website.

Chapter 10

Project Timing

Activity	Start Date	End Date	Duration	Status
Machining Parts - Projected	5-Feb	7-Mar	30	Projected
Machining Parts - Actual	19-Feb	8-Apr	48	Actual
Prep for Steering Committee Presentation - P	18-Jan	2-Feb	15	Projected
Prep for Steering Committee Presentation -A	22-Jan	31-Jan	9	Actual
Programming with Prototype - Projected	20-Dec	20-Jan	31	Projected
Programming with Prototype - Actual	2-Jan	12-Apr	100	Actual
Machine Build - Projected	5-Feb	7-Mar	30	Projected
Machine Build - Actual	9-Apr	14-Apr	5	Actual
Create Expo Deliverables - Projected	17-Jan	18-Mar	60	Projected
Create Expo Deliverables - Actual	27-Mar	23-Apr	27	Actual
Timing and Testing - Projected	5-Mar	19-Apr	45	Projected
Timing and Testing - Actual	13-Apr	26-Apr	13	Actual
Validation - Projected	10-Apr	20-Apr	10	Projected
Validation - Actual	23-Apr	9-May	17	Actual
Senior Design Expo - Projected & Actual	26-Apr	27-Apr	2	Projected
Senior Design Expo - Actual	26-Apr	27-Apr	2	Actual

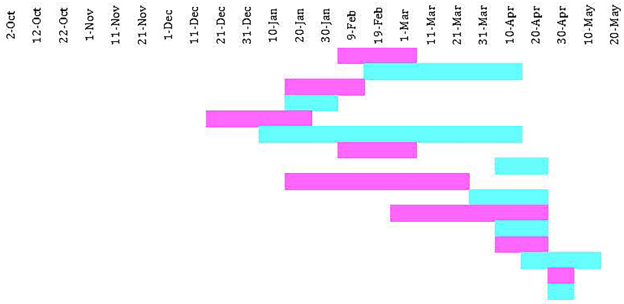


Figure 10.1: Year Timeline

Several factors impacted our intended schedule. The primary factors affecting our schedule was time and money. In December, the team requested an audience with the Steering Committee to ask for additional funds. We were able to give them our presentation on February 1, three weeks into the spring semester. Once granted the additional funds, a crucial order was held up because our index account had not been updated with the additional funds, making it appear as though we overspent. That mistake added one business week to a tight production schedule.

Using the team index account presented a learning challenge. All state funded entities use the eVA system, which is a compendium of vendors who apply to supply the state entities with tax free goods and services. Companies already listed as eVA accounts were preferred since the processing time was the shortest. Many of the needed vendors were not eVA accounts and required extra steps by the processing clerk before actual ordering. This slowed the arrival of critical parts. Additionally, the restriction of not using Amazon due to eVA, affected our parts choice, cost and arrival dates.

One metal supplier had not updated their website, so the raw material for the main support post had to be reordered from another company. This part was the center of the apparatus delaying the assembly of the entire device. A detailed construction schedule is listed in **Appendix F**. Parts ordered from a supplier overseas did not fit our components and had to be reordered from a vetted company. Some electronic parts like the accelerometer, needed to be tested with our device to judge if it gave the desired performance. So our team borrowed an accelerometer from a faculty member before purchasing the final one.

Since the fabrication of the device was delayed, testing and calibration was also delayed. Meanwhile, team members had classwork and job search tasks in addition to the demands of this project. Despite the delays, the team was able to produce a functioning apparatus for the Senior Capstone Expo on April 26, 2018. Validation and calibration continued after the expo. After modifying the software and running ten additional tests, the apparatus was calibrated to within 0.2 mm or 2 steps out of 10,000 steps that the encoder takes.

Chapter 11

Appendix A - Disciplines Associated with this Project

Team Member	Discipline	Task
Abdullah Almarri	ME: CAD Design	3D modeled designs
	Draftsmanship	Part drawings for fabrication
	Accounting	Budgeting
Arnaud Debraine	ME: Dynamic Systems and Control	Controller design
	Electrical Engineering	Circuit design
	Computer Engineering	Software development
Greg Nelson	ME: CAD Design	3D modeled designs
	ME: Materials	Material strength requirements
	Accounting	Budgeting
Stephanie Fulenwider	ME: Safety	Plexiglas guard around the apparatus
	Project Management	Writing and putting together reports
	Accounting	Budgeting

Table 11.1: Disciplines

Chapter 12

Appendix B - Cost Analysis Detail

ITEMIZED EXPENDITURES								
Part Name	**Part #**	**Quantity**	**Material**	**Size /Thickness**	**Amount**	**Actual Extension**	**total cost**	**Website**
Raw Materials								
Base Plate	201	1	Blanchard Ground 6061	0.375"	12" x 18"	$199.54	$199.54	www.grainger.com
Support Post	202	1	A36 Hot Roll Steel Tubing	7" x 3" x 0.375"	2'	$37.92	$37.92	www.discountsteel.com
Support Plate	203	1	A36 Hot Roll Steel Plate	0.375"	6" X 10"	$8.47	$8.47	www.onlinemetals.com
Support Arm Shaft	204	1	6061-T6 Aluminum SCH80	2" NOM	2'	$20.12	$20.12	www.onlinemetals.com
Support Arm	205	1	6061-T6 Aluminum	0.5"	12" x 12"	$36.00	$36.00	www.midweststeelsupply.com
Pendulum Arm Shaft	206	1	4130 Normalized Cold Roll	1"	2'	$19.60	$19.60	www.onlinemetals.com
Pendulum Arm	207	1	4130 Normalized Cold Roll	0.375"	2'	$2.97	$2.97	www.onlinemetals.com
Pendulum Body	208	1	A36 Hot Roll Steel Plate	0.250"	3" x 3"	$8.43	$8.43	www.midweststeelsupply.com
Heavy Side Plates	210	2	A36 Hot Roll Steel Plate	0.750"	3" x 3"	$6.93	$13.86	www.onlinemetals.com
Medium Side Plates	211	2	A36 Hot Roll Steel Plate	0.500"	3" x 3"	$5.67	$11.34	www.onlinemetals.com
Light Side Plates	212	2	A36 Hot Roll Steel Plate	0.250"	3" x 3"	$1.62	$3.24	www.onlinemetals.com
Stepper Support Bracket	215	1	A36 Hot Roll Steel Plate	0.750"	6" X 10"	$46.20	$46.20	www.onlinemetals.com
Magnetic Body A	217	1	A36 Hot Roll Steel Plate	0.500"	2" x 2"	$2.52	$2.52	www.onlinemetals.com
Magnetic Body B	218	1	A36 Hot Roll Steel Plate	0.500"	2" x 2"	$2.52	$2.52	www.onlinemetals.com
Magnet Support	219	1	A36 Hot Roll Steel Plate	0.500"	3" x 6"	$11.34	$11.34	www.onlinemetals.com
Vise Body	3002	1	1018 CR	1"	3" x 6"	$15.30	$15.30	www.midweststeelsupply.com
Vise Clamping Block	3005	1	1018 CR	2"	1" x 1.25"	$8.08	$8.08	www.midweststeelsupply.com
Vise Base	3001	1	1018 CR	0.250"	3" x 6"	$8.45	$8.45	www.midweststeelsupply.com
Prefabricated Parts								
Support Arm Bearings	UCF211-35	2	Flange Bearing	2.1875" I.D.	N/A	$46.35	$92.70	www.mscdirect.com
Pendulum Arm Bearings	60355K509	2	Ball Bearing	1" I.D.	N/A	$10.79	$21.58	www.mcmaster.com
Electromagnet	BDE-1012-12	1	Magnet	1" x 1.25"	N/A	$21.00	$21.00	www.buymagnets.com
Stepper Motor Spur Gear (BO)	213	1	Spur Gear	20 Tooth	N/A	$23.41	$23.41	www.misumi.com
Support Arm Shaft Spur Gear (BO)	214	1	Spur Gear	80 Tooth	N/A	$99.18	$99.18	www.misumi.com
Computer Electronics								
Planetary Gearbox Nema 17	17HS19-1684S-PG100	1	Stepper Motor	N/A	N/A	$69.00	$69.00	www.automationtechnologies.com
Arduino Due Board	A000062	1	N/A	N/A	N/A	$49.95	$49.95	www.kjdelectronics.com
Raspberry Pi 7" Touchscreen Case	B01HV97F64	1	N/A	N/A	N/A	$24.95	$24.95	www.adafruit.com
Parallax Keypad	27899	1	N/A	N/A	N/A	$6.50	$6.50	www.mouser.com
Raspberry Pi 7"	B0153R2A9I	1	N/A	N/A	N/A	$79.98	$79.98	www.adafruit.com
Accelerometer	3056D4	1	20 mV/g sensitivity, 250g range, 10-32 axial connector, 10-32 tapped hole, 10 grams, isolated, -67 to +250 F Operation	N/A	N/A	$349.00	$349.00	www.dytran.com
10 ft Cable	6011A10	1	Coaxial, Teflon Jacket, white, general purpose, 10-32 plug to BNC, 10 feet -67 to +250 F Operation	N/A	N/A	$52.80	$52.80	www.dytran.com
Current Source Power Unit	4110C	1	Current Source Power unit, 2 - 20 mA adjustable current with zero clamp, BNC jack input connectors, BNC jack output connectors	N/A	N/A	$366.00	$366.00	www.dytran.com

Table 12.1: Table of Detailed Expenditures

Shield Enclosure								
T-Slotted Extruded Aluminum	20-2020-1220	10	6105-T5	1" x 1"	320"	$9.64	$96.40	www.8020.net
Corner Bracket	JG653-Z	32	Nickel Coated Zinc Alloy	20 series 2 hole-20 mm	N/A	$1.50	$48.00	www.8020.net
Bolt Assembly	101619	114		M5 x 8.00 mm	N/A	$0.53	$60.42	www.8020.net
T-Handle Cam Latch	110.1.2.01.42	1	N/A	N/A	N/A	$18.10	$18.10	www.8020.net
Plexiglass Back Plate	N/A	1	Clear Acrylic	0.125"	24" x 48"	$31.67	$31.67	www.tapplastics.com
Plexiglass Side Plate	N/A	2	Clear Acrylic	0.125"	24" x 24"	$19.00	$38.00	www.tapplastics.com
Plexiglass Front Plate	N/A	2	Clear Acrylic	0.125"	10" x 24"	$10.00	$20.00	www.tapplastics.com
Plexiglass Door Plate	N/A	1	Clear Acrylic	0.125"	19.25" x 24"	$15.04	$15.04	www.tapplastics.com
Corner Bracket	JG653-Z	2	Nickel Coated Zinc Alloy		package	$14.99	$29.98	www.amazon.com
Flat Bracket	101619	1	Stainless Steel		package	$8.99	$8.99	www.amazon.com
Hardware								
Zinc Hex Flat head screws	91263A556	1	Zinc-plated Alloy Steel Hex Drive Flat head screw	1/4" - 20 Thread Size, 5/8" long	25 pack	$7.61	$7.61	www.mcmaster.com
support plate	90729A413	4	316 Stainless Hex Flat head Screw 100 degree Countersink	1/4" - 20 thread Size, 1" long	1 in a pack	$6.75	$27.00	www.mcmaster.com
Encoder bracket bolts	91273A309	4	18-8 Stainless Shoulder Screw,	3/8" dia., 1/2" Long shoulder, 3/8" - 16 thread	each	$6.67	$26.68	www.mcmaster.com
Encoder bracket nuts	94902A103	1	Steel Flange Nut, grade 8, black phosphate	3/8" -16 thread size	pack of 50	$6.55	$6.55	www.mcmaster.com
Encoder screws	91251A179	1	Black oxide Alloy steel Socket Head Screw	8-32 thread size, 1/8" long	pack of 25	$5.69	$5.69	www.mcmaster.com
flange bolts	91259A124	8	Alloy steel shoulder screw	3/4" dia., 1" long shoulder, 5/8"-11 Thread	each	$8.14	$65.12	www.mcmaster.com
flange nuts	93827A253	1	High-strength steel hex nut, grade 8, Zinc-aluminum Coated,	5/8"-11 Thread size	pack of 10	$6.56	$6.56	www.mcmaster.com
Arm bolt 1/4" - 28 thread	92562A144	1	Mil. Spec. Alloy Steel Socket head Screw	1/4" - 28 thread, 1-1/4" Long	each	$7.07	$7.07	www.mcmaster.com
arm bolt 1/4" - 20 thread	92562A257	1	Mil. Spec. Alloy Steel Socket head Screw	1/4" - 20 thread, 1/2" Long	each	$3.13	$3.13	www.mcmaster.com
magnetic body bolt	91255A028	1	Button Head Hex Drive screw, Black-Oxide Alloy Steel	10-32 Thread, 1-1/8" long	pack of 25	$10.40	$10.40	www.mcmaster.com
Large side plates bolts	91251A870	1	Black oxide Alloy steel Socket Head Screw	6-32 thread size, 1-1/8" Long	pack of 25	$14.91	$14.91	www.mcmaster.com
light side plates bolts	91274A016	1	Zinc-Aluminum-Coated Alloy Steel Socket Head Screw	6-32 thread size, 5/8" Long	pack of 25	$9.08	$9.08	www.mcmaster.com
medium side plates bolts	91274A028	1	Zinc-Aluminum-Coated Alloy Steel Socket Head Screw	6-32 thread size, 1" Long	pack of 25	$8.14	$8.14	www.mcmaster.com
vice bolt down	92235A518	4	Flanged Socket Head Screw	1/4" - 20 thread, 3/4" Long	each	$4.42	$17.68	www.mcmaster.com
magnet body to pendulum body	91251A953	1	Black oxide Alloy steel Socket Head Screw	3-48 thread size, 1" Long	pack of 25	$10.11	$10.11	www.mcmaster.com
Motor bracket bolts	90128A243	1	Zinc-plated Alloy Steel Socket head screw	1/4" - 20 thread, 5/8" Long	pack of 25	$4.70	$4.70	www.mcmaster.com
Hammer Bolts	90044A249	1	Black oxide Alloy steel Socket Head Screw	3-56 Thread Size, 1/2" Long	pack of 5	$7.49	$7.49	www.mcmaster.com
Hammer support bolts	91259A157	2	Alloy steel shoulder screw	1/8" diameter, 1/2" Long Shoulder, 4-40 Thread	each	$1.99	$3.98	www.mcmaster.com
support arm bolt	90128A197	1	Zinc-plated Alloy Steel Socket head screw	8-32 thread size, 3/4" Long	pack of 50	$6.52	$6.52	www.mcmaster.com
magnet attachment bolt	90128A946	1	Zinc-plated Alloy Steel Socket head screw	10-32 thread size, 7/8" Long	pack of 25	$3.71	$3.71	www.mcmaster.com
magnet attachment to support arm bolt	91255A245	1	Button Head Hex Drive screw, Black-Oxide Alloy Steel	10-24 thread size, 3/4" Long	pack of 50	$8.57	$8.57	www.mcmaster.com
							$2,339.25	**Total Spent**
							$2,250.00	budget
							-$89.25	overbudget

Table 12.2: Table of Detailed Expenditures Continued

Chapter 13

Appendix C - Actuator Applications Verification

Energy required [J]	Mass of the hammer [kg]
2.7	0.451
3.7	0.618
4.7	0.785
5.7	0.953
6.7	1.120
7.7	1.287
8.7	1.454
9.7	1.621
10.7	1.788
11.7	1.955
12.7	2.122
13.7	2.289
14.7	2.457
15.7	2.624
16.7	2.791
17.7	2.958
18.7	3.125
19.7	3.292
20.7	3.459
21.7	3.626

Table 13.1: SI Units Energy Required Data

Length of the arm [m]	Angle above the horizontal [deg]	angular tolerance [deg]	torque needed to lift the heavist mass [Nm]	Percent of the allowable torque provided by motor [%]	Maximum Gforce [gravity]
330	58.047	0.347	11.739	73.371	3.697
332	56.861	0.345	11.810	73.816	3.675
334	55.725	0.343	11.882	74.260	3.653
336	54.634	0.341	11.953	74.705	3.631
338	53.585	0.339	12.024	75.150	3.609
340	52.572	0.337	12.095	75.594	3.588
342	51.594	0.335	12.166	76.039	3.567
344	50.647	0.333	12.237	76.484	3.547
346	49.730	0.331	12.309	76.928	3.526
348	48.840	0.329	12.380	77.373	3.506
350	47.975	0.327	12.451	77.818	3.486
352	47.135	0.326	12.522	78.262	3.466
354	46.316	0.324	12.593	78.707	3.446
356	45.519	0.322	12.664	79.152	3.427
358	44.742	0.320	12.735	79.596	3.408
360	43.983	0.318	12.807	80.041	3.389
362	43.242	0.317	12.878	80.486	3.370
364	42.518	0.315	12.949	80.930	3.352
366	41.810	0.313	13.020	81.375	3.333
368	41.118	0.311	13.091	81.820	3.315
370	40.440	0.310	13.162	82.264	3.297
372	39.776	0.308	13.233	82.709	3.280
374	39.125	0.306	13.305	83.154	3.262
376	38.487	0.305	13.376	83.598	3.245
378	37.862	0.303	13.447	84.043	3.228
380	37.248	0.302	13.518	84.488	3.211
382	36.645	0.300	13.589	84.932	3.194
384	36.054	0.298	13.660	85.377	3.177
386	35.472	0.297	13.731	85.822	3.161
388	34.901	0.295	13.803	86.266	3.144
390	34.340	0.294	13.874	86.711	3.128
392	33.788	0.292	13.945	87.156	3.112
394	33.245	0.291	14.016	87.600	3.096
396	32.711	0.289	14.087	88.045	3.081
398	32.186	0.288	14.158	88.490	3.065
400	31.668	0.286	14.230	88.934	3.050

Table 13.2: SI Units Pendulum Arm Data

Length of the arm [in]	Encoder step to reach the required height	Stepper motor step to reach the required height	Encoder step tolerance check	Motor step tolerance check	Alignment check
330	1028	32899	Within Tolerance	Within Tolerance	99.9909% Aligned
332	1020	32636	Within Tolerance	Within Tolerance	99.9877% Aligned
334	1012	32383	Within Tolerance	Within Tolerance	99.9969% Aligned
336	1004	32141	Within Tolerance	Within Tolerance	99.9596% Aligned
338	997	31908	Within Tolerance	Within Tolerance	99.9875% Aligned
340	990	31683	Within Tolerance	Within Tolerance	99.9905% Aligned
342	983	31465	Within Tolerance	Within Tolerance	99.9714% Aligned
344	977	31255	Within Tolerance	Within Tolerance	99.9712% Aligned
346	970	31051	Within Tolerance	Within Tolerance	99.9646% Aligned
348	964	30853	Within Tolerance	Within Tolerance	99.9838% Aligned
350	958	30661	Within Tolerance	Within Tolerance	99.9837% Aligned
352	952	30474	Within Tolerance	Within Tolerance	99.9672% Aligned
354	947	30293	Within Tolerance	Within Tolerance	99.9637% Aligned
356	941	30115	Within Tolerance	Within Tolerance	99.99% Aligned
358	936	29943	Within Tolerance	Within Tolerance	99.9699% Aligned
360	930	29774	Within Tolerance	Within Tolerance	99.953% Aligned
362	925	29609	Within Tolerance	Within Tolerance	99.9696% Aligned
364	920	29448	Within Tolerance	Within Tolerance	99.9728% Aligned
366	915	29291	Within Tolerance	Within Tolerance	99.9624% Aligned
368	911	29137	Within Tolerance	Within Tolerance	99.9485% Aligned
370	906	28987	Within Tolerance	Within Tolerance	99.9828% Aligned
372	901	28839	Within Tolerance	Within Tolerance	99.9757% Aligned
374	897	28694	Within Tolerance	Within Tolerance	99.9651% Aligned
376	892	28553	Within Tolerance	Within Tolerance	99.9685% Aligned
378	888	28414	Within Tolerance	Within Tolerance	99.993% Aligned
380	884	28277	Within Tolerance	Within Tolerance	99.9611% Aligned
382	879	28143	Within Tolerance	Within Tolerance	99.9467% Aligned
384	875	28012	Within Tolerance	Within Tolerance	99.9572% Aligned
386	871	27883	Within Tolerance	Within Tolerance	99.9605% Aligned
388	867	27756	Within Tolerance	Within Tolerance	99.9568% Aligned
390	863	27631	Within Tolerance	Within Tolerance	99.9457% Aligned
392	860	27508	Within Tolerance	Within Tolerance	99.9564% Aligned
394	856	27388	Within Tolerance	Within Tolerance	99.9854% Aligned
396	852	27269	Within Tolerance	Within Tolerance	99.9817% Aligned
398	849	27152	Within Tolerance	Within Tolerance	99.9411% Aligned
400	845	27037	Within Tolerance	Within Tolerance	99.9889% Aligned

Table 13.3: SI Units Encoder and Stepper Motor Data

Length of the arm [in]	Angle above the horizontal [deg]	angular tolerance [deg]	torque needed to lift the heavist mass [ft.lbf]	Percent of the allowable torque provided by motor [%]	Maximum Gforce [gravity]
12.8	61.045	0.448	8.533	72.310	3.750
12.9	59.369	0.444	8.600	72.875	3.721
13.0	57.796	0.441	8.667	73.440	3.692
13.1	56.311	0.437	8.733	74.005	3.664
13.2	54.903	0.434	8.800	74.570	3.636
13.3	53.563	0.431	8.867	75.135	3.609
13.4	52.283	0.428	8.933	75.700	3.582
13.5	51.058	0.424	9.000	76.265	3.556
13.6	49.881	0.421	9.067	76.830	3.529
13.7	48.749	0.418	9.133	77.395	3.504
13.8	47.657	0.415	9.200	77.960	3.478
13.9	46.604	0.412	9.267	78.524	3.453
14.0	45.585	0.409	9.333	79.089	3.429
14.1	44.598	0.406	9.400	79.654	3.404
14.2	43.641	0.403	9.467	80.219	3.380
14.3	42.713	0.401	9.533	80.784	3.357
14.4	41.810	0.398	9.600	81.349	3.333
14.5	40.933	0.395	9.667	81.914	3.310
14.6	40.078	0.392	9.733	82.479	3.288
14.7	39.246	0.390	9.800	83.044	3.265
14.8	38.435	0.387	9.867	83.609	3.243
14.9	37.643	0.385	9.933	84.174	3.221
15.0	36.870	0.382	10.000	84.739	3.200
15.1	36.115	0.379	10.067	85.304	3.179
15.2	35.377	0.377	10.133	85.868	3.158
15.3	34.655	0.374	10.200	86.433	3.137
15.4	33.948	0.372	10.267	86.998	3.117
15.5	33.256	0.370	10.333	87.563	3.097
15.6	32.579	0.367	10.400	88.128	3.077
15.7	31.915	0.365	10.467	88.693	3.057
15.8	31.264	0.363	10.533	89.258	3.038
15.9	30.626	0.360	10.600	89.823	3.019
16.0	30.000	0.358	10.667	90.388	3.000

Table 13.4: US Units Pendulum Arm Data

Energy required [ft.lbf]	Mass of the hammer [lb]
2	1
3	1.5
4	2
5	2.5
6	3
7	3.5
8	4
9	4.5
10	5
11	5.5
12	6
13	6.5
14	7
15	7.5
16	8

Table 13.5: US Units Energy Required Data

Length of the arm [in]	Encoder step to reach the required height	Stepper motor step to reach the required height	Encoder step tolerance check	Motor step tolerance check	Alignment check
12.8	1049	33566	Within Tolerance	Within Tolerance	99.994% Aligned
12.9	1037	33193	Within Tolerance	Within Tolerance	99.9729% Aligned
13	1026	32844	Within Tolerance	Within Tolerance	99.9635% Aligned
13.1	1016	32514	Within Tolerance	Within Tolerance	99.9938% Aligned
13.2	1006	32201	Within Tolerance	Within Tolerance	99.9721% Aligned
13.3	997	31903	Within Tolerance	Within Tolerance	99.9969% Aligned
13.4	988	31619	Within Tolerance	Within Tolerance	99.9905% Aligned
13.5	980	31346	Within Tolerance	Within Tolerance	99.9553% Aligned
13.6	971	31085	Within Tolerance	Within Tolerance	99.9582% Aligned
13.7	964	30833	Within Tolerance	Within Tolerance	99.9514% Aligned
13.8	956	30591	Within Tolerance	Within Tolerance	99.9967% Aligned
13.9	949	30356	Within Tolerance	Within Tolerance	99.9605% Aligned
14	942	30130	Within Tolerance	Within Tolerance	99.9535% Aligned
14.1	935	29911	Within Tolerance	Within Tolerance	99.9699% Aligned
14.2	928	29698	Within Tolerance	Within Tolerance	99.9933% Aligned
14.3	922	29492	Within Tolerance	Within Tolerance	99.9593% Aligned
14.4	915	29291	Within Tolerance	Within Tolerance	99.9624% Aligned
14.5	909	29096	Within Tolerance	Within Tolerance	99.9725% Aligned
14.6	903	28906	Within Tolerance	Within Tolerance	99.9654% Aligned
14.7	898	28721	Within Tolerance	Within Tolerance	99.9478% Aligned
14.8	892	28541	Within Tolerance	Within Tolerance	99.9895% Aligned
14.9	886	28365	Within Tolerance	Within Tolerance	99.9542% Aligned
15	881	28193	Within Tolerance	Within Tolerance	99.9965% Aligned
15.1	876	28025	Within Tolerance	Within Tolerance	99.975% Aligned
15.2	871	27861	Within Tolerance	Within Tolerance	99.9605% Aligned
15.3	866	27701	Within Tolerance	Within Tolerance	99.9603% Aligned
15.4	861	27544	Within Tolerance	Within Tolerance	99.971% Aligned
15.5	856	27390	Within Tolerance	Within Tolerance	99.9927% Aligned
15.6	851	27240	Within Tolerance	Within Tolerance	99.9706% Aligned
15.7	847	27092	Within Tolerance	Within Tolerance	99.9557% Aligned
15.8	842	26948	Within Tolerance	Within Tolerance	99.9852% Aligned
15.9	838	26806	Within Tolerance	Within Tolerance	99.9627% Aligned
16	833	26667	Within Tolerance	Within Tolerance	99.9588% Aligned

Table 13.6: US Units Encoder and Stepper Motor Data

Chapter 14

Appendix D - Software Details

14.1 Software Interface Details

14.1.1 Windows Desktop Version

Figure 14.1: Windows GUI

1. **FILE** Let's the user access the **CHANGE DIRECTORY** function to decide where the next Output text files will be saved
2. The Accelerometer output graph
3. Functions to manipulate and save the above graph
4. The Previous Test results (Identical to the output text file)
5. User input functions to enter **BEFORE** a test is performed, see below
6. User input function to enter **AFTER** a test is performed, see below

User Inputs BEFORE a Test is Performed:

NOTE: Make sure to properly press **ENTER** after writing anything in the different text boxes.

- **Test File Name**: Let's the user edit the default output text file name.
  Default format: **IZOD**{**File count**}**_Date_**{**MM_DD_YYYY**}**_Time_**{**HH_MM_SS**}
  Example: **IZOD6_Date_05_06_2018_Time_11_17_41**
  Edited format: {**User Input**}**_IZOD**{**File count**}**_Date_**{**MM_DD_YYYY**}**_Time_**{**HH_MM_SS**}
  Example: **USERINPUT_IZOD6_Date_05_06_2018_Time_11_17_41**

- **Operator Name**: Let's the user add the name of the operator to the output text file
  Appears in the text file as: **Operator Name: User Input**
  Example: **Operator Name: Dr. Guven**

- **Added Mass**: Choose between 4 default options: No added mass, small plates, medium plates, and large plates

- **Specimen Material**: Let's the user add the specimen material to the output text file
  Appears in the text file as: **Specimen Material: User Input**
  Example: **Specimen Material: ABS**

- **Specimen Width (mm)**: Let's the user specify the width of the specimen
  Appears in the text file as: **Specimen Width (mm): User Input**
  Example: **Specimen Width (mm): 12.3**

- **Specimen Depth (mm)**: Let's the user specify the Depth of the specimen at the notch
  Appears in the text file as: **Specimen Depth (mm): User Input**
  Example: **Specimen Depth (mm): 12.3**

User Inputs AFTER a test is performed:

NOTE: Pressing **ENTER** does **NOT** save the note but allows the user to add a multi-line note.

1. **Operator Note**: Let's the user add a note to the previous test's output text file
   Appears in the text file as: **Operator Note: User Input**
   Example: **Operator Note: Full break**

2. Press **PRINT** to print the above note to the text file

14.1.2 Raspbian Touchscreen Version

Refer to 1.6.1 for User Inputs Instructions

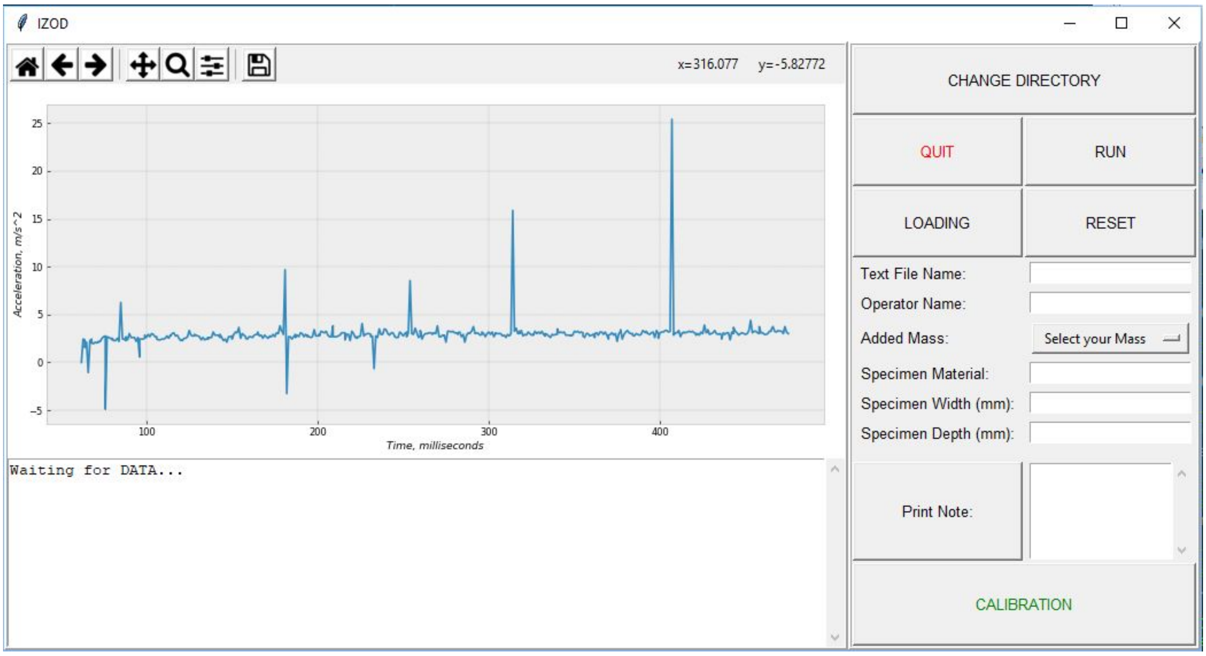


Figure 14.2: Raspbian Touchscreen GUI

14.2 TEXT FILE OUTPUT DETAILS

The text file will display **N/A** if the user did not enter required inputs.
The data is also saved below a dashed line in four columns:

- Time corresponding to the encoder data point in milliseconds
- Position of the hammer from 0 to 10,000 corresponding to 0 to 360 degrees.
- Time corresponding to the accelerometer data point in milliseconds
- accelerometer data point in *g*

```
Sun, 06, May, 2018, 12:24:09
File Number:    9
Operator Name: Dr. Guven

Operator Notes: ASTM Classification Example:
C = Complete Break
H = Hinge Break
P = Partial Break
NB = Non-Break

Mass Selected:  Medium Mass
Specimen Width (mm):
Specimen Depth (mm):

OUTPUT:
Initial Angle (degrees):    134.1
Final Angle (degrees):  132.732

Initial Height (mm):    610.3895419239126
Final Height (mm):  604.1475636734372
Height Difference (mm): 6.241978250475427

Initial Potential Energy (J):   12.3399084340486
Final Potential Energy (J): 12.213717805330731
Energy Difference (J):  0.12619062871786824
Impact Resistance (J/m):    N/A
Impact Strength (Full break) (J/m^2):   N/A

----------------------------------------

T_enc(ms)   Enc_data(raw)   T_acc(ms)   Acc_data(g)
0.0 601.0   262.0   0.0
0.0 602.0   263.0   1.3838013838013827
0.0 603.0   264.0   1.6280016280016278
0.0 604.0   265.0   1.7908017908017895
0.0 605.0   265.0   1.953601953601951
```

Figure 14.3: Output Text File

Chapter 15

Appendix E - Mechanical Drawings

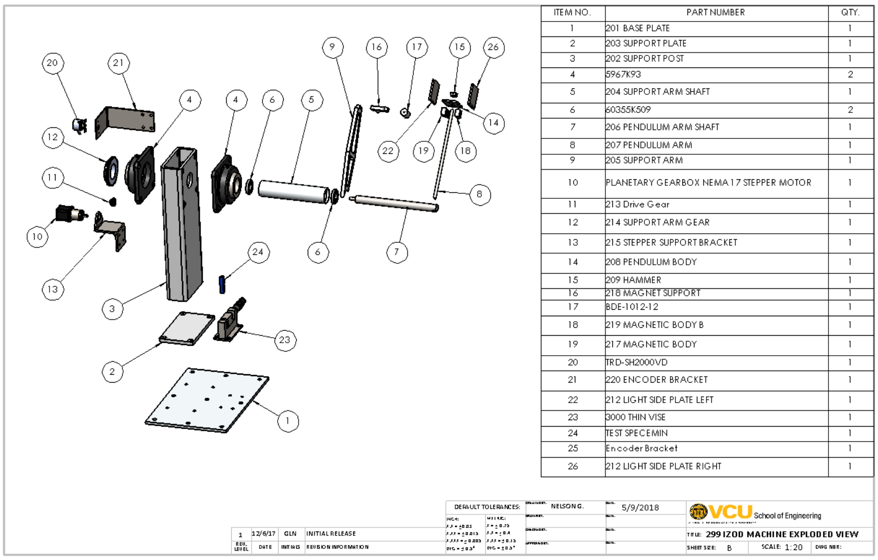


Figure 15.1: Support Arm

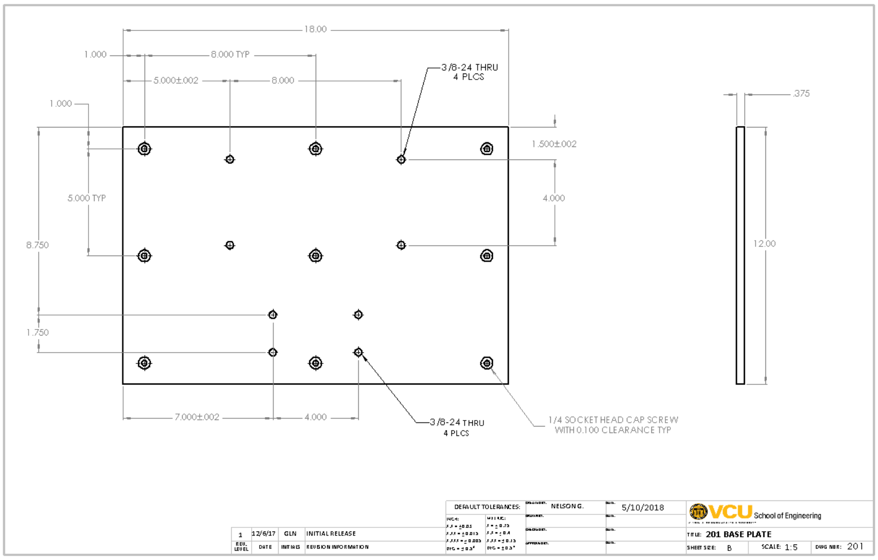


Figure 15.2: Support Arm

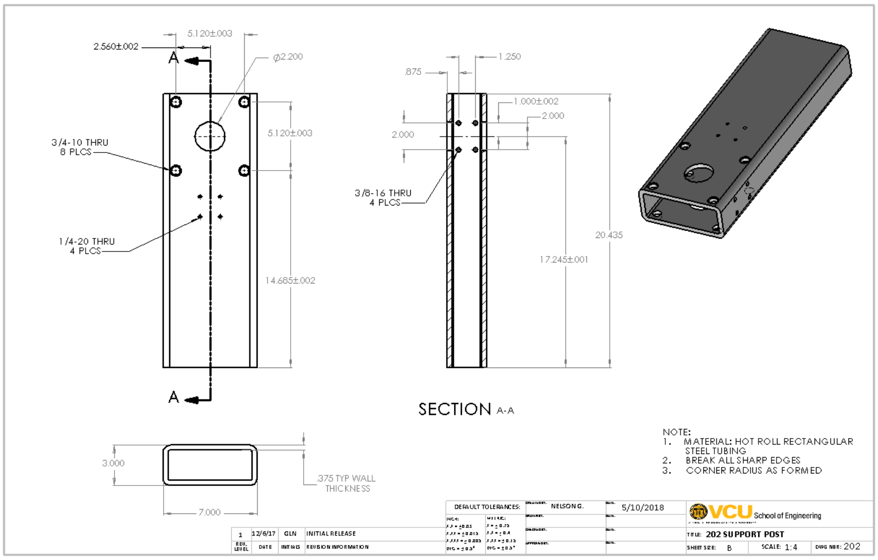


Figure 15.3: Support Arm

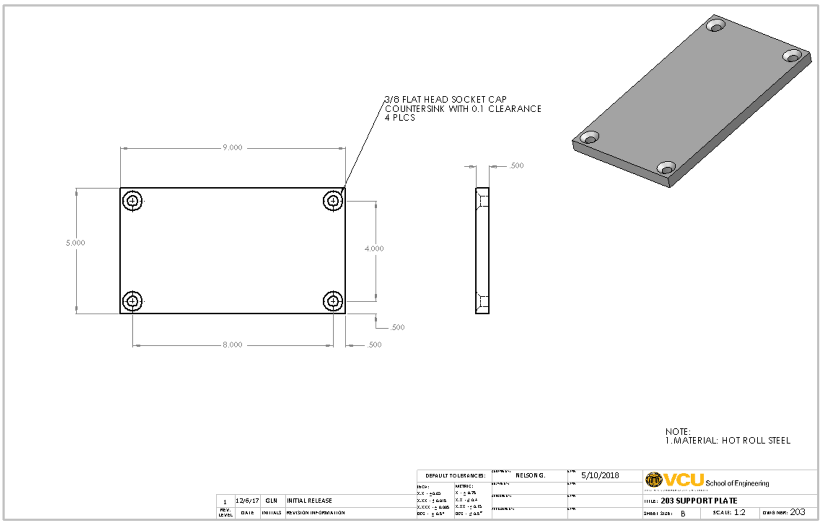


Figure 15.4: Support Arm

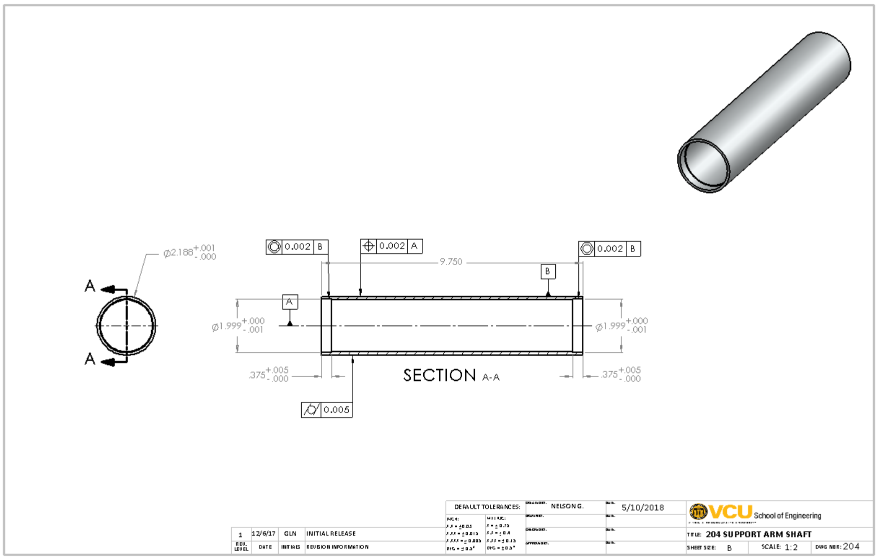


Figure 15.5: Support Arm

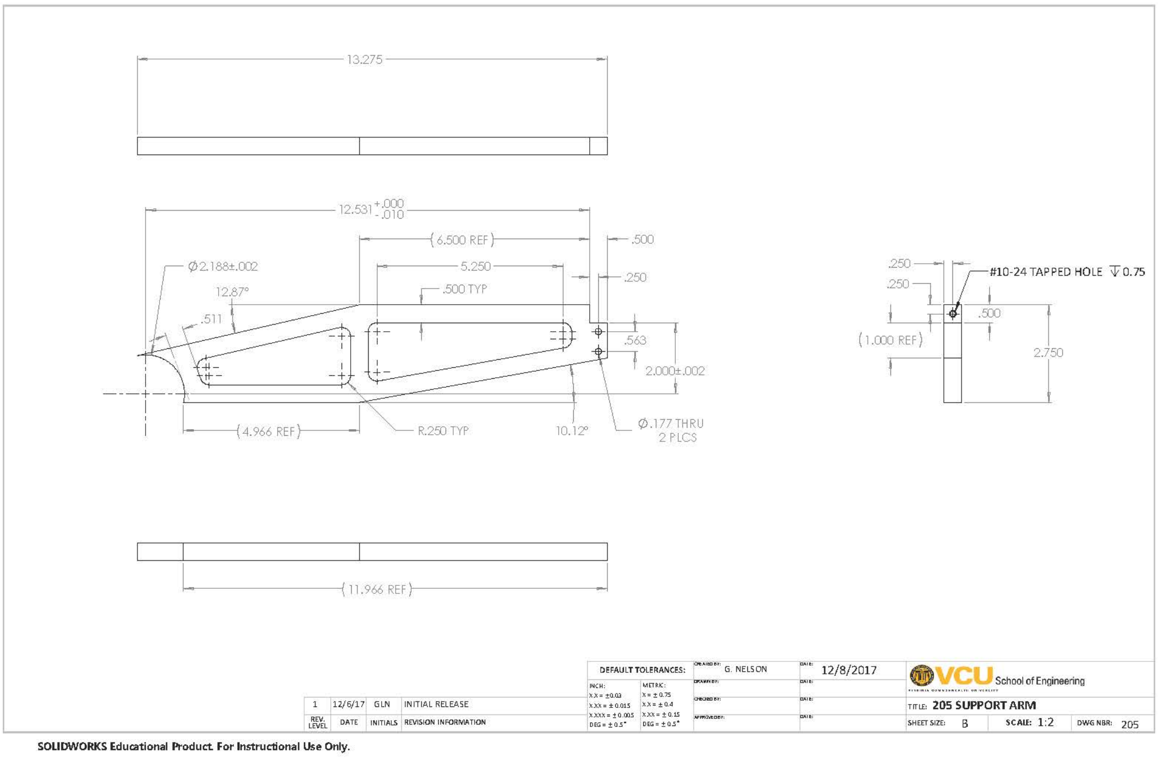


Figure 15.6: Support Arm

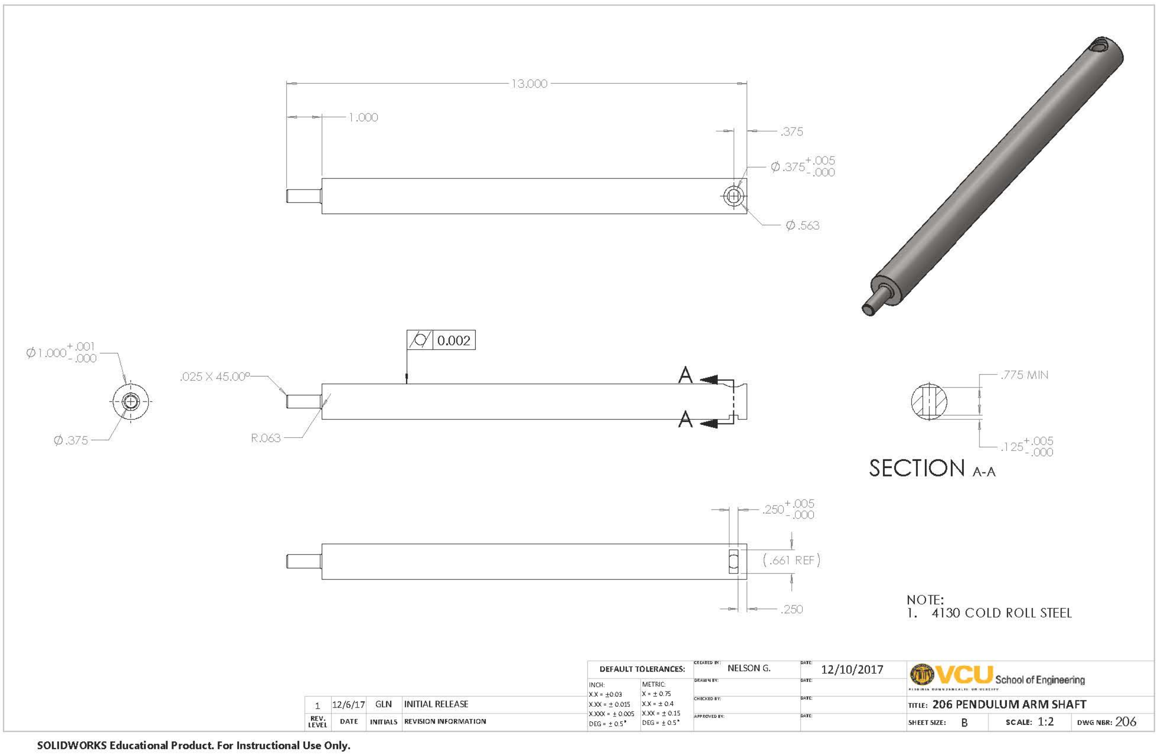


Figure 15.7: Pendulum Arm Shaft

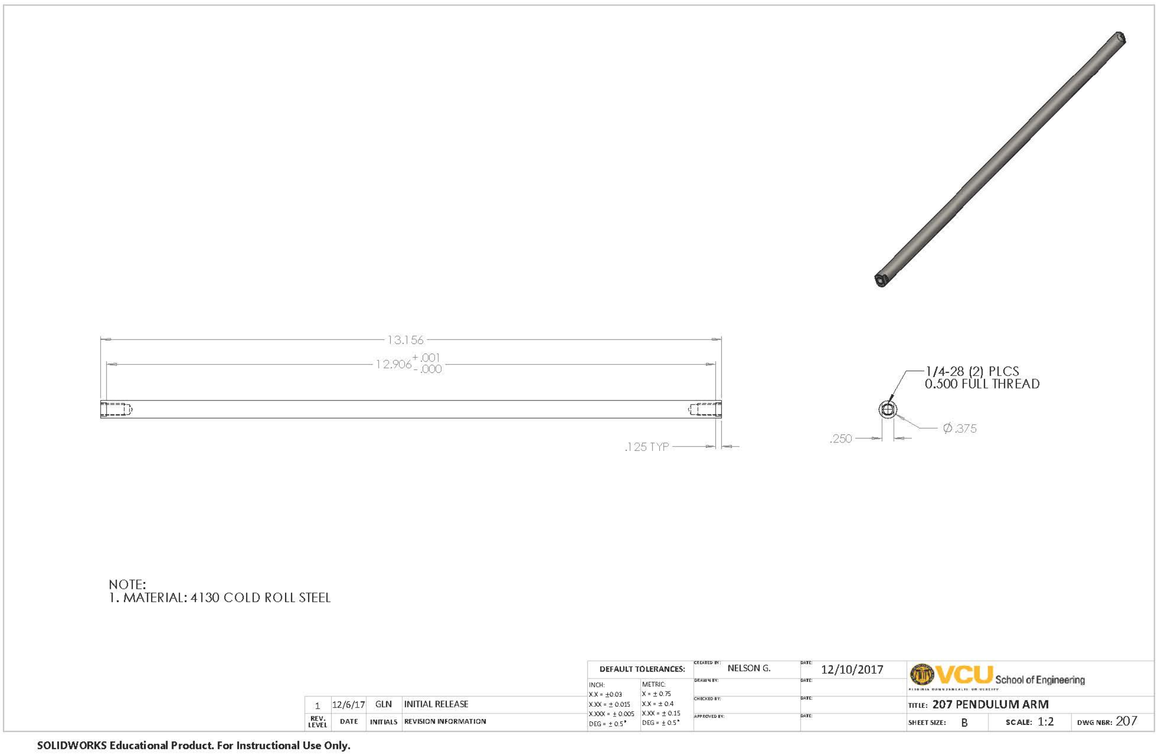


Figure 15.8: Pendulum Arm

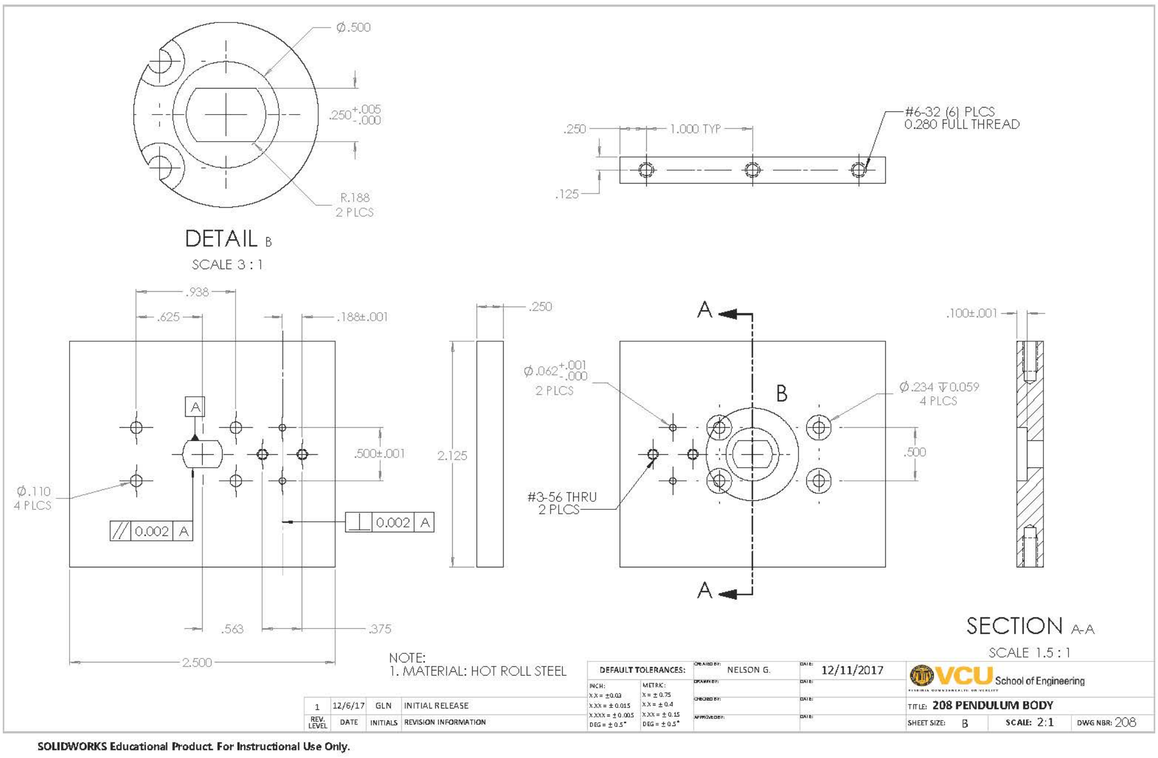


Figure 15.9: Pendulum Body

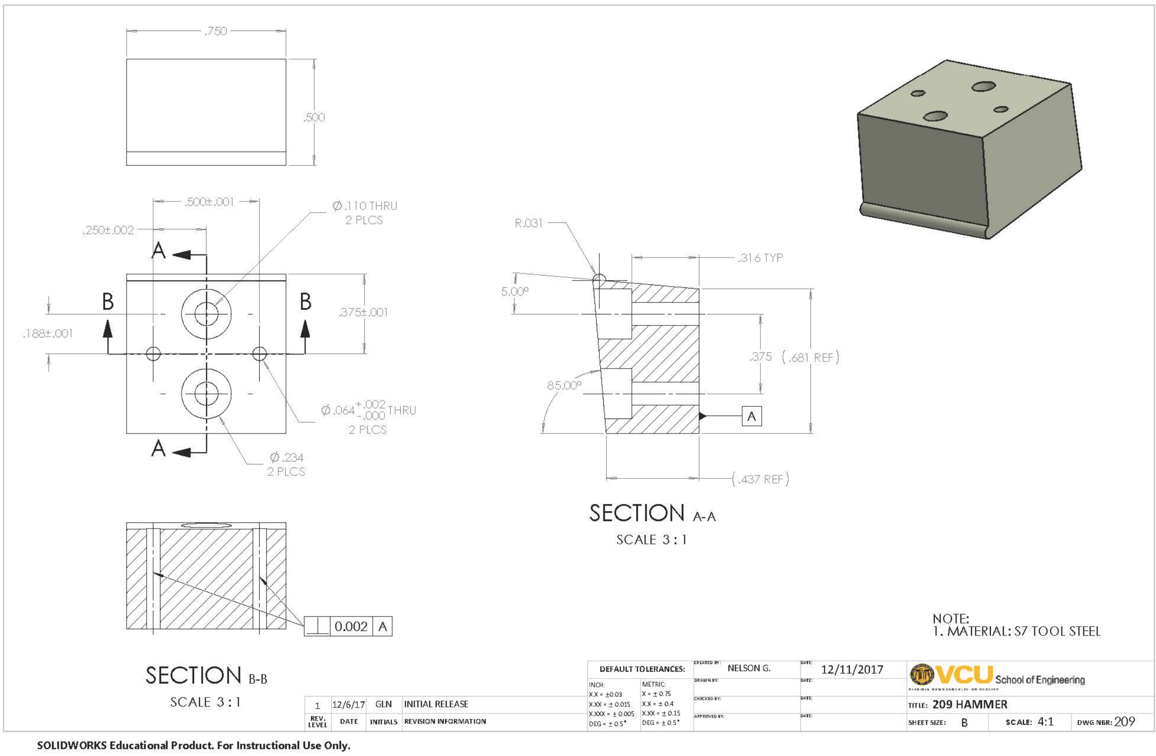


Figure 15.10: Hammer

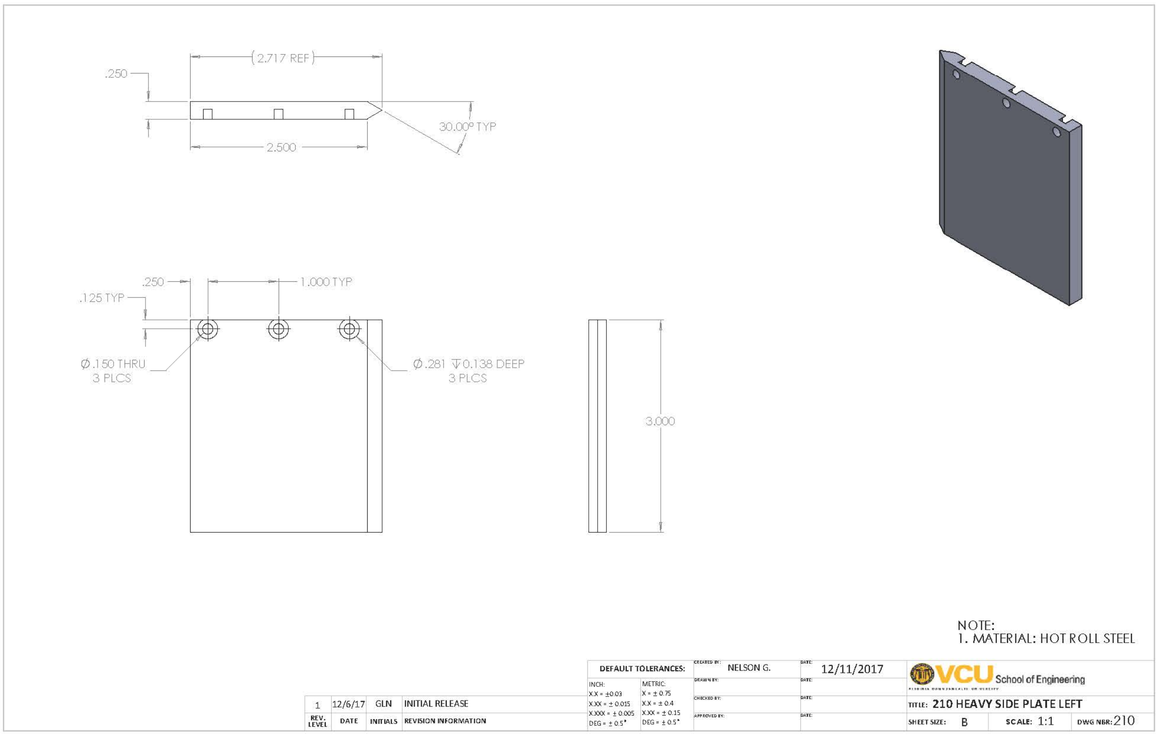


Figure 15.11: Left Side Heavy Plate

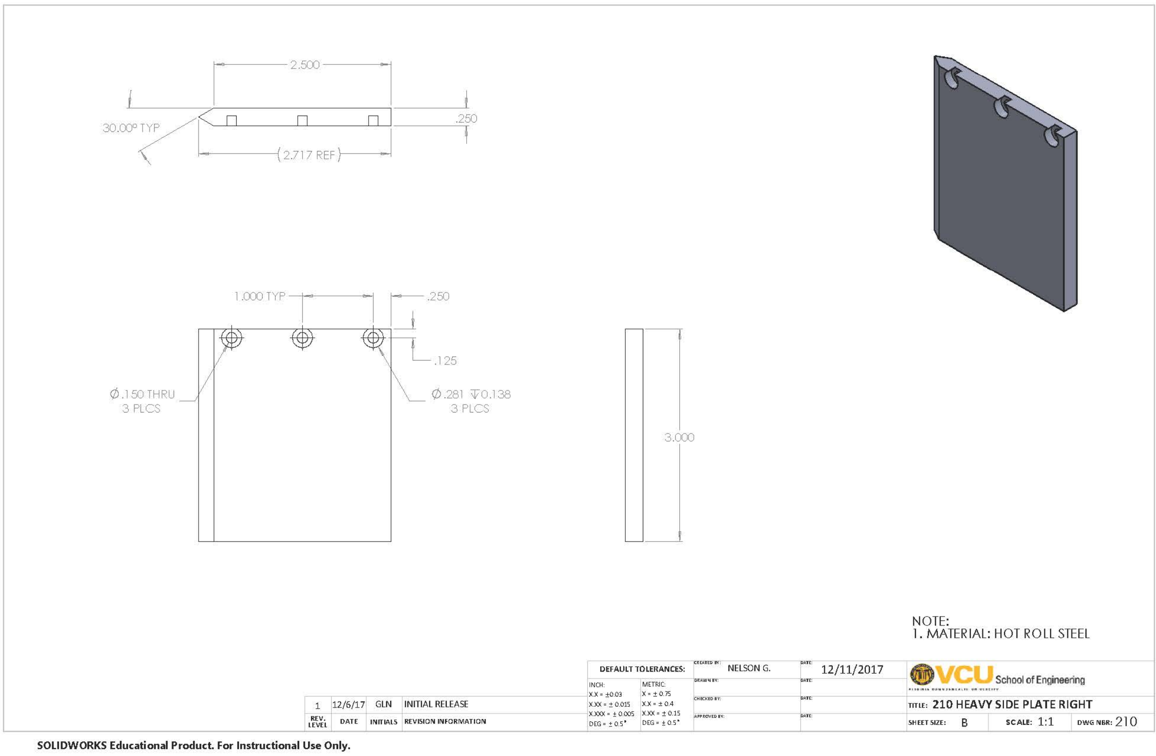


Figure 15.12: Right Side Heavy Plate

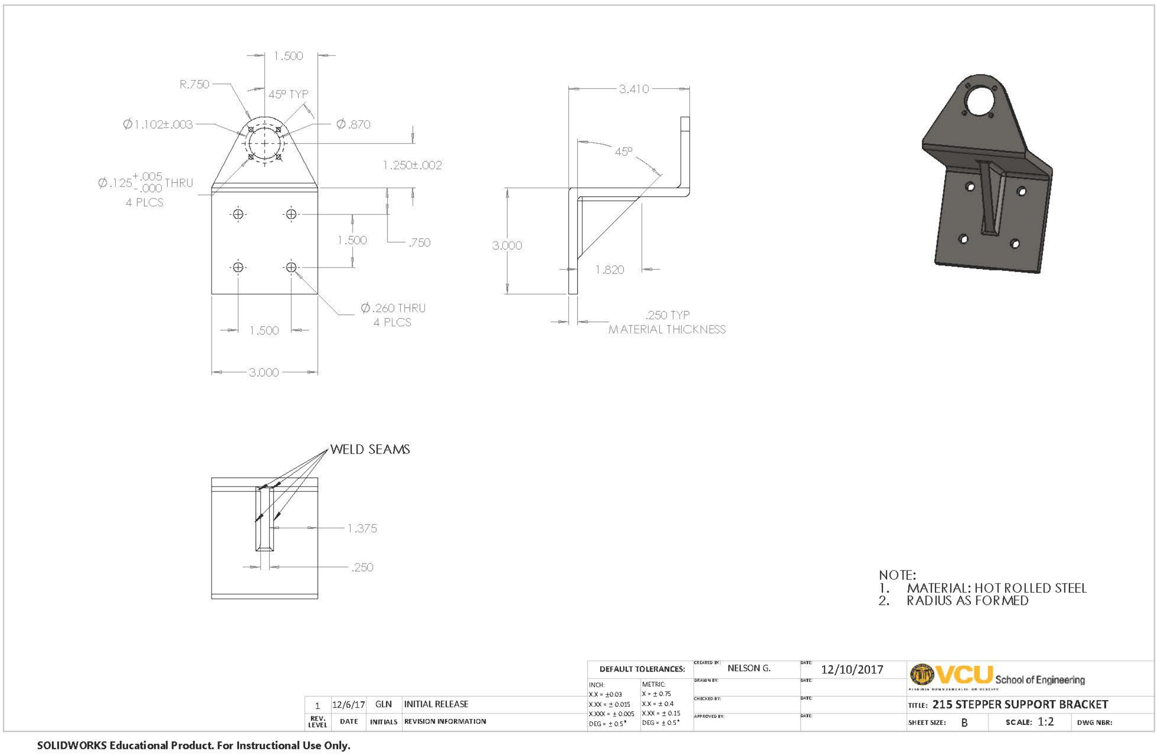


Figure 15.13: Stepper Support Bracket

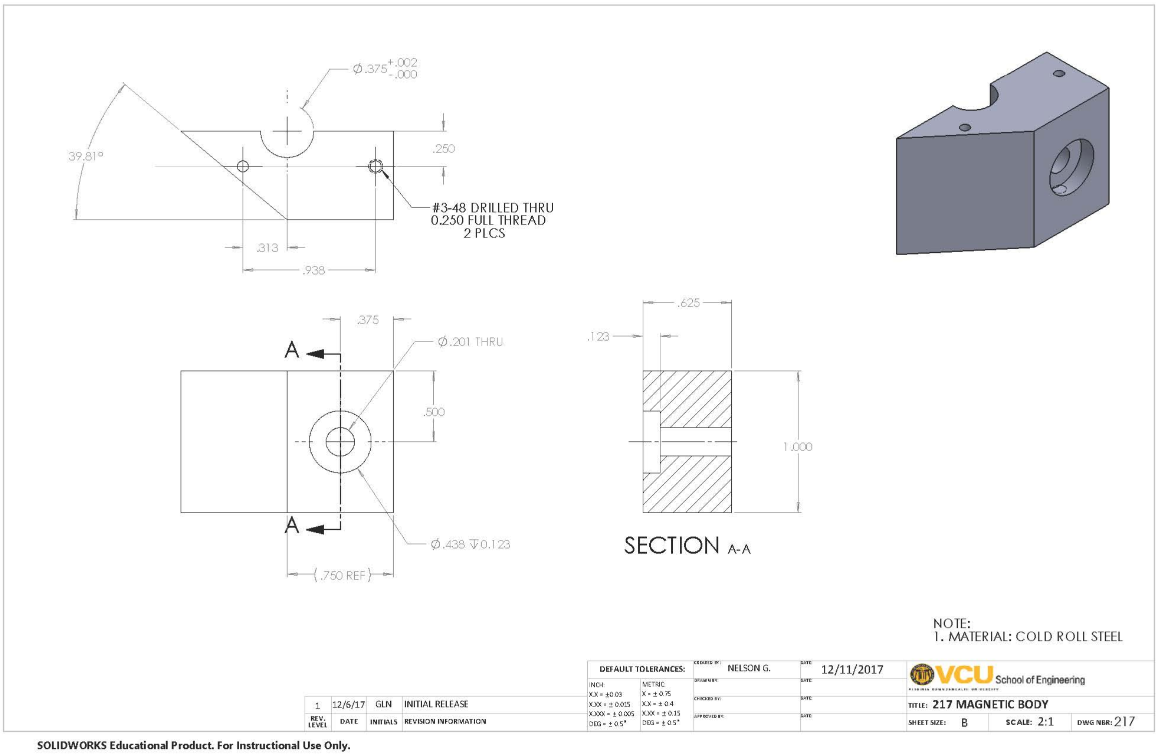


Figure 15.14: Magnetic Body

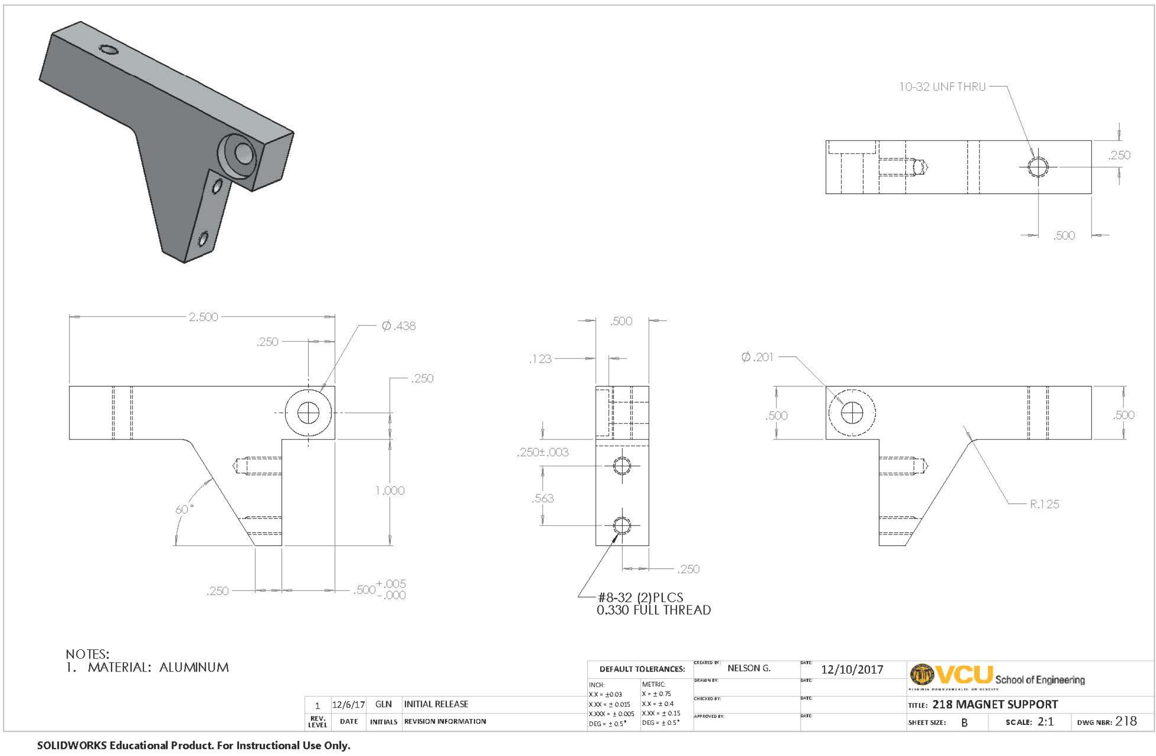


Figure 15.15: Magnet Support

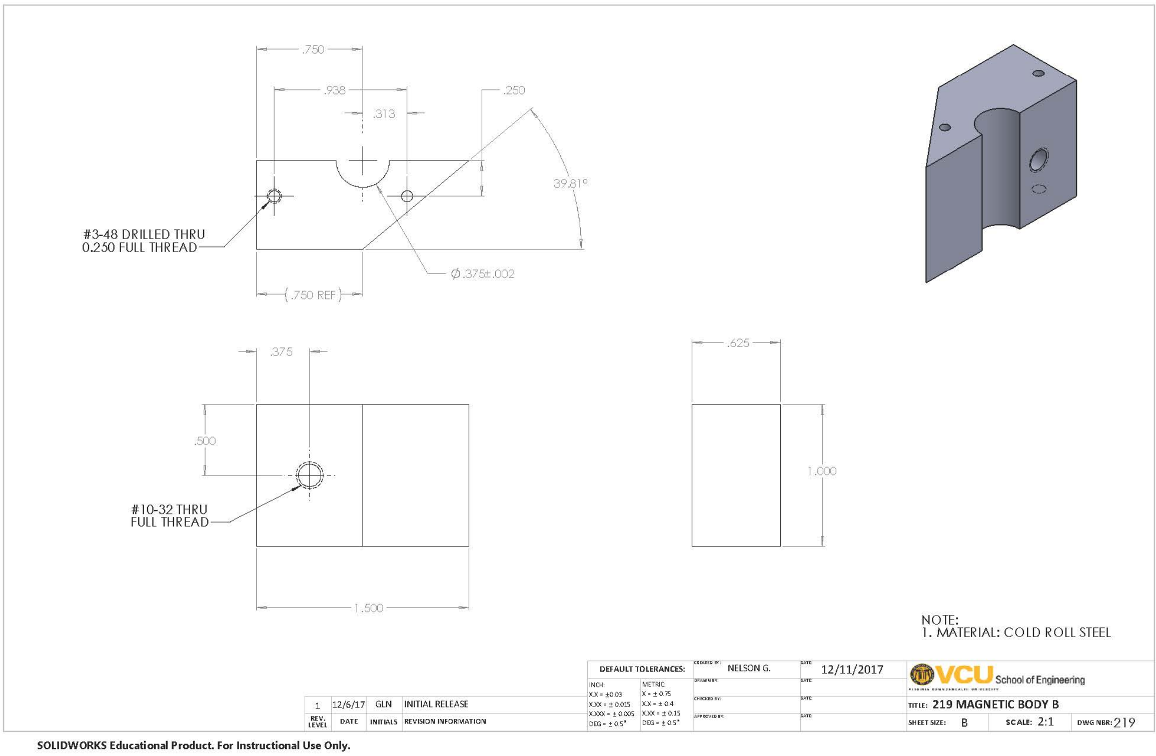


Figure 15.16: Magnetic Body B

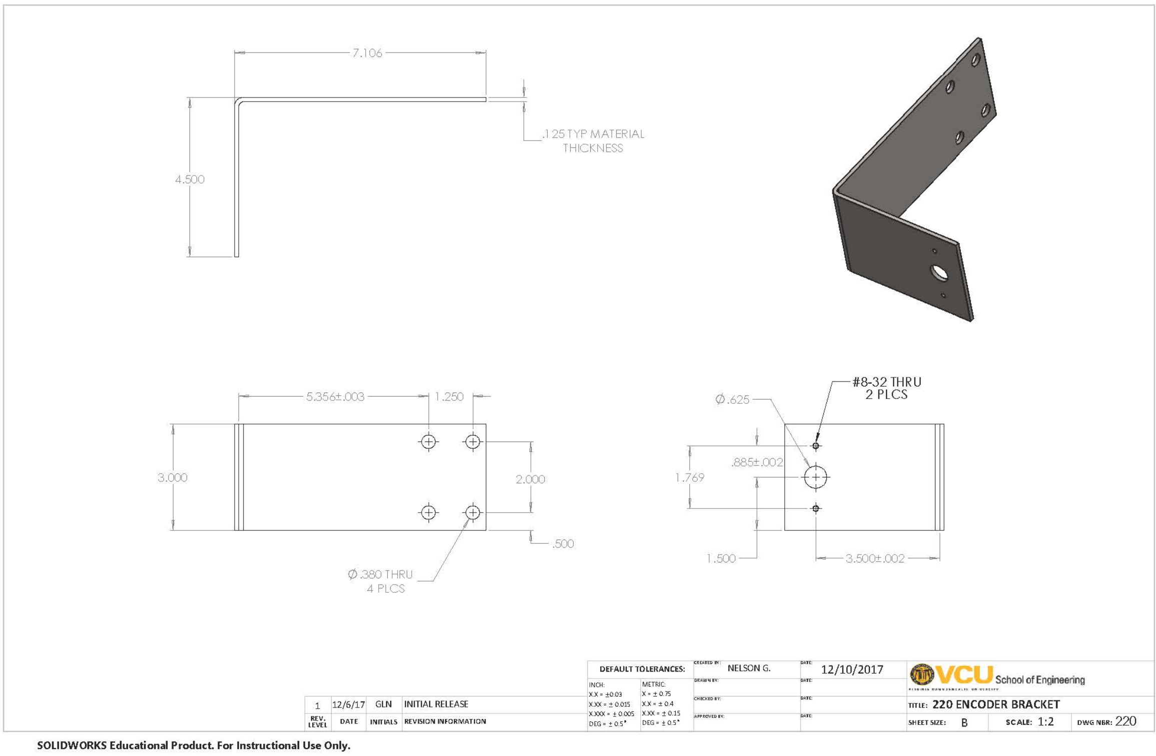


Figure 15.17: Encoder Bracket

Chapter 16

Appendix F - Construction Schedule Detail

Task	Date Started	Date Completed
Machining of Parts	19 February	8 April
Welding	9 April	9 April
Mounted Tester to Base	13 April	13 April
Adjustment to Main Structure; Alignment	23 April	24 April
Build of the Enclosure	24 April	26 April

Table 16.1: Construction Schedule

Chapter 17

Appendix G - Software Code

17.1 Arduino Code

```
""
#include <Stepper.h>
#include <Encoder.h>
#include "I2Cdev.h"
#include <ResponsiveAnalogRead.h>

/* ------------------------------ */
// accelerometer

#define analogPin A11
ResponsiveAnalogRead analog(analogPin, true);
int acc = 0;
int bits = 12;

/* ------------------------------ */
// encoder

long maxencoderstep = 10000;
int count = 0;
long oldPosition  = 99999;
long oldPositionreset = oldPosition;
long newPosition = 0;
unsigned long start;
unsigned long start2;
int recordtime = 2000;
int maxencpos = 0;
int accrecpos1 = 650; // acc start record enc pos
int accrecpos2 = 650; // acc end record enc pos
Encoder myEnc(3, 4);

/* ------------------------------ */
// state variables

```

```
bool analogtype = true;
bool stopsign = true;
bool calibbool = true;
char Key = 'A';
bool failsafe = true;

/* ------------------------------ */
// motor

int startmotorposition = 29760; // 29760 = 133.92 degrees in motor steps
int startencstep = 3720; // 3720 = 133.92 degrees in encoder steps
int loadingmotorposition = 6666; // 6666 = 30 degrees in motor steps
int loadpos = 0;
int calibpos1 = 2222; // 2222 = 10 degrees in motor steps
int calibpos2 = 444; // 444 = 2 degrees in motor steps
int calibpos3 = 4; // 4 = 0.018 degrees in motor steps
int calibbutton = 1;
const int stepsPerRevolution = 200;  // change this to fit the number of steps per revolution
Stepper myStepper(stepsPerRevolution, 8, 9, 10, 11);

/* ------------------------------ */

void setup() {
  myStepper.setSpeed(300);
  pinMode(7, OUTPUT);
  pinMode(6, OUTPUT);
  Serial.begin(250000);
  while (!Serial);
}

void loop() {
  char customKey;
  if (Serial.available()) {
    customKey = Serial.read();
    if (customKey == 'B' && failsafe == true) {
      failsafe = false;
      loadingmotorposition = abs(loadingmotorposition);
      digitalWrite(6, LOW);
      digitalWrite(7, HIGH);
      while (myEnc.read() < startencstep) {
        myStepper.step(calibpos3);
        startmotorposition = myEnc.read() * 80000 / 10000;
      }
      count = 0;
      stopsign = true;
      oldPosition  = oldPositionreset;
      loadpos = 0;
      digitalWrite(7, LOW);
      digitalWrite(6, HIGH);
    }
    else if (customKey == 'C' && failsafe == false) {
      failsafe = true;
      myStepper.step(-startmotorposition);
```

```
      digitalWrite(6, LOW);
      digitalWrite(7, HIGH);
      myStepper.step(-calibpos2);
      myStepper.setSpeed(50);
      calibbool = true;
      count = 0;
      oldPosition  = oldPositionreset;
    }
    else if (customKey == 'R') {
      failsafe = true;
      myStepper.step(-startmotorposition);
      digitalWrite(6, LOW);
      digitalWrite(7, HIGH);
      myStepper.step(-calibpos2);
      myStepper.setSpeed(50);
      calibbool = true;
      count = 0;
      oldPosition  = oldPositionreset;
    }
    else if (customKey == 'D' && failsafe == true) {
      digitalWrite(6, LOW);
      digitalWrite(7, HIGH);
      if (loadingmotorposition < 0) {
        myStepper.step(loadingmotorposition);
        loadpos = 0;
        loadingmotorposition = -loadingmotorposition;
      }
      else if (loadingmotorposition > 0) {
        myStepper.step(loadingmotorposition);
        loadpos = loadingmotorposition;
        loadingmotorposition = -loadingmotorposition;
      }
    }
    else if (customKey == 'E') {
      failsafe = true;
      if (calibbutton > 0) {
        digitalWrite(6, LOW);
        digitalWrite(7, HIGH);
        myStepper.step(calibpos1);
        digitalWrite(6, HIGH);
        digitalWrite(7, LOW);
        delay(300);
        digitalWrite(6, LOW);
        calibbutton = - calibbutton;
      }
      else if (calibbutton < 0) {
        customKey = 'F';
        calibbool = true;
        calibbutton = - calibbutton;
      }
    }
    if (customKey == 'F') {
      digitalWrite(6, LOW);
```

```
      digitalWrite(7, HIGH);
      myStepper.step(-(calibpos1 + calibpos2));
      myStepper.setSpeed(50);
    }
    Key = customKey;
  }

  if (Key == 'A') {
    myEnc.write(0);
  }
  else if (Key == 'B') {
    newPosition = myEnc.read();
    if (count == 0) {
      start = millis();
      start2 = millis();
    }
    if (newPosition < oldPosition) {
      unsigned long now = millis();
      unsigned long elapsed = now - start;
      oldPosition = newPosition;
      Serial.print(elapsed);
      Serial.print("\t");
      Serial.println(newPosition);
      count = count + 1;
    }
    else if (millis() - start > recordtime && count != 0) {
      stopsign = false;
      Serial.println("reset");
      Serial.println("");
      count = 0;
    }
    if (newPosition < maxencpos * (-1) + accrecpos1 && newPosition > maxencpos * (-1) - accrecpos2 &&
     stopsign == true) {
      if (analogtype == false) {
        analog.setAnalogResolution(4095);
        analog.update();
        acc = analog.getValue();
      }
      else {
        analogReadResolution(bits);
        acc = analogRead(analogPin);
      }
      unsigned long now2 = millis();
      unsigned long elapsed2 = now2 - start2;
      Serial.print("?");
      Serial.print("\t");
      Serial.print(elapsed2);
      Serial.print("\t");
      Serial.println(acc);
    }
    else if (newPosition < maxencpos * (-1) - accrecpos2) {
      stopsign = false;
    }
```

```
  }
  else if (Key == 'E') {
    myEnc.write(0);
  }
  else if (Key == 'F' && calibbool == true) {
    if (myEnc.read() > 0) {
      myStepper.step(-calibpos3);
    }
    else if (myEnc.read() < 0) {
      myStepper.step(calibpos3);
    }
    else {
      myStepper.setSpeed(300);
      calibbool = false;
    }
  }
  else if (Key == 'C' && calibbool == true) {
    if (myEnc.read() > 0) {
      myStepper.step(-calibpos3);
    }
    else if (myEnc.read() < 0) {
      myStepper.step(calibpos3);
    }
    else {
      myStepper.setSpeed(300);
      calibbool = false;
    }
  }
  else if (Key == 'R' && calibbool == true) {
    if (myEnc.read() > 0) {
      myStepper.step(-calibpos3);
    }
    else if (myEnc.read() < 0) {
      myStepper.step(calibpos3);
    }
    else {
      myStepper.setSpeed(300);
      calibbool = false;
    }
  }
//  Serial.println(myEnc.read());
}
```

17.2 Arduino-Python Communication code

```python
""# -*- coding: utf-8 -*-
import os.path
import time
import numpy as np
import serial


def readpref():
    """Fetches information from preferences.txt.

    If preferences.txt exists, fetches appropriate constants.
    If it doesn't revert to default constants.

    Args:

    Returns:
        A set of constants used in calculations of output values.

        count: Test File Count
        timesensitivity: Average time between each data point in
            the previous test
        timefactor: Unused
        armradius: Length of the arm from point of rotation to center of mass
        maxencstep: Maximum encoder step
        initialanglestep: Encoder step corresponding to the initial height,
            updated every run
        mass0: Mass of the hammer without weights
        mass1: Mass of the hammer with small plates
        mass2: Mass of the hammer with medium plates
        mass3: Mass of the hammer with Large plates
        mass0calibheight: Height loss on a free swing without weights
        mass1calibheight: Height loss on a free swing with small plates
        mass2calibheight: Height loss on a free swing with merdium plates
        mass3calibheight: Height loss on a free swing with large plates
    """
    try:
        if os.path.isfile("preferences.txt"):
            Fc = open("preferences.txt", "r")
            readlines = Fc.readlines()
            testread = [line.split("\t") for line in readlines]
            Fc.close()
            count = int(testread[0][1])
            timesensitivity = float(testread[1][1])
            timefactor = float(testread[2][1])
            armradius = float(testread[3][1])
            maxencstep = int(testread[4][1])
            initialanglestep = int(testread[5][1])
            mass0 = float(testread[6][1])
            mass1 = float(testread[7][1])
            mass2 = float(testread[8][1])
```

```
            mass3 = float(testread[9][1])
            mass0calibheight = float(testread[10][1])
            mass1calibheight = float(testread[11][1])
            mass2calibheight = float(testread[12][1])
            mass3calibheight = float(testread[13][1])

        elif not os.path.isfile("preferences.txt"):
            count = 0
            timesensitivity = 10
            initialanglestep = 3723
            maxencstep = 10000
            armradius = 359.918
            timefactor = 1.5
            mass0 = 414.1
            mass1 = 943.0
            mass2 = 2060.8
            mass3 = 3355.8
            mass0calibheight = 17.030
            mass1calibheight = 8.032
            mass2calibheight = 4.566
            mass3calibheight = 3.442
    except:
        pass

    return count,timesensitivity,timefactor,armradius,maxencstep,initialanglestep,mass0,mass1,mass2,mass3,
     mass0calibheight,mass1calibheight,mass2calibheight,mass3calibheight

def calc_angle(angle,length):
    """Calculates the vertical height of the
    pendulum depending on the encoder readings

    Args:
        angle: encoder readings in degrees
        length: length of the pendulum arm

    Returns:
        The maximum Height reached by the hammer

        height: vertical height of the pendulum
    """
    if angle >= 90:
        Height = length + length * np.sin(np.deg2rad(angle - 90))
    elif angle < 90:
        Height = length - length * np.sin(np.deg2rad(90 - angle))

    return Height

def vecreset():
    """Resets the time, encoder data, accelerometer data lists to empty lists

    Args:

    Returns:
```

```
        Empty lists

        timepoints: Empty list corresponding to the time(ms) for each
            encoder data point
        timepointsacc: Empty list corresponding to the time(ms) for each
            accelerometer data point
        enc: Empty list corresponding to each encoder data point
        acc: Empty list corresponding to each accelerometer data point
    """

    timepoints = []
    timepointsacc = []
    enc = []
    acc = []

    return timepoints, timepointsacc, enc, acc

def prefline(file, name, var):
    """Template for added lines in the output text file

    Args:
        file: text file name
        name: User input name
        var: User input variable

    Returns:
    """

    file.write(name + ":")
    file.write("\t")
    file.write(str(var))
    file.write("\n")


def sizecompare(vec1, vec2):
    """Two uneven lists made into even lists

    Args:
        vec1: A first list
        vec2: A second list

    Returns:
        Removes values at the end of the larger list until both lists are of
        the same length

        vec1: A first list
        vec2: A second list
    """

    if len(vec1) > len(vec2):
        vec1 = vec1[len(vec1)-len(vec2):len(vec1)]
    elif len(vec1) < len(vec2):
        vec2 = vec2[len(vec2)-len(vec1):len(vec2)]
```

```python
    return vec1, vec2

def startread(SerialData):
    """Only used when __name__ == '__main__' to simulate the GUI button presses

    Args:
        SerialData: Arduino COM port

    Returns:
        Returns a char corresponding to the simulated button press.
        Refer to readard()

        command: Character

    """

    command = input("Write to start: ").upper()
    if command == "B" or command == "C" or command == "D" or command == "E" or command == "Q":
        pass
    else:
        print("Wrong input")
        startread(SerialData)
    return command

def StartArduino(comport, bd):
    """Only used when __name__ == '__main__' to open the arduino port

    Args:
        comport: COM port of the arduino
        bd: Baudwidth

    Returns:
        Returns a string corresponding to the adequate Arduino COM port

        SerialData: Adequate String Arduino COM port
    """

    try:
        SerialData = serial.Serial(comport, bd)
    except:
        SerialData(comport, bd).close()
        SerialData = serial.Serial(comport, bd)
    return SerialData

def savedata(timepoints,timepointsacc, enc, acc):
    """Saves all the data sets into a DATA.txt file

    Args:
        timepoints: Llist corresponding to the time(ms) for each
            encoder data point
        timepointsacc: List corresponding to the time(ms) for each
            accelerometer data point
        enc: List corresponding to each encoder data point
```

```
        acc: List corresponding to each accelerometer data point

    Returns:
    """

    F = open("DATA.txt", "w")
    for i in range(0,len(timepoints)):
        F.write(str(timepoints[i]))
        F.write(",")
        F.write(str(enc[i]))
        F.write(",")
        try:
            F.write(str(timepointsacc[i]))
        except:
            F.write("N/A")
        F.write(",")
        try:
            F.write(str(acc[i]))
        except:
            F.write("N/A")
        F.write("\n")
    F.close()


def readard(SerialData, command):
    """Main arduino reading function

    Args:
        SerialData: COM port of the arduino
        command: Character corresponding to a button press

    Returns:
        command == B:
            Run routine.
            The magnet engages and the hammer is lifted to a 610mm+/-2
            vertical height then the magnet disengages and the hammer is
            dropped 2 seconds later. The data for a single swing is recorded,
            plotted and transformed on the GUI,
            and saved in an output text file.

        command == C:
            Reset routine.
            The magnet engages and the lifting arm is returned to
            the original position

        command == D:
            Loading routine.
            The magnet engages and the hammer is lifted out
            of the way to allow the placement of a specimen in the vice. if the
            command is given again, the hammer is lowered to its initial position.

        command == E:
            Calibration routine.
```

```
            The magnet engages and the hammer is lifted 10 degrees from its
            current position. The magnet then disengages and the hammer is dropped.
            Once the hammer stabilizes at 0 degrees, the command can be sent again
            to have the current encoder position of the hammer recorded as
            the 0 position and the lifting arm will connect to the hammer and
            return itself to that position.

        command == Q:
            Stops the program.
    """

    timepoints, timepointsacc, enc, acc = vecreset()
    count,timesensitivity,timefactor,armradius,maxencstep,initialanglestep,mass0,mass1,mass2,mass3,mass0calibheight,mass1calibheight,mass2calibheight,mass3calibheight = readpref()

    if command == "B":

        # flush any junk left in the serial buffer
        SerialData.reset_input_buffer()
        command = command.encode("utf-8")
        SerialData.write(command)
        time.sleep(0.05)
        run = True
        while run:
            data = SerialData.readline().decode("utf-8")

            if "?" in data:
                try:
                    datarecacc = data.split("\t")
                    timepointsacc.append(float(datarecacc[1]))
                    acc.append(float(datarecacc[2])*3.3/4095/0.0099)
                except:
                    pass
            else:
                try:
                    datarec = data.split("\t")
                    timepoints.append(float(datarec[0]))
                    enc.append(int(datarec[1]))
                except:
                    pass

            if data in ["reset\r\n"]:
                initialanglestep = np.max(enc)
                Height_step = np.abs(np.min(enc))

                acc = acc[1:len(acc)+1]
                timepoints, enc = sizecompare(timepoints, enc)
                timepointsacc, acc = sizecompare(timepointsacc, acc)
                timepoints = [i-timepoints[0] for i in timepoints]
                acc = [i-acc[0] for i in acc]

                savedata(timepoints, timepointsacc, enc, acc)

```

```
                initial_angle = float(initialanglestep)*360/float(maxencstep)
                end_angle = float(Height_step)*360/float(maxencstep)

                Height_initial = calc_angle(initial_angle,armradius)
                Height_end = calc_angle(end_angle,armradius)

                F = open("IZOD"+str(count)+"_"+time.strftime("Date_%m_%d_%Y_Time_%H_%M_%S", time.localtime())+".txt", "w")
                F.write(time.strftime("%a, %d, %b, %Y, %H:%M:%S", time.localtime()))
                F.write("\n")
                prefline(F,"File Number",count)
                prefline(F,"Initial Angle (degrees)",initial_angle)
                prefline(F,"Final Angle (degrees)",end_angle)
                F.write("\n")
                prefline(F,"Initial Height (mm)",Height_initial)
                prefline(F,"Final Height (mm)",Height_end)
                prefline(F,"Height Difference (mm)",Height_initial - Height_end)
                F.write("\n")
                F.close()

                count = count + 1
                Fc = open("preferences.txt", "w")
                prefline(Fc, "Count", count)
                prefline(Fc, "Time_Sensitivity_ms", timesensitivity)
                prefline(Fc, "Time_Factor", timefactor)
                prefline(Fc, "Arm_Radius_mm", armradius)
                prefline(Fc, "Max_encoder_Step", maxencstep)
                prefline(Fc, "Initial_Angle_Step", initialanglestep)
                prefline(Fc, "Mass_0", mass0)
                prefline(Fc, "Mass_1", mass1)
                prefline(Fc, "Mass_2", mass2)
                prefline(Fc, "Mass_3", mass3)
                prefline(Fc, "Mass_0_calib_height", mass0calibheight)
                prefline(Fc, "Mass_1_calib_height", mass1calibheight)
                prefline(Fc, "Mass_2_calib_height", mass2calibheight)
                prefline(Fc, "Mass_3_calib_height", mass3calibheight)
                Fc.close()

                timepoints, timepointsacc, enc, acc = vecreset()
                run = False

    if command == "C":
        SerialData.reset_input_buffer()
        command = command.encode("utf-8")
        SerialData.write(command)
        time.sleep(0.05)

    if command == "D":
        SerialData.reset_input_buffer()
        command = command.encode("utf-8")
        SerialData.write(command)
        time.sleep(0.05)

```

```
    if command == "E":
        SerialData.reset_input_buffer()
        command = command.encode("utf-8")
        SerialData.write(command)
        time.sleep(0.05)

    if command == "Q":
        SerialData.reset_input_buffer()
        command = command.encode("utf-8")
        SerialData.write(command)
        time.sleep(0.05)

if __name__ == '__main__':
    SerialData = StartArduino("com8", 250000)
    while True:
        command = startread(SerialData)
        readard(SerialData, command)
        if command == "Q":
            command = "C"
            readard(SerialData, command)
            break
    SerialData.close()
```

17.3 Software Interface Python Code

```python
""# -*- coding: utf-8 -*-
import glob
from Communication import *
import serial
import tkinter as tk
import numpy as np
from tkinter.scrolledtext import ScrolledText
from matplotlib.figure import Figure
import matplotlib.pyplot as plt
from matplotlib.backends.backend_tkagg import (
    FigureCanvasTkAgg, NavigationToolbar2TkAgg)
import matplotlib.animation as animation
from matplotlib import style
import os
import shutil

pause = False
style.use("bmh")
fig = Figure(figsize=(1,1), dpi=60)
ax = fig.add_subplot(111)
list1 = ['No Mass', 'Light Mass', 'Medium Mass', 'Heavy Mass']
g = 9.81

def animate(i):
    """Reads the DATA.txt file and plots its content
    The plot is refreshed every 1s to allow for the next DATA set.

    Args:
        i: counter

    Returns:
    """

    pullData = open("DATA.txt","r").read()
    dataList = pullData.split('\n')
    timepointsList = []
    timepointsaccList = []
    encList = []
    accList = []
    for eachLine in dataList:
        if len(eachLine) > 1:
            timepoints, enc, timepointsacc, acc = eachLine.split(',')
            try:
                timepointsList.append(float(timepoints))
            except:
                pass
            try:
                encList.append(float(enc))
            except:
                pass
```

```
            try:
                timepointsaccList.append(float(timepointsacc))
            except:
                pass
            try:
                accList.append(float(acc))
            except:
                pass
    if not pause:
        ax.clear()
        ax.grid(True)
        ax.plot(timepointsaccList[0:-1], accList[0:-1], "-")
        fig.tight_layout(pad=2.2)
        ax.set_xlabel('Time, milliseconds', fontsize='11', fontstyle='italic')
        ax.set_ylabel('Acceleration, m/s^2', fontsize='11', fontstyle='italic')

def onClick(event):
    """Pauses the animation refresh to allow the user to move or zoom the plot

    Args:
        event: MouseEvent

    Returns:
    """

    global pause
    pause ^= True

class App:
    """Main GUI application"""

    def note(self):
        """Adds the operator notes to the textfile and output window
        to the previous specimen test run

        Args:
            self: Class variables

        Returns:
        """

        f = open(self.moveto, "r", encoding="UTF8").readlines()
        f.insert(3,"\n")
        opnote = "Operator Notes:\t" + self.entry_4.get(1.0,tk.END)
        f.insert(4,opnote)
        fwrite = open(self.moveto, "w", encoding="UTF8")
        for i in range(0,len(f)):
            fwrite.write(f[i])
        fwrite.close()
        fwrite2 = open(self.moveto, "r", encoding="UTF8").read()
        self.T.delete('1.0', tk.END)
        self.T.insert(tk.END, fwrite2)

```

```
    def changedir(self):
        """opens the "Change Directory" window

        Args:
            self: Class variables

        Returns:
        """

        self.dir_path = tk.filedialog.askdirectory()

    def write_record(self):
        """Run routine and data transformation.
        See accelerometer.py for a description of the run routine.

        Modifies the data gathered through the run routine with the input from
        the user entered through the GUI.
        Able to:
            modify DATA in the output text file.
            change the directory.

        Args:
            self: Class variables

        Returns:
        """

        button = "B"
        readard(self.ser, button)
        Fc = open("preferences.txt", "r", encoding="UTF8")
        readlines = Fc.readlines()
        testread = [line.split("\t") for line in readlines]
        Fc.close()
        self.count = int(testread[0][1])-1
        Fread = glob.glob(’IZOD’+str(self.count) + ’*.txt’)
        self.Fileread = Fread[0]
        f = open(self.Fileread, "r", encoding="UTF8").readlines()
        opname = "Operator Name: " + self.entry_1.get() + "\n"
        f.insert(2,opname)
        f.insert(3,"\n")
        if not self.c.get() == "Select your Mass":
            f.insert(4,"Mass Selected:\t" + self.c.get() + "\n")
        else:
            f.insert(4,"Mass Selected:\t" + "N/A" + "\n")

        try:
            f.insert(5,"Specimen Width (mm):\t" + self.entry_2.get() + "\n")
        except:
            f.insert(5,"Specimen Width (mm):\t" + "N/A" + "\n")

        try:
            f.insert(6,"Specimen Depth (mm):\t" + self.entry_6.get() + "\n")
        except:
```

```
            f.insert(6,"Specimen Depth (mm):\t" + "N/A" + "\n")

        f.insert(7,"\n")
        f.insert(8,"UNCORRECTED OUTPUT:\n")

        Height_initial = float(f[12].split("\t")[1])/1000
        Height_end = float(f[13].split("\t")[1])/1000
        self.armradius = self.armradius/1000

        try:
            if self.c.get() == list1[0]:
                mass = self.allmass[0]/1000
                calibheight = self.mass0calibheight/1000
            elif self.c.get() == list1[1]:
                mass = self.allmass[1]/1000
                calibheight = self.mass1calibheight/1000
            elif self.c.get() == list1[2]:
                mass = self.allmass[2]/1000
                calibheight = self.mass2calibheight/1000
            elif self.c.get() == list1[3]:
                mass = self.allmass[3]/1000
                calibheight = self.mass3calibheight/1000

            energy_initial = mass*g*Height_initial
            energy_end = mass*g*Height_end
            calibenergy = mass*g*calibheight

            energy_difference = energy_initial - energy_end + calibenergy

            f.append("CORRECTED OUTPUT:\n")
            f.append("Initial Potential Energy (J):\t" + str(energy_initial) + "\n")
            f.append("Final Potential Energy (J):\t" + str(energy_end) + "\n")
            f.append("Energy Difference (J):\t" + str(energy_difference) + "\n")
        except:
            f.append("Initial Potential Energy (J):\t" + "N/A" + "\n")
            f.append("Final Potential Energy (J):\t" + "N/A" + "\n")
            f.append("Energy Difference (J):\t" + "N/A" + "\n")

        try:
            impact_resistance = energy_difference / (float(self.entry_2.get())/1000)
            f.append("Impact Resistance (J/m):\t" + str(impact_resistance) + "\n")
        except:
            f.append("Impact Resistance (J/m):\t" + "N/A" + "\n")

        try:
            fracture_toughness = energy_difference / (float(self.entry_2.get())/1000*float(self.entry_6.get
    ())/1000*2)
            f.append("Impact Strength (Full break) (J/m^2):\t" + str(fracture_toughness) + "\n")
        except:
            f.append("Impact Strength (Full break) (J/m^2):\t" + "N/A" + "\n")

        f.append("\n")
        f.append("-"*40+"\n")
```

```
        f.append("\n")

        fData = open("DATA.txt","r", encoding="UTF8").read()
        dataList = fData.split('\n')
        dataList2 = []
        for eachLine in dataList:
            if len(eachLine) > 1:
                d1,d2,d3,d4 = eachLine.split(',')
                dataList2.append(d1 + "\t")
                dataList2.append(d2 + "\t")
                dataList2.append(d3 + "\t")
                dataList2.append(d4 + "\n")

        dataList2.insert(0,"T_enc(ms)" + "\t" + "Enc_data(raw)" + "\t" + "T_acc(ms)" + "\t" + "Acc_data(g)" + "\n")
        f = f + dataList2

        fwrite = open(self.Fileread, "w", encoding="UTF8")
        for i in range(0,len(f)):
            fwrite.write(f[i])
        fwrite.close()
        fwrite2 = open(self.Fileread, "r", encoding="UTF8").read()
        self.T.delete('1.0', tk.END)
        self.T.insert(tk.END, fwrite2)
        if self.entry_5.get():
            newname = self.entry_5.get() + "_" + self.Fileread
            self.moveto =  self.dir_path + '/' + newname
            shutil.move(os.path.dirname(os.path.realpath(__file__)) + '/' + self.Fileread, self.moveto)
        elif not self.entry_5.get():
            self.moveto = self.dir_path + '/' + self.Fileread
            shutil.move(os.path.dirname(os.path.realpath(__file__)) + '/' + self.Fileread, self.moveto)

    def _quit(self,master):
        """Quits the application and restarts the kernel and resets the hammer
        to the ZERO position.

        Args:
            master: tkinter root
        Returns:
        """
        button = "C"
        readard(self.ser, button)
        master.quit()
        master.destroy()
        exit()

    def reset_hammer(self):
        """Reset routine.
        See Communication.py for a description.

        Args:
            self: Class variables

```

```
        Returns:
        """

        button = "C"
        readard(self.ser, button)

    def loading_hammer(self):
        """Loading routine.
        See Communication.py for a description.

        Args:
            self: Class variables

        Returns:
        """

        button = "D"
        readard(self.ser, button)

    def calibration(self):
        """Calibration routine.
        See Communication.py for a description.

        Args:
            self: Class variables

        Returns:
        """

        button = "E"
        readard(self.ser, button)

    def __init__(self, master, ser):
        """Framework of the application, each block between dotted lines
        represent a different entity (button, canvas, text entry, etc...)

        Args:
            self: Class variables
            master: Tkinter app
            ser: Arduino COM port

        Returns:
        """
        master.protocol('WM_DELETE_WINDOW', lambda master=master:self._quit(master))
        self.allmass = []
        self.count,self.timesensitivity,self.timefactor,self.armradius,self.maxencstep,self.initialanglestep,self.mass0,self.mass1,self.mass2,self.mass3,self.mass0calibheight,self.mass1calibheight,self.mass2calibheight,self.mass3calibheight = readpref()
        self.count = self.count-1
        self.allmass.append(self.mass0)
        self.allmass.append(self.mass1)
        self.allmass.append(self.mass2)
        self.allmass.append(self.mass3)
```

```python

        self.ser  = ser

        # Creates the frames where each widget is nested
        buttonwidth = 10
        buttonheight = 2
        buttonfont = 10
        titlefont = 20
        padxgen = 5
        padygen = 5
        padxbut = 1
        padybut = 1
        titleframe = tk.Frame(master, borderwidth=3, relief = tk.RIDGE)
        titleframe.pack(fill=tk.BOTH, side=tk.TOP)
        topframe = tk.Frame(master, borderwidth=3, relief = tk.RIDGE)
        topframe.pack(fill=tk.BOTH,expand = True, side=tk.TOP)
        bottomframe = tk.Frame(master, borderwidth=3, relief = tk.RIDGE)
        bottomframe.pack(fill=tk.BOTH, side=tk.LEFT, expand = True)
        bottomframe2 = tk.Frame(master, borderwidth=3, relief = tk.RIDGE)
        bottomframe2.pack(fill=tk.BOTH, side=tk.LEFT, expand = True)

        bottomframe.grid_rowconfigure(0, weight=1)
        bottomframe.grid_rowconfigure(4, weight=1)
        bottomframe.grid_columnconfigure(0, weight=1)
        bottomframe2.grid_rowconfigure(3, weight=1)
        bottomframe2.grid_columnconfigure(3, weight=1)


        try:
            Fread = glob.glob('DATA\\IZOD'+str(self.count) + '*.txt')
            self.Fileread = Fread[0]
        except:
            f = """Waiting for DATA..."""

        # ---------------------------------------------------------------------
        #  The output text box
        try:
            f = open(self.Fileread, "r").read()
        except: pass

        self.scroll = tk.Scrollbar(topframe)
        self.T = tk.Text(topframe, height = 10, width = int(master.winfo_width()/4))
        self.scroll.pack(side = tk.RIGHT, fill = tk.Y)
        self.T.pack(side = tk.RIGHT,fill = tk.BOTH, expand = False, padx = padxgen)
        self.scroll.config(command = self.T.yview)
        self.T.config(yscrollcommand = self.scroll.set)
        self.T.insert(tk.END, f)

        # ---------------------------------------------------------------------
        # The quit button

        self.quitbutton = tk.Button(bottomframe,
                                     text="QUIT", fg="red",font=("bold",buttonfont),
```

```
                        command=lambda master=master:self._quit(master), width = buttonwidth, height =
 buttonheight)
        self.quitbutton.grid(row = 1, columnspan = 1, rowspan=1, column = 1, padx = padxbut, pady = padybut
, sticky = tk.W+tk.E+tk.N+tk.S)

        # -------------------------------------------------------------------
        # The run button

        self.runbutton = tk.Button(bottomframe,text="RUN",font=("bold",buttonfont),
                              command=self.write_record, width = buttonwidth, height = buttonheight)
        self.runbutton.grid(row = 1, columnspan = 1, rowspan=1, column = 2, padx = padxbut, pady = padybut,
 sticky = tk.W+tk.E+tk.N+tk.S)

        # -------------------------------------------------------------------
        # The loading button

        self.clearbutton = tk.Button(bottomframe,
                        text="LOADING",font=("bold",buttonfont),
                        command=self.loading_hammer, width = buttonwidth, height = buttonheight)
        self.clearbutton.grid(row = 2, column = 1, padx = padxbut, pady = padybut, sticky = tk.W+tk.E+tk.N+
tk.S)

        # -------------------------------------------------------------------
        # The reset button

        self.resetbutton = tk.Button(bottomframe,text="RESET",font=("bold",buttonfont),
                                command=self.reset_hammer, width = buttonwidth, height = buttonheight)
        self.resetbutton.grid(row = 2, column = 2, padx = padxbut, pady = padybut, sticky = tk.W+tk.E+tk.N+
tk.S)

        # -------------------------------------------------------------------
        # The calibration button

        self.calibbutton = tk.Button(bottomframe,text="CALIBRATION", fg="green",font=("bold",buttonfont),
                                command=self.calibration, width = buttonwidth, height = buttonheight)
        self.calibbutton.grid(row = 3, column = 1, columnspan=2, padx = padxbut, pady = padybut, sticky =
tk.W+tk.E+tk.N+tk.S)

        # -------------------------------------------------------------------
        # The operator note button

        self.notebbutton = tk.Button(bottomframe2,text="Print", fg="black",font=("bold",buttonfont),
                                command=self.note, width = buttonwidth, height = buttonheight)
        self.notebbutton.grid(row = 1, column = 2, columnspan=1, padx = padxbut, pady = padybut+1, sticky =
 tk.W+tk.N+tk.S)

        # -------------------------------------------------------------------
        # The plot window

        self.canvas = FigureCanvasTkAgg(fig, topframe)
        self.canvas.draw()
        self.canvas.get_tk_widget().pack(side=tk.LEFT, fill= tk.BOTH, expand=True, anchor = tk.NW)

```

```
        self.toolbar = NavigationToolbar2TkAgg(self.canvas,topframe)
        self.toolbar.update()
        self.canvas._tkcanvas.pack(side=tk.TOP, fill=tk.BOTH, expand=True)

        # ---------------------------------------------------------------------
        # The added mass selection box

        self.label_4=tk.Label(bottomframe,text="Added Mass:",font=("bold",buttonfont))
        self.label_4.grid(row = 3, column = 3, sticky = tk.W, padx = padxgen, pady = padygen)
        self.c=tk.StringVar()
        self.droplist=tk.OptionMenu(bottomframe,self.c,*list1)
        self.c.set('Select')
        self.droplist.grid(row = 3, column = 4, sticky = tk.W+tk.E, padx = padxgen, pady = padygen)

        # ---------------------------------------------------------------------
        # The title label

        self.labeltitle=tk.Label(titleframe,text="IZOD Fracture Testing Machine",width=30,font=("bold",
    titlefont))
        self.labeltitle.pack(fill = tk.BOTH)

        # ---------------------------------------------------------------------
        # The change directory menu box

        self.dir_path = os.path.dirname(os.path.realpath(__file__))
        self.dir_path = self.dir_path + "\DATA"
        if not os.path.exists(self.dir_path):
            os.makedirs(self.dir_path)

        self.menu=tk.Menu(master)
        self.filemenu=tk.Menu(self.menu,tearoff = 0)
        self.menu.add_cascade(label="File", menu=self.filemenu)
        self.filemenu.add_command(label="Change Directory",command=self.changedir)
        self.filemenu.add_separator()
        self.filemenu.add_command(label="Exit" , command=lambda master=master:quit(master))
        master.config(menu=self.menu)
        self.menu.config(bg='white',bd=4,relief=tk.RAISED)

        # ---------------------------------------------------------------------
        # The operator name text entry box

        self.labelentry = tk.Label(bottomframe, text="Operator Name:",font=("bold", buttonfont))
        self.entry_1 = tk.Entry(bottomframe)
        self.labelentry.grid(row = 2, column = 3, sticky = tk.W, padx = padxgen, pady = padygen)
        self.entry_1.grid(row = 2, column = 4, sticky = tk.W+tk.E, padx = padxgen, pady = padygen)

        # ---------------------------------------------------------------------
        #  The specimen width text entry box

        self.labelentry2 = tk.Label(bottomframe, text="Specimen Width (mm):",font=("bold", buttonfont))
        self.entry_2 = tk.Entry(bottomframe)
        self.labelentry2.grid(row = 2, column = 5, sticky = tk.W, padx = padxgen, pady = padygen)
        self.entry_2.grid(row = 2, column = 6, sticky = tk.W+tk.E, padx = padxgen, pady = padygen)
```

```

        # ---------------------------------------------------------------------
        # The specimen material text entry box

        self.labelentry3 = tk.Label(bottomframe, text="Specimen Material:",font=("bold", buttonfont))
        self.entry_3 = tk.Entry(bottomframe)
        self.labelentry3.grid(row = 1, column = 5, sticky = tk.W, padx = padxgen, pady = padygen)
        self.entry_3.grid(row = 1, column = 6, sticky = tk.W+tk.E, padx = padxgen, pady = padygen)

        # ---------------------------------------------------------------------
        # The operator note text entry box

        self.labelentry4 = tk.Label(bottomframe2, text="Operator Note:",font=("bold", buttonfont))
        self.entry_4 = ScrolledText(bottomframe2, height = 5, width = 30)
        self.labelentry4.grid(row = 2, column = 1, sticky = tk.W, padx = padxgen, pady = padygen)
        self.entry_4.grid(row = 2, column = 2, rowspan=1, sticky = tk.W+tk.E, padx = padxgen, pady =
    padygen)

        # ---------------------------------------------------------------------
        # The output file name text entry box

        self.labelentry5 = tk.Label(bottomframe, text="Text File Name:",font=("bold", buttonfont))
        self.entry_5 = tk.Entry(bottomframe)
        self.labelentry5.grid(row = 1, column = 3, sticky = tk.W, padx = padxgen, pady = padygen)
        self.entry_5.grid(row = 1, column = 4, sticky = tk.W+tk.E, padx = padxgen, pady = padygen)

        # ---------------------------------------------------------------------
        # The After experiment label

        self.labelentry7 = tk.Label(bottomframe2, text="After Experiment:",font=("bold", buttonfont+3))
        self.labelentry7.grid(row = 1, column = 1, sticky = tk.W, padx = padxgen, pady = padygen)

        # ---------------------------------------------------------------------
        # The specimen depth text entry box

        self.labelentry6 = tk.Label(bottomframe, text="Specimen Depth (mm):",font=("bold", buttonfont))
        self.entry_6 = tk.Entry(bottomframe)
        self.labelentry6.grid(row = 3, column = 5, sticky = tk.W, padx = padxgen, pady = padygen)
        self.entry_6.grid(row = 3, column = 6, sticky = tk.W+tk.E, padx = padxgen, pady = padygen)

def main():
    """The main set up of the application window.
    - Opens the arduino port
    - Starts the tkinter app
    - Starts the plot animation
    - Create a window at the center of the screen

    Args:

    Returns:
    """

    comport = "com8"
```

```
    bd = 250000
    if os.path.isfile("DATA.txt"):
        pass
    elif not os.path.isfile("DATA.txt"):
        dataini = open("DATA.txt","w")
        dataini.write("0,0,0,0")
        dataini.close()
    try:
        ser = serial.Serial(comport, bd)
    except:
        serial.Serial(comport, bd).close()
        ser = serial.Serial(comport, bd)
#         ser = 1
    root = tk.Tk()
    root.title("IZOD")
    root.iconbitmap('logo.ico')
    w = 1500
    h = 800
    ws = root.winfo_screenwidth()
    hs = root.winfo_screenheight()
    x = (ws/2) - (w/2)
    y = (hs/2) - (h/2)
    root.geometry('%dx%d+%d+%d' % (w, h, x, y))
    app = App(root,ser)
    fig.canvas.mpl_connect('button_press_event', onClick)
    ani = animation.FuncAnimation(fig, animate, interval = 1000)
    root.mainloop()



if __name__ == '__main__':
    main()
```

Chapter 18

Appendix H - ASTM Standards

INTERNATIONAL

Designation: D256 – 10$^{\varepsilon 1}$

Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics[1]

This standard is issued under the fixed designation D256; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

ε^1 NOTE—Editorially corrected Figure 2 in October 2015.

1. Scope*

1.1 These test methods cover the determination of the resistance of plastics to "standardized" (see Note 1) pendulum-type hammers, mounted in "standardized" machines, in breaking standard specimens with one pendulum swing (see Note 2). The standard tests for these test methods require specimens made with a milled notch (see Note 3). In Test Methods A, C, and D, the notch produces a stress concentration that increases the probability of a brittle, rather than a ductile, fracture. In Test Method E, the impact resistance is obtained by reversing the notched specimen 180° in the clamping vise. The results of all test methods are reported in terms of energy absorbed per unit of specimen width or per unit of cross-sectional area under the notch. (See Note 4.)

NOTE 1—The machines with their pendulum-type hammers have been "standardized" in that they must comply with certain requirements, including a fixed height of hammer fall that results in a substantially fixed velocity of the hammer at the moment of impact. However, hammers of different initial energies (produced by varying their effective weights) are recommended for use with specimens of different impact resistance. Moreover, manufacturers of the equipment are permitted to use different lengths and constructions of pendulums with possible differences in pendulum rigidities resulting. (See Section 5.) Be aware that other differences in machine design may exist. The specimens are "standardized" in that they are required to have one fixed length, one fixed depth, and one particular design of milled notch. The width of the specimens is permitted to vary between limits.

NOTE 2—Results generated using pendulums that utilize a load cell to record the impact force and thus impact energy, may not be equivalent to results that are generated using manually or digitally encoded testers that measure the energy remaining in the pendulum after impact.

NOTE 3—The notch in the Izod specimen serves to concentrate the stress, minimize plastic deformation, and direct the fracture to the part of the specimen behind the notch. Scatter in energy-to-break is thus reduced. However, because of differences in the elastic and viscoelastic properties of plastics, response to a given notch varies among materials. A measure of a plastic's "notch sensitivity" may be obtained with Test Method D by comparing the energies to break specimens having different radii at the base of the notch.

NOTE 4—Caution must be exercised in interpreting the results of these standard test methods. The following testing parameters may affect test results significantly:

Method of fabrication, including but not limited to processing technology, molding conditions, mold design, and thermal treatments;
Method of notching;
Speed of notching tool;
Design of notching apparatus;
Quality of the notch;
Time between notching and test;
Test specimen thickness,
Test specimen width under notch, and
Environmental conditioning.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 5—These test methods resemble ISO 180:1993 in regard to title only. The contents are significantly different.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing
D883 Terminology Relating to Plastics
D3641 Practice for Injection Molding Test Specimens of Thermoplastic Molding and Extrusion Materials
D4066 Classification System for Nylon Injection and Extrusion Materials (PA)
D5947 Test Methods for Physical Dimensions of Solid Plastics Specimens

[1] These test methods are under the jurisdiction of ASTM Committee D20 on Plastics and are the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

Current edition approved May 1, 2010. Published June 2010. Originally approved in 1926. Last previous edition approved in 2006 as D256 - 06a$^{\varepsilon 1}$. DOI: 10.1520/D0256-10.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

D6110 Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *ISO Standard:*

ISO 180:1993 Plastics—Determination of Izod Impact Strength of Rigid Materials[3]

3. Terminology

3.1 *Definitions*—For definitions related to plastics see Terminology D883.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cantilever*—a projecting beam clamped at only one end.

3.2.2 *notch sensitivity*—a measure of the variation of impact energy as a function of notch radius.

4. Types of Tests

4.1 Four similar methods are presented in these test methods. (See Note 6.) All test methods use the same testing machine and specimen dimensions. There is no known means for correlating the results from the different test methods.

NOTE 6—Previous versions of this test method contained Test Method B for Charpy. It has been removed from this test method and has been published as D6110.

4.1.1 In Test Method A, the specimen is held as a vertical cantilever beam and is broken by a single swing of the pendulum. The line of initial contact is at a fixed distance from the specimen clamp and from the centerline of the notch and on the same face as the notch.

4.1.2 Test Method C is similar to Test Method A, except for the addition of a procedure for determining the energy expended in tossing a portion of the specimen. The value reported is called the "estimated net Izod impact resistance." Test Method C is preferred over Test Method A for materials that have an Izod impact resistance of less than 27 J/m (0.5 ft·lbf/in.) under notch. (See Appendix X4 for optional units.) The differences between Test Methods A and C become unimportant for materials that have an Izod impact resistance higher than this value.

4.1.3 Test Method D provides a measure of the notch sensitivity of a material. The stress-concentration at the notch increases with decreasing notch radius.

4.1.3.1 For a given system, greater stress concentration results in higher localized rates-of-strain. Since the effect of strain-rate on energy-to-break varies among materials, a measure of this effect may be obtained by testing specimens with different notch radii. In the Izod-type test it has been demonstrated that the function, energy-to-break versus notch radius, is reasonably linear from a radius of 0.03 to 2.5 mm (0.001 to 0.100 in.), provided that all specimens have the same type of break. (See 5.8 and 22.1.)

4.1.3.2 For the purpose of this test, the slope, *b* (see 22.1), of the line between radii of 0.25 and 1.0 mm (0.010 and 0.040 in.) is used, unless tests with the 1.0-mm radius give "nonbreak" results. In that case, 0.25 and 0.50-mm (0.010 and 0.020-in.) radii may be used. The effect of notch radius on the impact energy to break a specimen under the conditions of this test is measured by the value *b*. Materials with low values of *b*, whether high or low energy-to-break with the standard notch, are relatively insensitive to differences in notch radius; while the energy-to-break materials with high values of *b* is highly dependent on notch radius. The parameter *b* cannot be used in design calculations but may serve as a guide to the designer and in selection of materials.

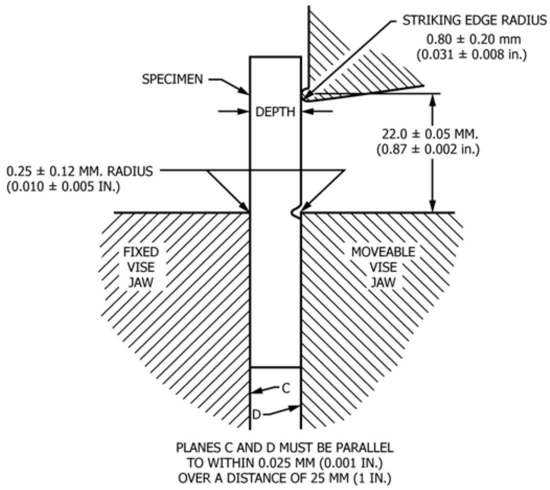


FIG. 1 Relationship of Vise, Specimen, and Striking Edge to Each Other for Izod Test Methods A and C

4.2 Test Method E is similar to Test Method A, except that the specimen is reversed in the vise of the machine 180° to the usual striking position, such that the striker of the apparatus impacts the specimen on the face opposite the notch. (See Fig. 1, Fig. 2.) Test Method E is used to give an indication of the unnotched impact resistance of plastics; however, results obtained by the reversed notch method may not always agree with those obtained on a completely unnotched specimen. (See 28.1.)[4,5]

5. Significance and Use

5.1 Before proceeding with these test methods, reference should be made to the specification of the material being tested. Any test specimen preparation, conditioning, dimensions, and testing parameters covered in the materials specification shall take precedence over those mentioned in these test methods. If there is no material specification, then the default conditions apply.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Supporting data giving results of the interlaboratory tests are available from ASTM Headquarters. Request RR:D20-1021.

[5] Supporting data giving results of the interlaboratory tests are available from ASTM Headquarters. Request RR:D20-1026.

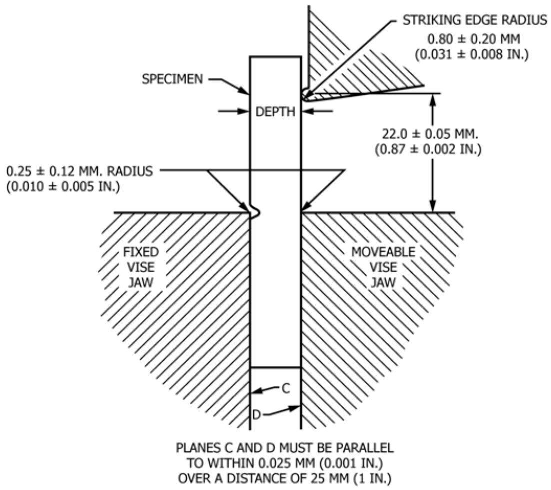


FIG. 2 Relationship of Vise, Specimen, and Striking Edge to Each Other for Test Method E

5.2 The pendulum impact test indicates the energy to break standard test specimens of specified size under stipulated parameters of specimen mounting, notching, and pendulum velocity-at-impact.

5.3 The energy lost by the pendulum during the breakage of the specimen is the sum of the following:

5.3.1 Energy to initiate fracture of the specimen;

5.3.2 Energy to propagate the fracture across the specimen;

5.3.3 Energy to throw the free end (or ends) of the broken specimen ("toss correction");

5.3.4 Energy to bend the specimen;

5.3.5 Energy to produce vibration in the pendulum arm;

5.3.6 Energy to produce vibration or horizontal movement of the machine frame or base;

5.3.7 Energy to overcome friction in the pendulum bearing and in the indicating mechanism, and to overcome windage (pendulum air drag);

5.3.8 Energy to indent or deform plastically the specimen at the line of impact; and

5.3.9 Energy to overcome the friction caused by the rubbing of the striker (or other part of the pendulum) over the face of the bent specimen.

5.4 For relatively brittle materials, for which fracture propagation energy is small in comparison with the fracture initiation energy, the indicated impact energy absorbed is, for all practical purposes, the sum of factors 5.3.1 and 5.3.3. The toss correction (see 5.3.3) may represent a very large fraction of the total energy absorbed when testing relatively dense and brittle materials. Test Method C shall be used for materials that have an Izod impact resistance of less than 27 J/m (0.5 ft·lbf/in.). (See Appendix X4 for optional units.) The toss correction obtained in Test Method C is only an approximation of the toss error, since the rotational and rectilinear velocities may not be the same during the re-toss of the specimen as for the original toss, and because stored stresses in the specimen may have been released as kinetic energy during the specimen fracture.

5.5 For tough, ductile, fiber filled, or cloth-laminated materials, the fracture propagation energy (see 5.3.2) may be large compared to the fracture initiation energy (see 5.3.1). When testing these materials, factors (see 5.3.2, 5.3.5, and 5.3.9) can become quite significant, even when the specimen is accurately machined and positioned and the machine is in good condition with adequate capacity. (See Note 7.) Bending (see 5.3.4) and indentation losses (see 5.3.8) may be appreciable when testing soft materials.

NOTE 7—Although the frame and base of the machine should be sufficiently rigid and massive to handle the energies of tough specimens without motion or excessive vibration, the design must ensure that the center of percussion be at the center of strike. Locating the striker precisely at the center of percussion reduces vibration of the pendulum arm when used with brittle specimens. However, some losses due to pendulum arm vibration, the amount varying with the design of the pendulum, will occur with tough specimens, even when the striker is properly positioned.

5.6 In a well-designed machine of sufficient rigidity and mass, the losses due to factors 5.3.6 and 5.3.7 should be very small. Vibrational losses (see 5.3.6) can be quite large when wide specimens of tough materials are tested in machines of insufficient mass, not securely fastened to a heavy base.

5.7 With some materials, a critical width of specimen may be found below which specimens will appear ductile, as evidenced by considerable drawing or necking down in the region behind the notch and by a relatively high-energy absorption, and above which they will appear brittle as evidenced by little or no drawing down or necking and by a relatively low-energy absorption. Since these methods permit a variation in the width of the specimens, and since the width dictates, for many materials, whether a brittle, low-energy break or a ductile, high energy break will occur, it is necessary that the width be stated in the specification covering that material and that the width be reported along with the impact resistance. In view of the preceding, one should not make comparisons between data from specimens having widths that differ by more than a few mils.

5.8 The type of failure for each specimen shall be recorded as one of the four categories listed as follows:

C =	*Complete Break*—A break where the specimen separates into two or more pieces.
H =	*Hinge Break*—An incomplete break, such that one part of the specimen cannot support itself above the horizontal when the other part is held vertically (less than 90° included angle).
P =	*Partial Break*—An incomplete break that does not meet the definition for a hinge break but has fractured at least 90 % of the distance between the vertex of the notch and the opposite side.
NB =	*Non-Break*—An incomplete break where the fracture extends less than 90 % of the distance between the vertex of the notch and the opposite side.

For tough materials, the pendulum may not have the energy necessary to complete the breaking of the extreme fibers and toss the broken piece or pieces. Results obtained from "non-break" specimens shall be considered a departure from standard and shall not be reported as a standard result. Impact resistance cannot be directly compared for any two materials that experience different types of failure as defined in the test method by this code. Averages reported must likewise be derived from specimens contained within a single failure category. This letter code shall suffix the reported impact identifying the types of failure associated with the reported value. If more than one type of failure is observed for a sample material, then the report will indicate the average impact resistance for each type of failure, followed by the percent of the specimens failing in that manner and suffixed by the letter code.

5.9 The value of the impact methods lies mainly in the areas of quality control and materials specification. If two groups of specimens of supposedly the same material show significantly different energy absorptions, types of breaks, critical widths, or critical temperatures, it may be assumed that they were made of different materials or were exposed to different processing or conditioning environments. The fact that a material shows twice the energy absorption of another under these conditions of test does not indicate that this same relationship will exist under another set of test conditions. The order of toughness may even be reversed under different testing conditions.

NOTE 8—A documented discrepancy exists between manual and digital impact testers, primarily with thermoset materials, including phenolics, having an impact value of less than 54 J/m (1 ft-lb/in.). Comparing data on the same material, tested on both manual and digital impact testers, may show the data from the digital tester to be significantly lower than data from a manual tester. In such cases a correlation study may be necessary to properly define the true relationship between the instruments.

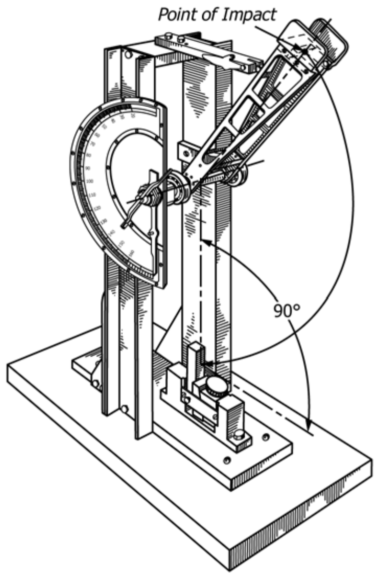


FIG. 3 Cantilever Beam (Izod-Type) Impact Machine

FIG. 4 Jig for Positioning Specimen for Clamping

TEST METHOD A—CANTILEVER BEAM TEST

6. Apparatus

6.1 The machine shall consist of a massive base on which is mounted a vise for holding the specimen and to which is connected, through a rigid frame and bearings, a pendulum-type hammer. (See 6.2.) The machine must also have a pendulum holding and releasing mechanism and a mechanism for indicating the breaking energy of the specimen.

6.2 A jig for positioning the specimen in the vise and graphs or tables to aid in the calculation of the correction for friction and windage also should be included. One type of machine is shown in Fig. 3. One design of specimen-positioning jig is illustrated in Fig. 4. Detailed requirements are given in subsequent paragraphs. General test methods for checking and calibrating the machine are given in Appendix X2. Additional instructions for adjusting a particular machine should be supplied by the manufacturer.

6.3 The pendulum shall consist of a single or multi-membered arm with a bearing on one end and a head, containing the striker, on the other. The arm must be sufficiently rigid to maintain the proper clearances and geometric relationships between the machine parts and the specimen and to minimize vibrational energy losses that are always included in the measured impact resistance. Both simple and compound pendulum designs may comply with this test method.

6.4 The striker of the pendulum shall be hardened steel and shall be a cylindrical surface having a radius of curvature of 0.80 ± 0.20 mm (0.031 ± 0.008 in.) with its axis horizontal and perpendicular to the plane of swing of the pendulum. The line of contact of the striker shall be located at the center of percussion of the pendulum within ±2.54 mm (±0.100 in.) (See Note 9.) Those portions of the pendulum adjacent to the cylindrical striking edge shall be recessed or inclined at a suitable angle so that there will be no chance for other than this cylindrical surface coming in contact with the specimen during the break.

NOTE 9—The distance from the axis of support to the center of percussion may be determined experimentally from the period of small amplitude oscillations of the pendulum by means of the following equation:

$$L = (g/4\pi^2)p^2$$

where:

L = distance from the axis of support to the center of percussion, m or (ft),
g = local gravitational acceleration (known to an accuracy of one part in one thousand), m/s^2 or (ft/s^2),
π = 3.1416 ($4\pi^2$ = 39.48), and
p = period, s, of a single complete swing (to and fro) determined by averaging at least 20 consecutive and uninterrupted swings. The angle of swing shall be less than 5° each side of center.

6.5 The position of the pendulum holding and releasing mechanism shall be such that the vertical height of fall of the striker shall be 610 ± 2 mm (24.0 ± 0.1 in.). This will produce a velocity of the striker at the moment of impact of approximately 3.5 m (11.4 ft)/s. (See Note 10.) The mechanism shall be so constructed and operated that it will release the pendulum without imparting acceleration or vibration to it.

NOTE 10—

$$V = (2gh)^{0.5}$$

where:

V = velocity of the striker at the moment of impact (m/s),
g = local gravitational acceleration (m/s^2), and
h = vertical height of fall of the striker (m).

This assumes no windage or friction.

6.6 The effective length of the pendulum shall be between 0.33 and 0.40 m (12.8 and 16.0 in.) so that the required elevation of the striker may be obtained by raising the pendulum to an angle between 60 and 30° above the horizontal.

6.7 The machine shall be provided with a basic pendulum capable of delivering an energy of 2.7 ± 0.14 J (2.00 ± 0.10 ft·lbf). This pendulum shall be used with all specimens that extract less than 85 % of this energy. Heavier pendulums shall be provided for specimens that require more energy to break. These may be separate interchangeable pendulums or one basic pendulum to which extra pairs of equal calibrated weights may be rigidly attached to opposite sides of the pendulum. It is imperative that the extra weights shall not significantly change the position of the center of percussion or the free-hanging rest point of the pendulum (that would consequently take the machine outside of the allowable calibration tolerances). A range of pendulums having energies from 2.7 to 21.7 J (2 to 16 ft·lbf) has been found to be sufficient for use with most plastic specimens and may be used with most machines. A series of pendulums such that each has twice the energy of the next will be found convenient. Each pendulum shall have an energy within ±0.5 % of its nominal capacity.

6.8 A vise shall be provided for clamping the specimen rigidly in position so that the long axis of the specimen is vertical and at right angles to the top plane of the vise. (See Fig. 1.) This top plane shall bisect the angle of the notch with a tolerance of 0.12 mm (0.005 in.). Correct positioning of the specimen is generally done with a jig furnished with the machine. The top edges of the fixed and moveable jaws shall have a radius of 0.25 ± 0.12 mm (0.010 ± 0.005 in.). For specimens whose thickness approaches the lower limiting value of 3.00 mm (0.118 in.), means shall be provided to prevent the lower half of the specimen from moving during the clamping or testing operations (see Fig. 4 and Note 11.)

NOTE 11—Some plastics are sensitive to clamping pressure; therefore, cooperating laboratories should agree upon some means of standardizing the clamping force. One method is using a torque wrench on the screw of the specimen vise. If the faces of the vise or specimen are not flat and parallel, a greater sensitivity to clamping pressure may be evident. See the calibration procedure in Appendix X2 for adjustment and correction instructions for faulty instruments.

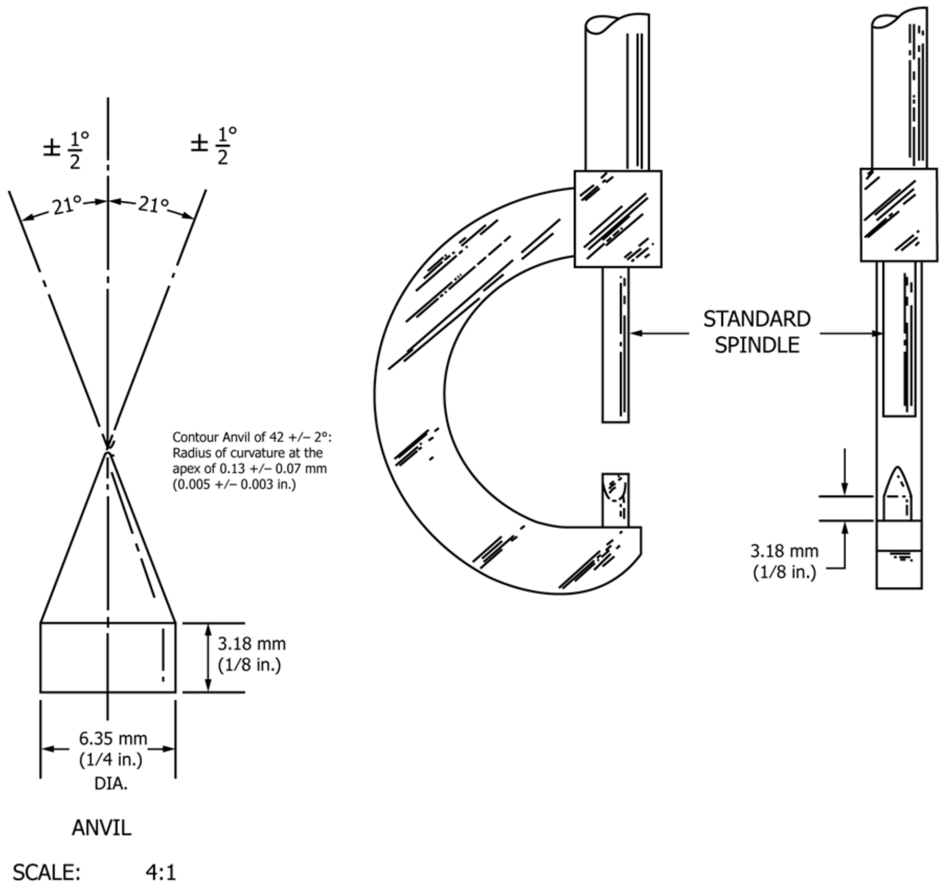
6.9 When the pendulum is free hanging, the striking surface shall come within 0.2 % of scale of touching the front face of a standard specimen. During an actual swing this element shall make initial contact with the specimen on a line 22.00 ± 0.05 mm (0.87 ± 0.002 in.) above the top surface of the vise.

6.10 Means shall be provided for determining the energy expended by the pendulum in breaking the specimen. This is accomplished using either a pointer and dial mechanism or an electronic system consisting of a digital indicator and sensor (typically an encoder or resolver). In either case, the indicated breaking energy is determined by detecting the height of rise of the pendulum beyond the point of impact in terms of energy removed from that specific pendulum. Since the indicated energy must be corrected for pendulum-bearing friction, pointer friction, pointer inertia, and pendulum windage, instructions for making these corrections are included in 10.3 and Annex A1 and Annex A2. If the electronic display does not automatically correct for windage and friction, it shall be incumbent for the operator to determine the energy loss manually. (See Note 12.)

NOTE 12—Many digital indicating systems automatically correct for windage and friction. The equipment manufacturer may be consulted for details concerning how this is performed, or if it is necessary to determine the means for manually calculating the energy loss due to windage and friction.

6.11 The vise, pendulum, and frame shall be sufficiently rigid to maintain correct alignment of the hammer and specimen, both at the moment of impact and during the propagation of the fracture, and to minimize energy losses due to vibration. The base shall be sufficiently massive that the impact will not cause it to move. The machine shall be so designed, constructed, and maintained that energy losses due to pendulum air drag (windage), friction in the pendulum bearings, and friction and inertia in the indicating mechanism are held to a minimum.

6.12 A check of the calibration of an impact machine is difficult to make under dynamic conditions. The basic parameters are normally checked under static conditions; if the machine passes the static tests, then it is assumed to be accurate. The calibration procedure in Appendix X2 should be used to establish the accuracy of the equipment. However, for some machine designs it might be necessary to change the recommended method of obtaining the required calibration measurements. Other methods of performing the required checks may be substituted, provided that they can be shown to result in an equivalent accuracy. Appendix X1 also describes a dynamic test for checking certain features of the machine and specimen.



NOTE 1—These views not to scale.
NOTE 2—Micrometer to be satin-chrome finished with friction thimble.
NOTE 3—Special anvil for micrometer caliper 0 to 25.4 mm range (50.8 mm frame) (0 to 1 in. range (2-in. frame)).
NOTE 4—Anvil to be oriented with respect to frame as shown.
NOTE 5—Anvil and spindle to have hardened surfaces.
NOTE 6—Range: 0 to 25.4 mm (0 to 1 in. in thousandths of an inch).
NOTE 7—Adjustment must be at zero when spindle and anvil are in contact.

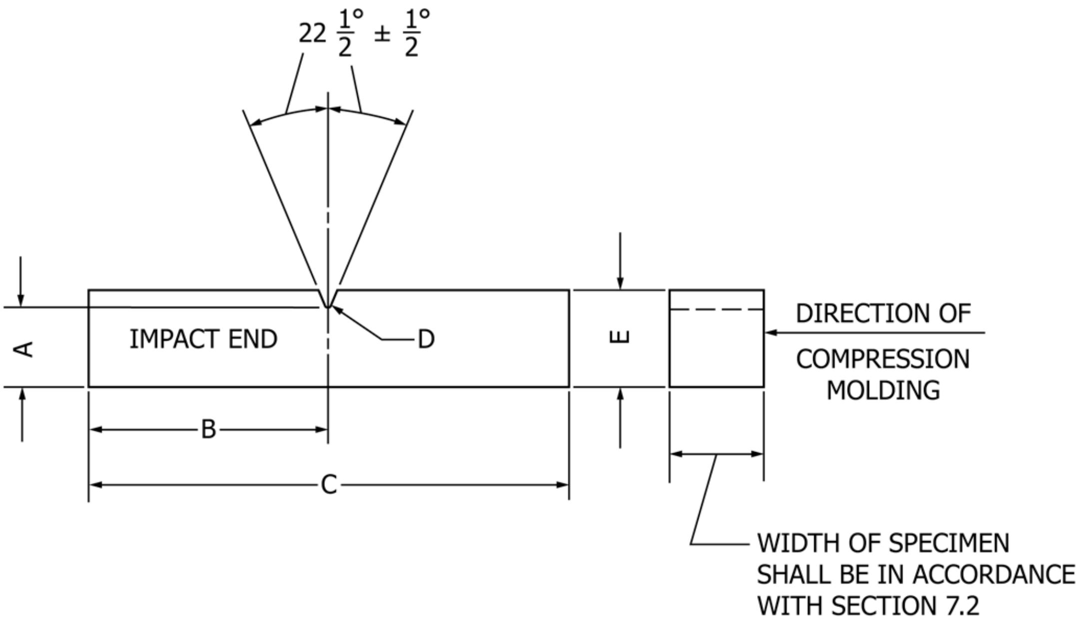
FIG. 5 Early (ca. 1970) Version of a Notch-Depth Micrometer

6.13 *Micrometers*—Apparatus for measurement of the width of the specimen shall comply with the requirements of Test Methods D5947. Apparatus for the measurement of the depth of plastic material remaining in the specimen under the notch shall comply with requirements of Test Methods D5947, provided however that the one anvil or presser foot shall be a tapered blade conforming to the dimensions given in Fig. 5. The opposing anvil or presser foot shall be flat and conforming to Test Methods D5947.

7. Test Specimens

7.1 The test specimens shall conform to the dimensions and geometry of Fig. 6, except as modified in accordance with 7.2, 7.3, 7.4, and 7.5. To ensure the correct contour and conditions of the specified notch, all specimens shall be notched as directed in Section 8.

7.1.1 Studies have shown that, for some materials, the location of the notch on the specimen and the length of the impacted end may have a slight effect on the measured impact



	mm	in.
A	10.16 ± 0.05	0.400 ± 0.002
B	31.8 ± 1.0	1.25 ± 0.04
C	63.5 ± 2.0	2.50 ± 0.08
D	0.25R ± 0.05	0.010R ± 0.002
E	12.70 ± 0.20	0.500 ± 0.008

FIG. 6 Dimensions of Izod-Type Test Specimen

resistance. Therefore, unless otherwise specified, care must be taken to ensure that the specimen conforms to the dimensions shown in Fig. 6 and that it is positioned as shown in Fig. 1 or Fig. 2.

7.2 Molded specimens shall have a width between 3.0 and 12.7 mm (0.118 and 0.500 in.). Use the specimen width as specified in the material specification or as agreed upon between the supplier and the customer. All specimens having one dimension less than 12.7 mm (0.500 in.) shall have the notch cut on the shorter side. Otherwise, all compression-molded specimens shall be notched on the side parallel to the direction of application of molding pressure. (See Fig. 6.)

NOTE 13—While subsection 7.5 requires perpendicular pairs of plane parallel surfaces, the common practice has been to accept the non-parallel drafted surfaces formed when directly injection molding specimens for Izod testing. Users must be aware that employing a trapezoidal section rather than a rectangular section may lead to data shifts and scatter. Unequal stress, created by clamping in the fracture region and dynamic twisting, caused by uneven striking of the specimen are prone to occur when the faces of the specimen are not parallel. Interlaboratory comparisons must clearly spell out the specimen preparation conditions.

7.2.1 Extreme care must be used in handling specimens less than 6.35 mm (0.250 in.) wide. Such specimens must be accurately positioned and supported to prevent twist or lateral buckling during the test. Some materials, furthermore, are very sensitive to clamping pressure (see Note 11).

7.2.2 A critical investigation of the mechanics of impact testing has shown that tests made upon specimens under 6.35 mm (0.250 in.) wide absorb more energy due to crushing, bending, and twisting than do wider specimens. Therefore, specimens 6.35 mm (0.250 in.) or over in width are recommended. The responsibility for determining the minimum specimen width shall be the investigator's, with due reference to the specification for that material.

7.2.3 Material specification should be consulted for preferred molding conditions. The type of mold and molding machine used and the flow behavior in the mold cavity will influence the impact resistance obtained. A specimen taken from one end of a molded plaque may give different results than a specimen taken from the other end. Cooperating laboratories should therefore agree on standard molds conforming to the material specification. Practice D3641 can be used as a guide for general molding tolerances, but refer to the material specification for specific molding conditions.

7.2.4 The impact resistance of a plastic material may be different if the notch is perpendicular to, rather than parallel to, the direction of molding. The same is true for specimens cut with or across the grain of an anisotropic sheet or plate.

7.3 For sheet materials, the specimens shall be cut from the sheet in both the lengthwise and crosswise directions unless otherwise specified. The width of the specimen shall be the thickness of the sheet if the sheet thickness is between 3.0 and 12.7 mm (0.118 and 0.500 in.). Sheet material thicker than 12.7 mm shall be machined down to 12.7 mm. Specimens with a 12.7-mm square cross section may be tested either edgewise or flatwise as cut from the sheet. When specimens are tested flatwise, the notch shall be made on the machined surface if the specimen is machined on one face only. When the specimen is cut from a thick sheet, notation shall be made of the portion of the thickness of the sheet from which the specimen was cut, for example, center, top, or bottom surface.

7.4 The practice of cementing, bolting, clamping, or otherwise combining specimens of substandard width to form a composite test specimen is not recommended and should be avoided since test results may be seriously affected by interface effects or effects of solvents and cements on energy absorption of composite test specimens, or both. However, if Izod test data on such thin materials are required when no other means of preparing specimens are available, and if possible sources of error are recognized and acceptable, the following technique of preparing composites may be utilized.

7.4.1 The test specimen shall be a composite of individual thin specimens totaling 6.35 to 12.7 mm (0.250 to 0.500 in.) in width. Individual members of the composite shall be accurately aligned with each other and clamped, bolted, or cemented together. The composite shall be machined to proper dimensions and then notched. In all such cases the use of composite specimens shall be noted in the report of test results.

7.4.2 Care must be taken to select a solvent or adhesive that will not affect the impact resistance of the material under test. If solvents or solvent-containing adhesives are employed, a conditioning procedure shall be established to ensure complete removal of the solvent prior to test.

7.5 Each specimen shall be free of twist (see Note 14) and shall have mutually perpendicular pairs of plane parallel surfaces and free from scratches, pits, and sink marks. The specimens shall be checked for compliance with these requirements by visual observation against straightedges, squares, and flat plates, and by measuring with micrometer calipers. Any specimen showing observable or measurable departure from one or more of these requirements shall be rejected or machined to the proper size and shape before testing.

NOTE 14—A specimen that has a slight twist to its notched face of 0.05 mm (0.002 in.) at the point of contact with the pendulum striking edge will be likely to have a characteristic fracture surface with considerable greater fracture area than for a normal break. In this case the energy to break and toss the broken section may be considerably larger (20 to 30 %) than for a normal break. A tapered specimen may require more energy to bend it in the vise before fracture.

8. Notching Test Specimens

8.1 Notching shall be done on a milling machine, engine lathe, or other suitable machine tool. Both the feed speed and the cutter speed shall be constant throughout the notching operation (see Note 15). Provision for cooling the specimen with either a liquid or gas coolant is recommended. A single-tooth cutter shall be used for notching the specimen, unless notches of an equivalent quality can be produced with a multi-tooth cutter. Single-tooth cutters are preferred because of the ease of grinding the cutter to the specimen contour and because of the smoother cut on the specimen. The cutting edge shall be carefully ground and honed to ensure sharpness and freedom from nicks and burrs. Tools with no rake and a work relief angle of 15 to 20° have been found satisfactory.

NOTE 15—For some thermoplastics, cutter speeds from 53 to 150 m/min (175 to 490 ft/min) at a feed speed of 89 to 160 mm/min (3.5 to 6.3 in./min) without a water coolant or the same cutter speeds at a feed speed of from 36 to 160 mm/min (1.4 to 6.3 in./min) with water coolant produced suitable notches.

8.2 Specimens may be notched separately or in a group. However, in either case an unnotched backup or "dummy bar" shall be placed behind the last specimen in the sample holder to prevent distortion and chipping by the cutter as it exits from the last test specimen.

8.3 The profile of the cutting tooth or teeth shall be such as to produce a notch of the contour and depth in the test specimen as specified in Fig. 6 (see Note 16). The included angle of the notch shall be 45 ± 1° with a radius of curvature at the apex of 0.25 ± 0.05 mm (0.010 ± 0.002 in.). The plane bisecting the notch angle shall be perpendicular to the face of the test specimen within 2°.

NOTE 16—There is evidence that notches in materials of widely varying physical dimensions may differ in contour even when using the same cutter.

8.4 The depth of the plastic material remaining in the specimen under the notch shall be 10.16 ± 0.05 mm (0.400 ± 0.002 in.). This dimension shall be measured with apparatus in accordance with 6.13. The tapered blade will be fitted to the notch. The specimen will be approximately vertical between the anvils. For specimens with a draft angle, position edge of the non-cavity (wider edge) surface centered on the micrometer's flat circular anvil.

8.5 Cutter speed and feed speed should be chosen appropriate for the material being tested since the quality of the notch may be adversely affected by thermal deformations and stresses induced during the cutting operation if proper conditions are not selected.[6] The notching parameters used shall not alter the physical state of the material such as by raising the temperature of a thermoplastic above its glass transition temperature. In general, high cutter speeds, slow feed rates, and lack of coolant induce more thermal damage than a slow cutter speed, fast feed speed, and the use of a coolant. Too high a feed speed/cutter speed ratio, however, may cause impacting and cracking of the specimen. The range of cutter speed/feed ratios possible to produce acceptable notches can be extended by the use of a suitable coolant. (See Note 17.) In the case of new types of plastics, it is necessary to study the effect of variations in the notching conditions. (See Note 18.)

NOTE 17—Water or compressed gas is a suitable coolant for many plastics.

NOTE 18—Embedded thermocouples, or another temperature measuring device, can be used to determine the temperature rise in the material near the apex of the notch during machining. Thermal stresses induced during the notching operation can be observed in transparent materials by

[6] Supporting data are available from ASTM Headquarters. Request RR:D20-1066.

viewing the specimen at low magnification between crossed polars in monochromatic light.

8.6 A notching operation notches one or more specimens plus the "dummy bar" at a single pass through the notcher. The specimen notch produced by each cutter will be examined after every 500 notching operations or less frequently if experience shows this to be acceptable. The notch in the specimen, made of the material to be tested, shall be inspected and verified. One procedure for the inspection and verification of the notch is presented in Appendix X1. Each type of material being notched must be inspected and verified at that time. If the angle or radius does not fall within the specified limits for materials of satisfactory machining characteristics, then the cutter shall be replaced with a newly sharpened and honed one. (See Note 19.)

NOTE 19—A carbide-tipped or industrial diamond-tipped notching cutter is recommended for longer service life.

9. Conditioning

9.1 *Conditioning*—Condition the test specimens at 23 ± 2°C (73 ± 3.6°F) and 50 ± 10 % relative humidity for not less than 40 h after notching and prior to testing in accordance with Procedure A of Practice D618, unless it can be documented (between supplier and customer) that a shorter conditioning time is sufficient for a given material to reach equilibrium of impact resistance.

9.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications (for example, Specification D4066) call for testing "dry as-molded specimens." Such requirements take precedence over the above routine preconditioning to 50 % relative humidity and require sealing the specimens in water vapor-impermeable containers as soon as molded and not removing them until ready for testing.

9.2 *Test Conditions*—Conduct tests in the standard laboratory atmosphere of 23 ± 2°C (73 ± 3.6°F) and 50 ± 10 % relative humidity, unless otherwise specified in the material specification or by customer requirements. In cases of disagreement, the tolerances shall be ±1°C (±1.8°F) and ± 5 % relative humidity.

10. Procedure

10.1 At least five and preferably ten or more individual determinations of impact resistance must be made on each sample to be tested under the conditions prescribed in Section 9. Each group shall consist of specimens with the same nominal width (±0.13 mm (±0.005 in.)). In the case of specimens cut from sheets that are suspected of being anisotropic, prepare and test specimens from each principal direction (lengthwise and crosswise to the direction of anisotropy).

10.2 Estimate the breaking energy for the specimen and select a pendulum of suitable energy. Use the lightest standard pendulum that is expected to break each specimen in the group with a loss of not more than 85 % of its energy (see Note 20). Check the machine with the proper pendulum in place for conformity with the requirements of Section 6 before starting the tests. (See Appendix X1.)

NOTE 20—Ideally, an impact test would be conducted at a constant test velocity. In a pendulum-type test, the velocity decreases as the fracture progresses. For specimens that have an impact energy approaching the capacity of the pendulum there is insufficient energy to complete the break and toss. By avoiding the higher 15 % scale energy readings, the velocity of the pendulum will not be reduced below 1.3 m/s (4.4 ft/s). On the other hand, the use of too heavy a pendulum would reduce the sensitivity of the reading.

10.3 If the machine is equipped with a mechanical pointer and dial, perform the following operations before testing the specimens. If the machine is equipped with a digital indicating system, follow the manufacturer's instructions to correct for windage and friction. If excessive friction is indicated, the machine shall be adjusted before starting a test.

10.3.1 With the indicating pointer in its normal starting position but without a specimen in the vise, release the pendulum from its normal starting position and note the position the pointer attains after the swing as one reading of Factor *A*.

10.3.2 Without resetting the pointer, raise the pendulum and release again. The pointer should move up the scale an additional amount. Repeat (10.3.2) until a swing causes no additional movement of the pointer and note the final reading as one reading of Factor *B* (see Note 21).

10.3.3 Repeat the preceding two operations several times and calculate and record the average *A* and *B* readings.

NOTE 21—Factor *B* is an indication of the energy lost by the pendulum to friction in the pendulum bearings and to windage. The difference *A* – *B* is an indication of the energy lost to friction and inertia in the indicating mechanism. However, the actual corrections will be smaller than these factors, since in an actual test the energy absorbed by the specimen prevents the pendulum from making a full swing. Therefore, the indicated breaking energy of the specimen must be included in the calculation of the machine correction before determining the breaking energy of the specimen (see 10.8). The *A* and *B* values also provide an indication of the condition of the machine.

10.3.4 If excessive friction is indicated, the machine shall be adjusted before starting a test.

10.4 Check the specimens for conformity with the requirements of Sections 7, 8, and 10.1.

10.5 Measure and record the width of each specimen after notching to the nearest 0.025 mm (0.001 in.). Measure the width in one location adjacent to the notch centered about the anticipated fracture plane.

10.6 Measure and record the depth of material remaining in the specimen under the notch of each specimen to the nearest 0.025 mm (0.001 in.). The tapered blade will be fitted to the notch. The specimen will be approximately vertical between the anvils. For specimens with a draft angle, position edge of the non-cavity (wider edge) surface centered on the micrometer's flat circular anvil.

10.7 Position the specimen precisely (see 6.7) so that it is rigidly, but not too tightly (see Note 11), clamped in the vise. Pay special attention to ensure that the "impacted end" of the specimen as shown and dimensioned in Fig. 6 is the end projecting above the vise. Release the pendulum and record the indicated breaking energy of the specimen together with a description of the appearance of the broken specimen (see failure categories in 5.8).

10.8 Subtract the windage and friction correction from the indicated breaking energy of the specimen, unless determined automatically by the indicating system (that is, digital display or computer). If a mechanical dial and pointer is employed, use the *A* and *B* factors and the appropriate tables or the graph described in Annex A1 and Annex A2 to determine the correction. For those digital systems that do not automatically compensate for windage and friction, follow the manufacturer's procedure for performing this correction.

10.8.1 In other words, either manually or automatically, the windage and friction correction value is subtracted from the uncorrected, indicated breaking energy to obtain the new breaking energy. Compare the net value so found with the energy requirement of the hammer specified in 10.2. If a hammer of improper energy was used, discard the result and make additional tests on new specimens with the proper hammer. (See Annex A1 and Annex A2.)

10.9 Divide the net value found in 10.8 by the measured width of the particular specimen to obtain the impact resistance under the notch in J/m (ft·lbf/in.). If the optional units of kJ/m^2 ($ft·lbf/in.^2$) are used, divide the net value found in 10.8 by the measured width and depth under the notch of the particular specimen to obtain the impact strength. The term, "depth under the notch," is graphically represented by Dimension A in Fig. 6. Consequently, the cross-sectional area (width times depth under the notch) will need to be reported. (See Appendix X4.)

10.10 Calculate the average Izod impact resistance of the group of specimens. However, only values of specimens having the same nominal width and type of break may be averaged. Values obtained from specimens that did not break in the manner specified in 5.8 shall not be included in the average. Also calculate the standard deviation of the group of values.

11. Report

11.1 Report the following information:

11.1.1 The test method used (Test Method A, C, D, or E),

11.1.2 Complete identification of the material tested, including type source, manufacturer's code number, and previous history,

11.1.3 A statement of how the specimens were prepared, the testing conditions used, the number of hours the specimens were conditioned after notching, and for sheet materials, the direction of testing with respect to anisotropy, if any,

11.1.4 The capacity of the pendulum in joules, or foot pound-force, or inch pound-force,

11.1.5 The width and depth under the notch of each specimen tested,

11.1.6 The total number of specimens tested per sample of material,

11.1.7 The type of failure (see 5.8),

11.1.8 The impact resistance must be reported in J/m (ft·lbf/in.); the optional units of kJ/m^2 ($ft·lbf/in.^2$) may also be required (see 10.9),

11.1.9 The number of those specimens that resulted in failures which conforms to each of the requirement categories in 5.8,

11.1.10 The average impact resistance and standard deviation (in J/m (ft·lbf/in.)) for those specimens in each failure category, except non-break as presented in 5.8. Optional units (kJ/m^2 ($ft·lbf/in.^2$)) may also need to be reported (see Appendix X4), and

11.1.11 The percent of specimens failing in each category suffixed by the corresponding letter code from 5.8.

TEST METHOD C—CANTILEVER BEAM TEST FOR MATERIALS OF LESS THAN 27 J/m (0.5 ft·lbf/in.)

12. Apparatus

12.1 The apparatus shall be the same as specified in Section 6.

13. Test Specimens

13.1 The test specimens shall be the same as specified in Section 7.

14. Notching Test Specimens

14.1 Notching test specimens shall be the same as specified in Section 8.

15. Conditioning

15.1 Specimen conditioning and test environment shall be in accordance with Section 9.

16. Procedure

16.1 The procedure shall be the same as in Section 10 with the addition of a procedure for estimating the energy to toss the broken specimen part.

16.1.1 Make an estimate of the magnitude of the energy to toss each different type of material and each different specimen size (width). This is done by repositioning the free end of the broken specimen on the clamped portion and striking it a second time with the pendulum released in such a way as to impart to the specimen approximately the same velocity it had attained during the test. This is done by releasing the pendulum from a height corresponding to that to which it rose following the breakage of the test specimen. The energy to toss is then considered to be the difference between the reading previously described and the free swing reading obtained from this height. A reproducible method of starting the pendulum from the proper height must be devised.

17. Report

17.1 Report the following information:

17.1.1 Same as 11.1.1,

17.1.2 Same as 11.1.2,

17.1.3 Same as 11.1.3,

17.1.4 Same as 11.1.4,

17.1.5 Same as 11.1.5,

17.1.6 Same as 11.1.6,

17.1.7 The average reversed notch impact resistance, J/m (ft·lbf/in.) (see 5.8 for failure categories),

17.1.8 Same as 11.1.8,

17.1.9 Same as 11.1.9,

17.1.10 Same as 11.1.10, and

17.1.11 Same as 11.1.11.

17.1.12 The estimated toss correction, expressed in terms of joule (J) or foot pound-force (ft·lbf).

17.1.13 The difference between the Izod impact energy and the toss correction energy is the net Izod energy. This value is divided by the specimen width (at the base of notch) to obtain the net Izod impact resistance for the report.

TEST METHOD D—NOTCH RADIUS SENSITIVITY TEST

18. Apparatus

18.1 The apparatus shall be the same as specified in Section 6.

19. Test Specimens

19.1 The test specimens shall be the same as specified in Section 7. All specimens must be of the same nominal width, preferably 6.35-mm (0.25-in.).

20. Notching Test Specimens

20.1 Notching shall be done as specified in Section 8 and Fig. 6, except those ten specimens shall be notched with a radius of 0.25 mm (0.010 in.) and ten specimens with a radius of 1.0 mm (0.040 in.).

21. Conditioning

21.1 Specimen conditioning and test environment shall be in accordance with Section 9.

22. Procedure

22.1 Proceed in accordance with Section 10, testing ten specimens of each notch radius.

22.2 The average impact resistance of each group shall be calculated, except that within each group the type of break must be homogeneously C, H, C and H, or P.

22.3 If the specimens with the 0.25-mm (0.010-in.) radius notch do not break, the test is not applicable.

22.4 If any of ten specimens tested with the 1.0-mm (0.040-in.) radius notch fail as in category NB, non-break, the notch sensitivity procedure cannot be used without obtaining additional data. A new set of specimens should be prepared from the same sample, using a 0.50-mm (0.020-in.) notch radius and the procedure of 22.1 and 22.2 repeated.

23. Calculation

23.1 Calculate the slope of the line connecting the values for impact resistance for 0.25 and 1.0-mm notch radii or (0.010 and 0.040-in. notch radii) by the equation presented as follows. (If a 0.500-mm (0.020-in.) notch radius is substituted, adjust the calculation accordingly.)

$$b = (E_2 - E_1)/(R_2 - R_1)$$

where:

E_2 = average impact resistance for the larger notch, J/m of notch,
E_1 = average impact resistance for the smaller notch, J/m of notch,
R_2 = radius of the larger notch, mm, and
R_1 = radius of the smaller notch, mm.

Example:

$$E_{1.0} = 330.95 \text{ J/m}; E_{0.25} = 138.78 \text{ J/m}$$
$$b = (330.95 - 138.78 \text{ J/m})/(1.00 - 0.25 \text{ mm})$$
$$b = 192.17 \text{ J/m } 0.75 \text{ mm} = 256.23 \text{ J/m}$$
of notch per mm of radius

24. Report

24.1 Report the following information:
24.1.1 Same as 11.1.1,
24.1.2 Same as 11.1.2,
24.1.3 Same as 11.1.3,
24.1.4 Same as 11.1.4,
24.1.5 Same as 11.1.5,
24.1.6 Same as 11.1.6,
24.1.7 The average reversed notch impact resistance, in J/m (ft·lbf/in.) (see 5.8 for failure categories),
24.1.8 Same as 11.1.8,
24.1.9 Same as 11.1.9,
24.1.10 Same as 11.1.10, and
24.1.11 Same as 11.1.11.
24.1.12 Report the average value of *b* with its units, and the average Izod impact resistance for a 0.25-mm (0.010-in.) notch.

TEST METHOD E—CANTILEVER BEAM REVERSED NOTCH TEST

25. Apparatus

25.1 The apparatus shall be the same as specified in Section 6.

26. Test Specimens

26.1 The test specimen shall be the same as specified in Section 7.

27. Notching Test Specimens

27.1 Notch the test specimens in accordance with Section 8.

28. Conditioning

28.1 Specimen conditioning and test environment shall be in accordance with Section 9.

29. Procedure

29.1 Proceed in accordance with Section 10, except clamp the specimen so that the striker impacts it on the face opposite the notch, hence subjecting the notch to compressive rather than tensile stresses during impact (see Fig. 2 and Note 22, Note 23, and Note 24).

NOTE 22—The reversed notch test employs a standard 0.25-mm (0.010-in.) notch specimen to provide an indication of unnotched impact resistance. Use of the reversed notch test obviates the need for machining unnotched specimens to the required 10.2 ± 0.05-mm (0.400 ± 0.002-in.) depth before testing and provides the same convenience of specimen mounting as the standard notch tests (Test Methods A and C).

NOTE 23—Results obtained by the reversed notch test may not always agree with those obtained on unnotched bars that have been machined to the 10.2-mm (0.400-in.) depth requirement. For some materials, the

TABLE 1 Precision Data, Test Method A—Notched Izod

NOTE 1—Values in ft·lbf/in. of width (J/m of width).

NOTE 2—See Footnote 10.

Material	Average	S_r[A]	S_R[B]	I_r[C]	I_R[D]	Number of Laboratories
Phenolic	0.57 (30.4)	0.024 (1.3)	0.076 (4.1)	0.06 (3.2)	0.21 (11.2)	19
Acetal	1.45 (77.4)	0.075 (4.0)	0.604 (32.3)	0.21 (11.2)	1.70 (90.8)	9
Reinforced nylon	1.98 (105.7)	0.083 (4.4)	0.245 (13.1)	0.23 (12.3)	0.69 (36.8)	15
Polypropylene	2.66 (142.0)	0.154 (8.2)	0.573 (30.6)	0.43 (23.0)	1.62 (86.5)	24
ABS	10.80 (576.7)	0.136 (7.3)	0.585 (31.2)	0.38 (20.3)	1.65 (88.1)	25
Polycarbonate	16.40 (875.8)	0.295 (15.8)	1.056 (56.4)	0.83 (44.3)	2.98 (159.1)	25

[A] S_r = within-laboratory standard deviation of the average.
[B] S_R = between-laboratories standard deviation of the average.
[C] $I_r = 2.83\ S_r$.
[D] $I_R = 2.83\ S_R$.

effects arising from the difference in the clamped masses of the two specimen types during test, and those attributable to a possible difference in toss energies ascribed to the broken ends of the respective specimens, may contribute significantly to a disparity in test results.

NOTE 24—Where materials are suspected of anisotropy, due to molding or other fabricating influences, notch reversed notch specimens on the face opposite to that used for the standard Izod test; that is, present the same face to the impact blow.

30. Report

30.1 Report the following information:

30.1.1 Same as 11.1.1,

30.1.2 Same as 11.1.2,

30.1.3 Same as 11.1.3,

30.1.4 Same as 11.1.4,

30.1.5 Same as 11.1.5,

30.1.6 Same as 11.1.6,

30.1.7 The average reversed notch impact resistance, J/m (ft·lbf/in.) (see 5.8 for failure categories),

30.1.8 Same as 11.1.8,

30.1.9 Same as 11.1.9,

30.1.10 Same as 11.1.10, and

30.1.11 Same as 11.1.11.

31. Precision and Bias

31.1 Table 1 and Table 2 are based on a round robin in accordance with Practice E691. For each material, all the test bars were prepared at one source, except for notching. Each participating laboratory notched the bars that they tested. Table 1 and Table 2 are presented on the basis of a test result being the average for five specimens. In the round robin each laboratory tested, on average, nine specimens of each material.

31.2 Table 3 is based on a round robin[5] involving five materials tested by seven laboratories. For each material, all the samples were prepared at one source, and the individual specimens were all notched at the same laboratory. Table 3 is presented on the basis of a test result being the average for five specimens. In the round robin, each laboratory tested ten specimens of each material.

31.3 *Concept of I_r and I_R*—If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing five specimens. (**Warning—**The following explanations of I_r and I_R (see 31.3 – 31.3.3) are only intended to present a meaningful way of considering the precision of this test method. The data in Tables 1-3 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and may not be representative of other lots, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles of 31.3 – 31.3.3 would then be valid for such data.)

31.3.1 *Repeatability, I_r (Comparing Two Test Results for the Same Material, Obtained by the Same Operator Using the Same Equipment on the Same Day)*—The two test results should be judged not equivalent if they differ by more than the I_r value for that material.

31.3.2 *Reproducibility, I_R (Comparing Two Test Results for the Same Material, Obtained by Different Operators Using Different Equipment on Different Days)*—The two test results should be judged not equivalent if they differ by more than the I_R value for that material.

31.3.3 Any judgment in accordance with 31.3.1 and 31.3.2 would have an approximate 95 % (0.95) probability of being correct.

31.4 *Bias*—There is no recognized standards by which to estimate bias of these test methods.

NOTE 25—Numerous changes have occurred since the collection of the original round-robin data in 1973. Consequently, a new task group has been formed to evaluate a precision and bias statement for the latest revision of these test methods.

32. Keywords

32.1 impact resistance; Izod impact; notch sensitivity; notched specimen; reverse notch impact

TABLE 2 Precision Data, Test Method C—Notched Izod

NOTE 1—Values in ft·lbf/in. of width (J/m of width).

NOTE 2—See Footnote 10.

Material	Average	S_r[A]	S_R[B]	I_r[C]	I_R[D]	Number of Laboratories
Phenolic	0.45 (24.0)	0.038 (2.0)	0.129 (6.9)	0.10 (5.3)	0.36 (19.2)	15

[A] S_r = within-laboratory standard deviation of the average.
[B] S_R = between-laboratories standard deviation of the average.
[C] $I_r = 2.83\ S_r$.
[D] $I_R = 2.83\ S_R$.

TABLE 3 Precision Data, Test Method E—Reversed Notch Izod

NOTE 1—Values in ft·lbf/in. of width (J/m of width).

NOTE 2—See Footnote 8.

Material	Average	S_r[A]	S_R[B]	I_r[C]	I_R[D]
Acrylic sheet, unmodified	3.02 (161.3)	0.243 (13.0)	0.525 (28.0)	0.68 (36.3)	0.71 (37.9)
Premix molding compounds laminate	6.11 (326.3)	0.767 (41.0)	0.786 (42.0)	2.17 (115.9)	2.22 (118.5)
acrylic, injection molded	10.33 (551.6)	0.878 (46.9)	1.276 (68.1)	2.49 (133.0)	3.61 (192.8)
compound (SMC) laminate	11.00 (587.4)	0.719 (38.4)	0.785 (41.9)	2.03 (108.4)	2.22 (118.5)
Preformed mat laminate	19.43 (1037.6)	0.960 (51.3)	1.618 (86.4)	2.72 (145.2)	4.58 (244.6)

[A] S_r = within-laboratory standard deviation of the average.
[B] S_R = between-laboratories standard deviation of the average.
[C] $I_r = 2.83\ S_r$.
[D] $I_R = 2.83\ S_R$.

ANNEXES

(Mandatory Information)

A1. INSTRUCTIONS FOR THE CONSTRUCTION OF A WINDAGE AND FRICTION CORRECTION CHART

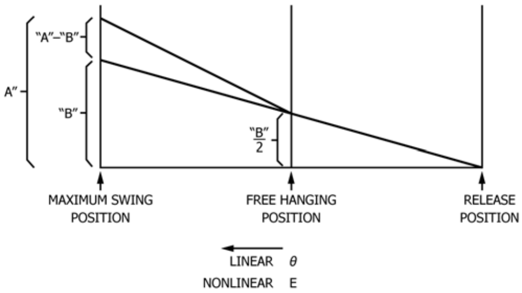


FIG. A1.1 Method of Construction of a Windage and Friction Correction Chart

A1.1 The construction and use of the chart herein described is based upon the assumption that the friction and windage losses are proportional to the angle through which these loss torques are applied to the pendulum. Fig. A1.1 shows the assumed energy loss versus the angle of the pendulum position during the pendulum swing. The correction chart to be described is principally the left half of Fig. A1.1. The windage and friction correction charts should be available from commercial testing machine manufacturers. The energy losses designated as *A* and *B* are described in 10.3.

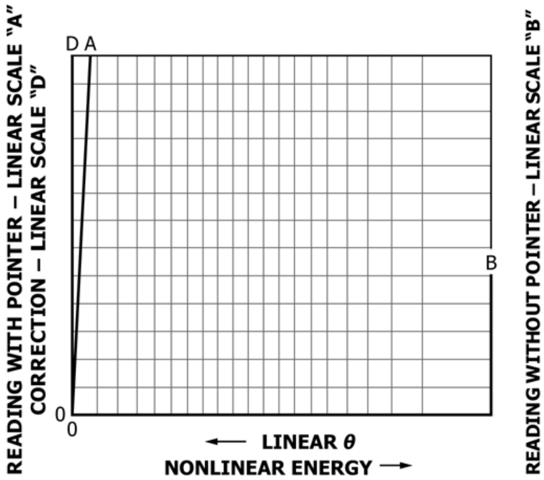


FIG. A1.2 Sample Windage and Friction Correction Chart

A1.2 Start the construction of the correction chart (see Fig. A1.2) by laying off to some convenient linear scale on the abscissa of a graph the angle of pendulum position for the portion of the swing beyond the free hanging position. For convenience, place the free hanging reference point on the right end of the abscissa with the angular displacement increasing linearly to the left. The abscissa is referred to as Scale C. Although angular displacement is the quantity to be represented linearly on the abscissa, this displacement is more conveniently expressed in terms of indicated energy read from the machine dial. This yields a nonlinear Scale C with indicated pendulum energy increasing to the right.

A1.3 On the right-hand ordinate lay off a linear Scale B starting with zero at the bottom and stopping at the maximum expected pendulum friction and windage value at the top.

A1.4 On the left ordinate construct a linear Scale D ranging from zero at the bottom to 1.2 times the maximum ordinate value appearing on Scale B, but make the scale twice the scale used in the construction of Scale B.

A1.5 Adjoining Scale D draw a curve OA that is the focus of points whose coordinates have equal values of energy correction on Scale D and indicated energy on Scale C. This curve is referred to as Scale A and utilizes the same divisions and numbering system as the adjoining Scale D.

A1.6 *Instructions for Using Chart:*

A1.6.1 Locate and mark on Scale A the reading A obtained from the free swing of the pendulum with the pointer prepositioned in the free hanging or maximum indicated energy position on the dial.

A1.6.2 Locate and mark on Scale B the reading B obtained after several free swings with the pointer pushed up close to the zero indicated energy position of the dial by the pendulum in accordance with instructions in 10.3.

A1.6.3 Connect the two points thus obtained by a straight line.

A1.6.4 From the indicated impact energy on Scale C project up to the constructed line and across to the left to obtain the correction for windage and friction from Scale D.

A1.6.5 Subtract this correction from the indicated impact reading to obtain the energy delivered to the specimen.

A2. PROCEDURE FOR THE CALCULATION OF WINDAGE AND FRICTION CORRECTION

A2.1 The procedure for the calculation of the windage and friction correction in this annex is based on the equations developed by derivation in Appendix X3. This procedure can be used as a substitute for the graphical procedure described in Annex A1 and is applicable to small electronic calculator and computer analysis.

A2.2 Calculate L, the distance from the axis of support to the center of percussion as indicated in 6.3. (It is assumed here that the center of percussion is approximately the same as the center of gravity.)

A2.3 Measure the maximum height, h_M, of the center of percussion (center of gravity) of the pendulum at the start of the test as indicated in X2.16.

A2.4 Measure and record the energy correction, E_A, for windage of the pendulum plus friction in the dial, as determined with the first swing of the pendulum with no specimen in the testing device. This correction must be read on the energy scale, E_M, appropriate for the pendulum used.

A2.5 Without resetting the position of the indicator obtained in A2.4, measure the energy correction, E_B, for pendulum windage after two additional releases of the pendulum with no specimen in the testing device.

A2.6 Calculate β_{max} as follows:

$$\beta_{max} = \cos^{-1}\{1 - [(h_M/L)(1 - E_A/E_M)]\}$$

where:

E_A = energy correction for windage of pendulum plus friction in dial, J (ft·lbf),
E_M = full-scale reading for pendulum used, J (ft·lbf),
L = distance from fulcrum to center of gravity of pendulum, m (ft),
h_M = maximum height of center of gravity of pendulum at start of test, m (ft), and
β_{max} = maximum angle pendulum will travel with one swing of the pendulum.

A2.7 Measure specimen breaking energy, E_s, J (ft·lbf).

A2.8 Calculate β for specimen measurement E_s as:

$$\beta = \cos^{-1}\{1 - [(h_M/L)(1 - E_s/E_M)]\}$$

where:

β = angle pendulum travels for a given specimen, and
E_s = dial reading breaking energy for a specimen, J (ft·lbf).

A2.9 Calculate total correction energy, E_{TC}, as:

$$E_{TC} = (E_A - (E_B/2))(\beta/\beta_{max}) + (E_B/^2)$$

where:

E_{TC} = total correction energy for the breaking energy, E_s, of a specimen, J (ft·lbf), and

E_B = energy correction for windage of the pendulum, J (ft·lbf).

A2.10 Calculate the impact resistance using the following formula:

$$I_s = (E_s - E_{TC})/t$$

where:

I_s = impact resistance of specimen, J/m (ft·lbf/in.) of width, and

t = width of specimen or width of notch, m (in.).

APPENDIXES

(Nonmandatory Information)

X1. PROCEDURE FOR THE INSPECTION AND VERIFICATION OF NOTCH

X1.1 The purpose of this procedure is to describe the microscopic method to be used for determining the radius and angle of the notch. These measurements could also be made using a comparator if available.

NOTE X1.1—The notch shall have a radius of 0.25 ± 0.05 mm (0.010 ± 0.002 in.) and an angle of 45 ± 1°.

X1.2 *Apparatus:*

X1.2.1 *Optical Device* with minimum magnification of 60×, Filar glass scale and camera attachment.

X1.2.2 *Transparent Template,* (will be developed in this procedure).

X1.2.3 *Ruler.*

X1.2.4 *Compass.*

X1.2.5 *Plastic 45°–45°–90° Drafting Set Squares (Triangles).*

X1.3 A transparent template must be developed for each magnification and for each microscope used. It is preferable that each laboratory standardize on one microscope and one magnification. It is not necessary for each laboratory to use the same magnification because each microscope and camera combination has somewhat different blowup ratios.

X1.3.1 Set the magnification of the optical device at a suitable magnification with a minimum magnification of 60×.

X1.3.2 Place the Filar glass slide on the microscope platform. Focus the microscope so the most distinct image of the Filar scale is visible.

X1.3.3 Take a photograph of the Filar scale (see Fig. X1.1).

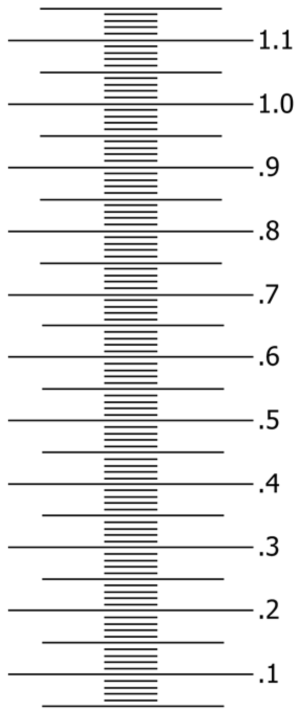
X1.3.4 Create a template similar to that shown in Fig. X1.2.

X1.3.4.1 Find the approximate center of the piece of paper.

X1.3.4.2 Draw a set of perpendicular coordinates through the center point.

X1.3.4.3 Draw a family of concentric circles that are spaced according to the dimensions of the Filar scale.

X1.3.4.4 This is accomplished by first setting a mechanical compass at a distance of 0.1 mm (0.004 in.) as referenced by the magnified photograph of the Filar eyepiece. Subsequent circles shall be spaced 0.02 mm apart (0.001 in.), as rings with the outer ring being 0.4 mm (0.016 in.) from the center.



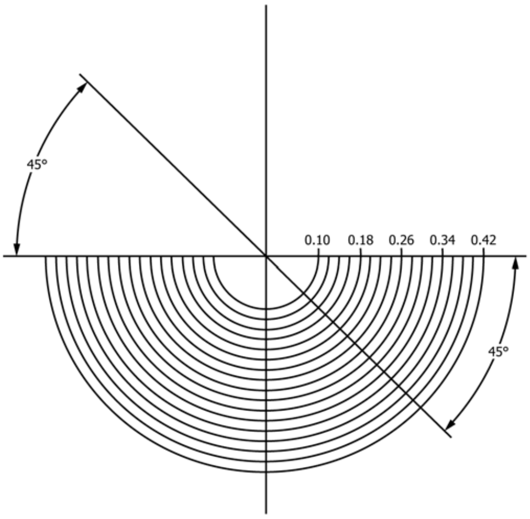
NOTE 1—100× reference.

NOTE 2—0.1 mm major scale; 0.01 mm minor scale.

FIG. X1.1 Filar Scale

X1.3.5 Photocopy the paper with the concentric circles to make a transparent template of the concentric circles.

X1.3.6 Construct Fig. X1.3 by taking a second piece of paper and find it's approximate center and mark this point. Draw one line through this center point. Label this line zero degree (0°). Draw a second line perpendicular to the first line through this center point. Label this line "90°." From the center draw a line that is 44 degrees relative to the "0°." Label the line "44°." Draw another line at 46°. Label the line "46°."



NOTE 1—Magnification = 100×.

FIG. X1.2 Example of Transparent Template for Determining Radius of Notch

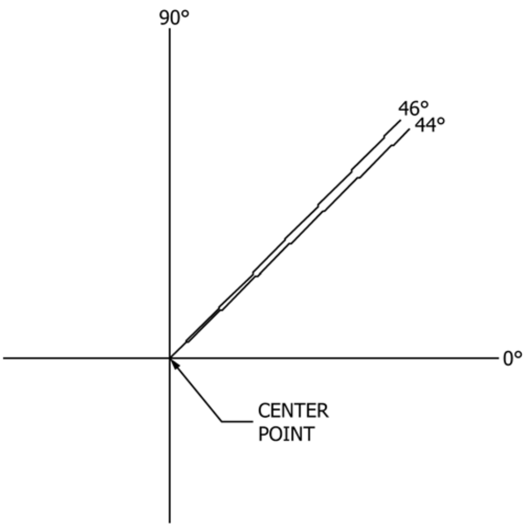


FIG. X1.3 Example of Transparent Template for Determining Angle of Notch

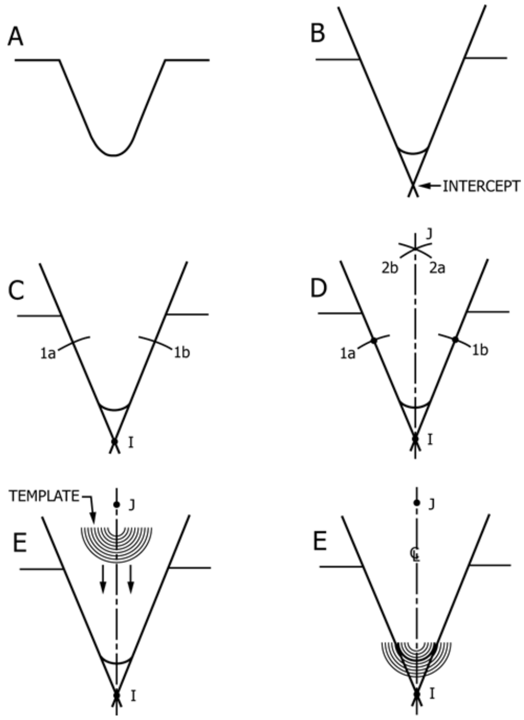


FIG. X1.4 Determination of Notching Radius

X1.4 Place a microscope glass slide on the microscope platform. Place the notched specimen on top of the slide. Focus the microscope. Move the specimen around using the platform adjusting knobs until the specimen's notch is centered and near the bottom of the viewing area. Take a picture of the notch.

X1.4.1 *Determination of Notching Radius* (see Fig. X1.4):

X1.4.1.1 Place the picture on a sheet of paper. Position the picture so that bottom of the notch in the picture faces downwards and is about 64 mm (2.5 in.) from the bottom of the paper. Tape the picture down to the paper.

X1.4.1.2 Draw two lines along the sides of the notch projecting down to a point where they intersect below Notch Point I (see Fig. X1.4).

X1.4.1.3 Open the compass to about 51 mm (2 in.). Using Point I as a reference, draw two arcs intersecting both sides of the notch (see Fig. X1.4). These intersections are called 1a and 1b.

X1.4.1.4 Close the compass to about 38 mm (1.5 in.). Using Point 1a as the reference point draw an arc (2a) above the notch, draw a second arc (2b) that intersects with arc 2a at Point J. Draw a line between *I* and *J*. This establishes the centerline of the notch (see Fig. X1.4).

X1.4.1.5 Place the transparent template on top of the picture and align the center of the concentric circles with the drawn centerline of the notch (see Fig. X1.4).

X1.4.1.6 Slide the template down the centerline of the notch until one concentric circle touches both sides of the notch. Record the radius of the notch and compare it against the ASTM limits of 0.2 to 0.3 mm (0.008 to 0.012 in.).

X1.4.1.7 Examine the notch to ensure that there are no flat spots along the measured radius.

X1.4.2 *Determination of Notch Angle:*

X1.4.2.1 Place transparent template for determining notch angle (see Fig. X1.3) on top of the photograph attached to the sheet of paper. Rotate the picture so that the notch tip is pointed towards you. Position the center point of the template on top of Point I established in 0° axis of the template with the right side straight portion of the notch. Check the left side straight portion of the notch to ensure that this portion falls between the 44 and 46° degree lines. If not, replace the blade.

X1.5 A picture of a notch shall be taken at least every 500 notches or if a control sample gives a value outside its three-sigma limits for that test.

X1.6 If the notch in the control specimen is not within the requirements, a picture of the notching blade should be taken and analyzed by the same procedure used for the specimen notch. If the notching blade does not meet ASTM requirements or shows damage, it should be replaced with a new blade which has been checked for proper dimensions.

X1.7 It is possible that the notching cutter may have the correct dimensions but does not cut the correct notch in the specimen. If that occurs it will be necessary to evaluate other conditions (cutter and feed speeds) to obtain the correct notch dimension for that material.

X2. CALIBRATION OF PENDULUM-TYPE HAMMER IMPACT MACHINES FOR USE WITH PLASTIC SPECIMENS

X2.1 This calibration procedure applies specifically to the Izod impact machine. However, much of this procedure can be applied to the Charpy impact machine as well.

X2.2 Locate the impact machine on a sturdy base. It shall not "walk" on the base and the base shall not vibrate appreciably. Loss of energy from vibrations will give high readings. It is recommended that the impact tester be bolted to a base having a mass of at least 23 kg if it is used at capacities higher than 2.7 J (2 ft·lbf).

X2.3 Check the level of the machine in both directions in the plane of the base with spirit levels mounted in the base, by a machinist's level if a satisfactory reference surface is available, or with a plumb bob. The machine should be made level to within $\tan^{-1}$ 0.001 in the plane of swing and to within $\tan^{-1}$ 0.002 in the plane perpendicular to the swing.

X2.4 With a straightedge and a feeler gauge or a depth gauge, check the height of the movable vise jaw relative to the fixed vise jaw. It must match the height of the fixed vise jaw within 0.08 mm (0.003 in.).

X2.5 Contact the machine manufacturer for a procedure to ensure the striker radius is in tolerance (0.80 ± 0.20 mm) (see 6.3).

X2.6 Check the transverse location of the center of the pendulum striking edge that shall be within 0.40 mm (0.016 in.) of the center of the vise. Readjust the shaft bearings or relocate the vise, or straighten the pendulum shaft as necessary to attain the proper relationship between the two centers.

X2.7 Check the pendulum arm for straightness within 1.2 mm (0.05 in.) with a straightedge or by sighting down the shaft. Allowing the pendulum to slam against the catch sometimes bends the arm especially when high-capacity weights are on the pendulum.

X2.8 Insert vertically and center with a locating jig and clamp in the vise a notched machined metal bar 12.7-mm (0.500-in.) square, having opposite sides parallel within 0.025 mm (0.001 in.) and a length of 60 mm (2.4 in.). Check the bar for vertical alignment within $\tan^{-1}$ 0.005 in both directions with a small machinist's level. Shim up the vise, if necessary, to correct for errors in the plane of pendulum swing, using care to preserve solid support for the vise. For errors in the plane perpendicular to the plane of pendulum swing, machine the inside face of the clamp-type locating jig for correct alignment if this type of jig is used. If a blade-type jig is used, use shims or grind the base of the vise to bring the top surface level.

X2.9 Insert and clamp the bar described in X2.8 in a vertical position in the center of the vise so that the notch in the bar is slightly below the top edge of the vise. Place a thin film of oil on the striking edge of the pendulum with an oiled tissue and let the striking edge rest gently against the bar. The striking edge should make contact across the entire width of the bar. If only partial contact is made, examine the vise and pendulum for the cause. If the cause is apparent, make the appropriate correction. If no cause is apparent, remove the striker and shim up or grind its back face to realign the striking edge with the surface of the bar.

X2.10 Check the oil line on the face of the bar for horizontal setting of striking edge within $\tan^{-1}$ 0.002 with a machinist's square.

X2.11 Without taking the bar of X2.8 from the vise of the machine, scratch a thin line at the top edge of the vise on the face opposite the striking face of the bar. Remove the bar from the vise and transfer this line to the striking face, using a machinist's square. The distance from the striking oil line to the top edge of the vise should be 22 ± 0.05 mm (0.87 ± 0.002 in.). Correct with shims or grinding, as necessary, at the bottom of the vise.

X2.12 When the pendulum is hanging free in its lowest position, the energy reading must be within 0.2 % of full scale.

X2.13 Insert the bar of X2.8 into the vise and clamp it tightly in a vertical position. When the striking edge is held in contact with the bar, the energy reading must be within 0.2 % of full scale.

X2.14 Swing the pendulum to a horizontal position and support it by the striking edge in this position with a vertical bar. Allow the other end of this bar to rest at the center of a load pan on a balanced scale. Subtract the weight of the bar from the total weight to find the effective weight of the pendulum. The effective pendulum weight should be within 0.4 % of the required weight for that pendulum capacity. If weight must be added or removed, take care to balance the added or removed weight without affecting the center of percussion relative to the striking edge. It is not advisable to add weight to the opposite side of the bearing axis from the striking edge to decrease the effective weight of the pendulum since the distributed mass can lead to large energy losses from vibration of the pendulum.

X2.15 Calculate the effective length of the pendulum arm, or the distance to the center of percussion from the axis of rotation, by the procedure in Note 9. The effective length must be within the tolerance stated in 6.6.

X2.16 Measure the vertical distance of fall of the pendulum striking edge from its latched height to its lowest point. This distance should be 610 ± 2.0 mm (24 ± 0.1 in.). This measurement may be made by blocking up a level on the top of the vise and measuring the vertical distance from the striking edge to the bottom of the level (top of vise) and subtracting 22.0 mm (0.9 in.). The vertical falling distance may be adjusted by varying the position of the pendulum latch.

X2.17 Notch a standard specimen on one side, parallel to the molding pressure, at 32 mm (1.25 in.) from one end. The depth of the plastic material remaining in the specimen under the notch shall be 10.16 ± 0.05 mm (0.400 ± 0.002 in.). Use a jig to position the specimen correctly in the vise. When the specimen is clamped in place, the center of the notch should be within 0.12 mm (0.005 in.) of being in line with the top of the fixed surface of the vise and the specimen should be centered midway within 0.40 mm (0.016 in.) between the sides of the clamping faces. The notched face should be the striking face of the specimen for the Izod test. Under no circumstances during the breaking of the specimen should the top of the specimen touch the pendulum except at the striking edge.

X2.18 If a clamping-type locating jig is used, examine the clamping screw in the locating jig. If the thread has a loose fit the specimen may not be correctly positioned and may tend to creep as the screw is tightened. A burred or bent point on the screw may also have the same effect.

X2.19 If a pointer and dial mechanism is used to indicate the energy, the pointer friction should be adjusted so that the pointer will just maintain its position anywhere on the scale. The striking pin of the pointer should be securely fastened to the pointer. Friction washers with glazed surfaces should be replaced with new washers. Friction washers should be on either side of the pointer collar. A heavy metal washer should back the last friction washer installed. Pressure on this metal washer is produced by a thin-bent, spring washer and locknuts. If the spring washer is placed next to the fiber friction washer the pointer will tend to vibrate during impact.

X2.20 The free-swing reading of the pendulum (without specimen) from the latched height should be less than 2.5 % of pendulum capacity on the first swing. If the reading is higher than this, then the friction in the indicating mechanism is excessive or the bearings are dirty. To clean the bearings, dip them in grease solvent and spin-dry in an air jet. Clean the bearings until they spin freely, or replace them. Oil very lightly with instrument oil before replacing. A reproducible method of starting the pendulum from the proper height must be devised.

X2.21 The shaft about which the pendulum rotates shall have no detectable radial play (less than 0.05 mm (0.002 in.)). An endplay of 0.25 mm (0.010 in.) is permissible when a 9.8-N (2.2-lbf) axial force is applied in alternate directions.

X2.22 The clamping faces of the vise should be parallel in the horizontal and vertical directions within 0.025 mm (0.001 in.). Inserting the machined square metal bar of X2.7 into the vise in a vertical position and clamping until the jaws begin to bind may check parallelism. Any freedom between the metal bar and the clamping surfaces of the jaws of the vise must not exceed the specified tolerance.

X2.23 The top edges of the fixed and moveable jaws of the vise shall have a radius of 0.25 ± 0.12 mm (0.010 ± 0.005 in.). Depending upon whether Test Method A, C, D, or E is used, a stress concentration may be produced as the specimen breaks. Consequently, the top edge of the fixed and moveable jaw needs to be carefully examined.

X2.24 If a brittle unfilled or granular-filled plastic bar such as a general-purpose wood-flour-filled phenolic material is available, notch and break a set of bars in accordance with these test methods. Examine the surface of the break of each bar in the vise. If the break is flat and smooth across the top surface of the vise, the condition of the machine is excellent. Considerable information regarding the condition of an impact machine can be obtained by examining the broken sections of specimens. No weights should be added to the pendulum for the preceding tests.

X2.25 The machine should not be used to indicate more than 85 % of the energy capacity of the pendulum. Extra weight added to the pendulum will increase available energy of the machine. This weight must be added so as to maintain the center of percussion within the tolerance stated in 6.4. Correct effective weight for any range can be calculated as follows:

$$W = E_p / h$$

where:

W = effective pendulum weight, N (lbf) (see X2.14),
E_p = potential or available energy of the machine, J (ft·lbf), and
h = vertical distance of fall of the pendulum striking edge, m (ft) (see X2.16).

Each 4.5 N (1 lbf) of added effective weight increases the capacity of the machine by 2.7 J (2 ft·lbf).

NOTE X2.1—If the pendulum is designed for use with add-on weight, it is recommended that it be obtained through the equipment manufacturer.

X3. DERIVATION OF PENDULUM IMPACT CORRECTION EQUATIONS

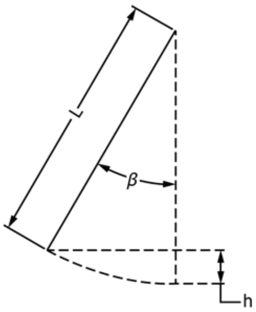


FIG. X3.1 Swing of Pendulum from Its Rest Position

X3.1 From right triangle distances in Fig. X3.1:

$$L - h = L\cos\beta \tag{X3.1}$$

X3.2 But the potential energy gain of pendulum E_p is:

$$E_p = hW_p g \tag{X3.2}$$

X3.3 Combining Eq X3.1 and Eq X3.2 gives the following:

$$L - E_p/W_p g = L\cos\beta \tag{X3.3}$$

X3.4 The maximum energy of the pendulum is the potential energy at the start of the test, E_M, or

$$E_M = h_M W_p g \tag{X3.4}$$

X3.5 The potential energy gained by the pendulum, E_p, is related to the absorption of energy of a specimen, E_s, by the following equation:

$$E_M - E_s = E_p \tag{X3.5}$$

X3.6 Combining Eq X3.3-X3.5 gives the following:

$$(E_M - E_s)/E_M = \mathrm{L}/\mathrm{h_M}\ (1 - \cos\beta) \tag{X3.6}$$

X3.7 Solving Eq X3.6 for β gives the following:

$$\beta = \cos^{-1}\{1 - [(h_M/L)(1 - E_s/E_M)]\} \tag{X3.7}$$

X3.8 From Fig. X3.2, the total energy correction E_{TC} is given as:

$$E_{TC} = m\beta + b \tag{X3.8}$$

X3.9 But at the zero point of the pendulum potential energy:

$$E_B/2 = m(0) + b \tag{X3.9}$$

or:

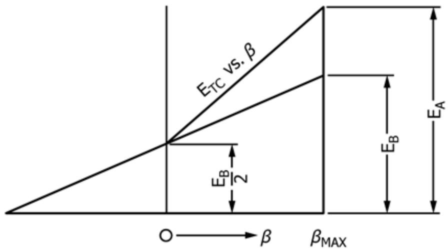


FIG. X3.2 Total Energy Correction for Pendulum Windage and Dial Friction as a Function of Pendulum Position

$$b = E_B/2 \tag{X3.10}$$

X3.10 The energy correction, E_A, on the first swing of the pendulum occurs at the maximum pendulum angle, β_{max}. Substituting in Eq X3.8 gives the following:

$$E_A = m\beta_{max} + (E_B/2) \tag{X3.11}$$

X3.11 Combining Eq X3.8 and Eq X3.11 gives the following:

$$E_{TC} = (E_A - (E_B/2))(\beta/\beta_{max}) + (E_B/2) \tag{X3.12}$$

X3.12 *Nomenclature:*

b	=	intercept of total correction energy straight line,
E_A	=	energy correction, including both pendulum windage plus dial friction, J,
E_B	=	energy correction for pendulum windage only, J,
E_M	=	maximum energy of the pendulum (at the start of test), J,
E_p	=	potential energy gain of pendulum from the pendulum rest position, J,
E_s	=	uncorrected breaking energy of specimen, J,
E_{TC}	=	total energy correction for a given breaking energy, E_s, J,
g	=	acceleration of gravity, m/s^2,
h	=	distance center of gravity of pendulum rises vertically from the rest position of the pendulum, m,
h_M	=	maximum height of the center of gravity of the pendulum, m,
m	=	slope of total correction energy straight line,
L	=	distance from fulcrum to center of gravity of pendulum, m,
W_p	=	weight of pendulum, as determined in X2.14, kg, and
β	=	angle of pendulum position from the pendulum rest position.

X4. UNIT CONVERSIONS

X4.1 Joules per metre (J/m) cannot be converted directly into kJ/m^2. Note that the optional units of kJ/m^2 (ft·lbf/in.^{2}) may also be required; therefore, the cross-sectional area under the notch must be reported.

X4.2 The following examples are approximations:

X4.2.1 *Example 1:*

1 ft·lbf/39.37 in.	= 1.356 J/m
1 ft·lbf/in.	= (39.37)(1.356) J/m
1 ft·lbf/in.	= 53.4 J/m
1 ft·lbf/in.	= 0.0534 kJ/m

X4.2.2 *Example 2:*

1 ft·lbf/1550 in.^{2}	= 1.356 J/m^2
1 ft·lbf/in.^{2}	= (1550)(1.356) J/m^2
1 ft·lbf/in.^{2}	= 2101 J/m^2
1 ft·lbf/in.^{2}	= 2.1 kJ/m^2

SUMMARY OF CHANGES

Committee D20 has identified the location of selected changes to this standard since the last issue, D256 - 06a$^{\varepsilon 1}$, that may impact the use of this standard. (May 1, 2010)

(1) Revised Note 6 and Note 16.

(2) Revised Section 9.