2019

VibCo Engineering Test Bench

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Engineering Test Bench
Final Design Report

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May 6, 2019

Abstract

The VIBCO Engineering Test Bench was designed to be an all-inclusive, easy-to-use testing station for use by VIBCO's engineering team. It features both loaded and unloaded testing areas, precision data acquisition instruments, and numerous sensors. The test bench was designed with convenience in mind. The main goal was to create an easy-to-use station where the majority of VIBCO's small electric and pneumatic units can be quickly set up and tested with minimal user training.

The test bench is constructed almost fully out of steel. It utilizes 2"x2"x1/4" angle steel and 1/4" steel plates. The height and other dimensions were carefully selected for ease of operation. A portion of the bench is vibration isolated using four Firestone air mounts. The bench is relatively portable, with heavy-duty casters allowing it to be transported from one area of VIBCO's shop to another.

Several modular mounting plates were designed to attach many different VIBCO models to the isolated portion of the test bench. These plates can accommodate over 60 different units each. They attach to mounting rails affixed the isolated bench top section using ¾"cap screws.

Using AstroNova's DAXUS data acquisition system and associated software, various sensors were interfaced to collect the necessary data from VIBCO's vibration units. A thermocouple measures temperature data. A current clamp measures current draw of electric units. A tri-axial accelerometer measures acceleration of the vibrating assembly, which is in turn used to calculate both vibration speed (VPM) and force outputted by the unit.

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List of Acronyms

QFD – Quality Functional Deployment
VPM – Vibrations per Minute
dB – Decibels
COTS – Consumer Off-The-Shelf
CNC – Computer Numerically Controlled
RMS – Root Mean Square

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Introduction

VIBCO Vibrators in Wyoming, Rhode Island is a small company that manufactures industrial vibration products used in construction and manufacturing operations. VIBCO's current engineering testing process is both inefficient and outdated. To test units, the production line is interrupted, and a technician manually records data using low-tech measuring devices. The process costs VIBCO precious production time and may produce inaccurate data due to the archaic instruments used during the testing. As an innovator on the forefront of lean manufacturing in Rhode Island, VIBCO is dissatisfied with these issues and created a new project for the University of Rhode Island's Mechanical Engineering Capstone Design program.

Capstone Team 4 was tasked with designing a test bench complete with electronic data acquisition for use by VIBCO's engineering team. The bench must include means to test both "loaded" units, meaning bolted to a rigid mounting point, and "unloaded" units, meaning the vibrator alone placed into a box with high density foam lining or a comparable material. The test data to be recorded includes vibration speed (VPM) which is equivalent to RPM 1:1, vibration force, temperature, voltage and amperage for electric units, and air pressure and consumption for pneumatic units.

The bench design work was carried out using SolidWorks. After consulting with VIBCO's engineering team, team 4 settled on test bench dimensions of 6' by 4' with a height of 32". This will allow adequate workspace and a comfortable working height. The bench will be constructed mainly from 2"x2"x¼" angle steel and ¼" hot-rolled pickled and oiled flat steel plates. Rigidity was a top priority during the design process, as any loose or flexible parts may cause the test data to be invalid or compromise the longevity of the bench.

For the data acquisition side of the project, Team 4 consulted AstroNova Test and Measurement for help. AstroNova graciously allowed the team to use a demo unit of their DAXUS model with two UNIV-4 input modules with four channels each and several adaptors for different sensors. The unit allows for numerous different types of sensor interfaces and is ideal equipment for our application. The DAXUS software is relatively simple to use and can be set up to output data automatically.

Several sensors were used for data collection. The most important of these is the accelerometer. After investing numerous options, Team 4 decided on a PCB Piezotronics 356A15 piezoelectric tri-axis accelerometer. This extremely sensitive sensor collects acceleration data in three dimensions. This signal is then manipulated in the DAXUS software and converted to both a vibration speed (VPM) channel and vibration force channel. Other sensors include a basic K-type thermocouple for temperature measurement and a current measurement clamp. Voltage is simply measured with generic multimeter probes connected directly to the DAXUS.

Construction of the bench by VIBCO's fabrication department has been heavily delayed. However, testing could still be performed on the electronic data acquisition portion. First, a small mounting bracket was fabricated and a VIBCO SPR-20 electronic vibrator was attached. A series of tests were then run on the vibrator. The tests proved that data was successfully being recorded and the system successfully collects the data that VIBCO needs it to.

In the future, further work will be done to increase the convenience and ease-of-use of the DAXUS software. Much research still needs to be done regarding air flow measurement, as this was a major area of difficulty during our research. A power supply and air regulator will also need to be added.

Patent Searches

A patent search is a vital tool in the pre-design research stage as it can provide insight into the problem at hand and assist in designing a new solution by explaining current solutions that can be combined and improved upon. Patent searches also help the designer in avoiding any kind of patent infringement in a new design which can cause a large amount of legal trouble leading to unnecessary time and resources wasted. Below are a selection of patents which aided our team in the design and development of the engineering test bench.

Austin Abraham:

US5788367A - *Pneumatic Vibrator*

Date: August 4th, 1998
Rights: Jury Alexeevich Budaev
Relevance: This patent is relevant to our project as it provided background knowledge on the basic design and operations of a pneumatic vibrator. Since pneumatic and electric vibrators comprise most of VIBCO's product line it is most helpful to understand the fundamentals of their operation. Although George Donoyan has had hands on experience with these vibrators, the rest of the group began the project as unfamiliar with industrial vibration equipment. Budaev's patent on a pneumatic vibrator is a good basis for learning more about the internal workings of these machines.

US5580234A - *Hydraulically Operated Rotary Vibrator*

Date: December 3rd, 1996
Rights: Theodore S. Wadensten
Relevance: This patent is of significant relevance to our project as it is a patent of one of VIBCO's main products. Seeing as this is one of the vibrators that VIBCO is expected to test using our bench design, we should be expected to know their principles of operating and mounting systems. While Patent Number 5,788,367 gave us a basic

overview of vibrator design, this patent and its information are tailored exclusively to our project. It is also noteworthy that this patent may be referenced if our designed vibrator mounting plates ever reach mass production.

US4389120A - *Rotary Vibrator with resilient shock mount to provide linear movement*

Date: June 21st, 1983
Rights: Theodore S. Wadensten
Relevance: Similar to 5,580,234, this patent is also one of VIBCO's own products. It is also helpful as a learning tool for gaining a greater understanding on the inner workings of industrial vibrators. However, the addition of the "shock mount" also offers insight on more complex vibration damping systems. Since our group plans on implementing sensitive electronics, protecting them from vibration is key to ensure accurate data collection.

Stephen Grabarz:

US4528637A - *Data acquisition system and analog to digital converter therefor*

Date: July 9, 1985
Rights: Westinghouse Electric Corp
Relevance: This patent is relevant to our Capstone project because it is for a data acquisition system, which we will also be employing on our bench. The system is used to measure temperature and involves analog to digital conversion. There is a lot of relevant background about data acquisition in the patent, but the hardware itself will probably not be of much use to us, since it is from the early eighties and obsolete now. Also, we will be using units from AstroNova, which will take care of the analog to digital conversion for us.

US6786089B2 - *Airflow meter*

Date: September 7, 2004

Rights: Denso Corp

Relevance: This patent is relevant to our Capstone project because it details an air flow meter. It was filed by Denso, which is one of the largest sensor manufacturers in the world. One of the parameters to be recorded by our test bench is air consumption of the pneumatic units. We will be employing a sensor similar to the one described in this patent. This patent contains a lot of useful information about air flow sensors and how they work, which will be beneficial to us when choosing a sensor for our application.

George Donoyan:

US5638299A - *Light Weight, Self-Contained Programmable Data-Acquisition System*

Date: June 10th, 1977

Rights: Keith Miller, Long Beach, CA

Relevance: This patent describes a serial interface device for the purpose of electronically collecting analog values and converting them to digital values to be displayed on the screen of a host computer used in conjunction with this device. The device also included an internal non-volatile for storing data to be accessed/ extracted by a PC at a later time. This is relevant to our mission because integrating data acquisition is a large part of our project. This invention brings together into a single compact unit the different parts which previously had to be purchased separately at the time and pieced together into a bulky system which was not suitable for harsh industrial environments. This helped us choose our data acquisition unit provided by AstroNova along with some advice from their engineering team.

US6354155B1 – *Multi-Component Force and Moment Measuring Platform and Load Transducer*

Date: March 12th, 2002

Rights: Necip Berme of Bertec Corporation, Worthington, OH

Relevance: This patent describes a device that is capable of measuring both force and moment in the X, Y and Z directions. The device consists of two cylindrical load cells each with six strain gages affixed in a circular pattern around the middle and a plate fixed to the top of the two load cells. The load is applied to the top plate and measurements are recorded for Fx, Fy, Fz and Mx, My and Mz simultaneously. This device gave us guidance in the design of the loaded vibration testing station on the bench which consists of two steel rails with ¾-10 UNC bolt holes for securing the modular vibrator adaptor plates. For the loaded testing station, strain gages in a full bridge configuration will be affixed to the two steel rails to measure vibration amplitude.

US4349821A – *Data Acquisition System and Analog to Digital Converter Therefor*

Date: September 14th, 1982

Rights: Gyorgy I. Vancsa of Westinghouse Electric Corporation, Pittsburgh, PA

Relevance: This patent describes a multi-channel analog to digital converter that employs a voltage/ frequency converter on each channel and has all channels synchronized to a central clock. The convertor receives a string of timed pulses representing the analog signal and converts the string to digital data that can be amplified and processed for display and monitoring by a central computer at a remote location. The test bench will employ a similar system for data collection and monitoring in which analog data will be collected and signals sent to the A/D converter inside the two DAXUS DXS-100 data acquisition units mounted on the test bench. After conversion to digital data, the signals will be amplified and conditioned if necessary based on the parameter being measured and made ready for a PC to display and record.

Evaluation of the Competition

Given the nature of our project being the design and manufacture of a bespoke purpose-built engineering test bench, doing a market analysis for any competition against our final product is not applicable. Since the final test bench will be a single production to be used by VIBCO's engineering department only, it will not be available to the general public for purchase. Therefore, it is not needed to attempt to establish a market hold or gain market dominance.

Specifications Definition

In order to meet the functional requirements set forth by VIBCO, target parameters for several different components of the test bench are specified in the table below.

TABLE 1: DESIGN SPECIFICATIONS

Functional Requirements	Engineering Specifications
Overall Dimensions	2' x 6' x 3.5'
Test Bench Weight	< 400 lbs
Vibrator Compatibility	Accommodate 95+ of VIBCO's catalog of small electric and pneumatic vibrators
Maximum Vibrator Weight	60 lbs
Maximum Vibrator Speed	20000 rpm
Maximum Vibrator Force	4000 lbs
Power Supply Requirements (electric units)	12 VDC, 120/240 VAC
Air Supply Pressure (pneumatic units)	80 psi

Given the nature of their manufacturing floor and assembly areas, a mobile and compact testing area is vital in order to reduce interruptions and obstructions to their everyday workloads. As a result the bench must have small enough dimensions and be light enough for a two person crew to effectively move it. Through evaluation of some of VIBCO's existing mobile tables used for assembly and product packaging, it was decided that a 6'x2' footprint design weighing less than 400 pounds would closely match the tables used by their staff. Since the purpose of the bench is an “all-in-one” testing suite, it was also imperative that the majority of VIBCO’s product line be compatible with the bench. As a result the bench would have to be able to mount and support over 95 different vibrators as found in VIBCO’s catalog. Not only would the bench have the ability to mount a wide range of vibrators but must also be able to support the wide range of forces and speeds produced by them. Also, since the larger electrical units require a voltage source larger than the common household 120 volts, they must also be accommodated. Pneumatic units must also be able to be supplied a maximum of 80 psi of compressed air.

Conceptual Design

Austin Abraham:

1. **Bench Vertical Mounting Plate** - A flat, vertical steel/aluminum plate that will function as a universal mounting surface for data acquisition equipment, tools, power/air inputs and other accessories. The plate is similar in concept to the “pegboards” that are found in many workshops and home garages in which items are placed vertically for easy access and organization

2. **Benchtop Laptop Mount** - A simple rigid mounting system for use with a laptop for data acquisition purposes. Construction will consist of simple steel channel lined with urethane rubber for vibration/shock resistance. Rubber donut isolators will serve as standoffs from the bench surface and can either be screwed or epoxied to the bench.

3. **Vertical Wall Laptop Mount** - Similar in design to the benchtop mount, this design allows for the placement of a data acquisition laptop on the vertical mounting plate. Construction will also consist of simple steel channel lined with urethane rubber. Gusset Plates will also be used to strengthen the mount because of the unsupported weight of the laptop. Rubber standoffs will also be used.

4. **Swivel/Extension Arm Mount for Touch Screen/Tablet** - A mounting system for a touch screen/tablet that allows the user to move and tilt the screen to suit their workspace needs. The system will use a rigid mounting plate that will be bolted to the vertical wall, utilizing two ball joints for multiple degrees of movement freedom. The mount will be able to rotate 180 degrees both vertically and horizontally.

5. **Benchtop Tablet/Touchscreen Station** - Loosely based on the benchtop laptop mount, this mount is exclusively for the use of a smaller tablet, touchscreen. Considering the smaller footprint of these devices and the lack of a folding screen, the mount will position the tablet at a 45 degree angle for easier viewing and access. Like the laptop mount, this design also features simple steel channel construction with rubber donut isolators for vibration resistance.

6. **Power Distribution Center** - Because the bench must be able to accommodate a large array of VIBCO's products, it must also be equipped with the necessary power outlets. The power distribution center combines both 220V and 110V outputs, mounted onto a simple sheet metal plate with protruding mounting tabs. These tabs can be used for screwing/bolting the center to the vertical wall plate.

7. **Non-Slip Benchtop** - A high grip benchtop surface that will prevent tools, sensitive data equipment and vibrators in testing from moving across the benchtop during vibration. The design may either consist of a rubberized spray coating similar to truck bed liner or a simple urethane rubber mat epoxied to the surface for increased cushioning.

8. **Pneumatic Coupling Rack** - A vertically mounted rack for the organization of several necessary adapters and fittings used to supply VIBCO's pneumatic operated product line with air. The rack will be simply constructed using two eighth-inch steel plates joined at a 90 degree angle. Mounting tabs will allow the rack to be mounted to the vertical wall, while fittings and adapters will sit securely in designated mounting holes.

9. **Documentation Organizer** - A trifold mount to facilitate the organization of important product documents and test information. Construction will consist of a simple sheet metal plate with mounting screw tabs that can be used to secure the mount to the vertical bench wall. A commercial trifold case/hanger will be attached securely to the plate using sheet metal screws or epoxy.

10. **Air Pressure Regulator Mount** - Precise metering of airflow to the vibrators is a must during testing as the units are designed for a specified air pressure output. Exceeding this value could damage the equipment in testing. Therefore, a vertical wall mount was designed in order to secure a commercial air pressure regulator in an easily accessible location. This regulator limits the amount of airflow to the vibrator. Although the usage of brass hard line may be sufficient to keep the regulator in a desired position, a simple strap fabricated out of thin (1/16in) sheet metal secured to the wall using self-tapping screws provides increased security.

11. **Hand Tool Rack** - Similar to the air coupling rack in design, the hand tool rack is another device to facilitate the easy storage and access of the basic tools needed to hook up and prepare a vibrator for testing. Construction will also consist of two eighth inch steel plates joined at a 90 degree angle, most likely by a weldment. Slots cut into the horizontal plate will secure the majority of basic hand tools (wrenches, screwdrivers, ect). Mounting tabs will allow the rack to be secured to the vertical wall using self-tapping screws or bolts.

12. **LED Worklight** - Although the work area inside VIBCO seems to have adequate lighting, increased visibility is always welcome to the technician that must manually hook up and prepare the vibrators for testing. Sitting at the top of the bench vertical wall, a commercial LED light bar will be able to swivel 90 degrees in order for the technician to direct light to the location of their desire. The mount will simply be constructed of two eighth inch steel tabs on either side of the bar, secured with bolts so that the bar has the freedom of movement to tilt up and down.

13. **Benchtop Battery Maintainer** - Although most of VIBCO's product line consists of vibrators that are pneumatically driven or electrically driven via a cord, some portable units rely on battery power. A technician performing testing would lose a lot of time if the battery in one of these units ran low. A commercial battery tender would allow for the real-time charging of the batteries during lengthy test times. The mount for this device would consist of steel channel lined with urethane rubber. A commercial ratcheting strap is a simple solution to keep the ungainly battery maintainer secured to the mount.

14. **Power Strip Mount for Accessory Power** - A mount for a commercial power strip to power laptops, desktops, chargers, lights, power tools and other data acquisition equipment. A simple sheet metal box with an open top will be enough to secure the power strip from moving in an excessive manner. Nut inserts combined with set screws would also aid in securing the strip. Mounting tabs will allow it to be screwed to the vertical wall.

15. **Emergency Shutoff Switch** - Although not a part of the design specifications, an emergency shutoff button will add an increased margin of safety in case there is a catastrophic failure to a vibrator. A master momentary switch connected to the main

power input to the bench will be able to kill all power to prevent further damage to data equipment, the bench or the operator.

16. **Benchtop Toolbox Mount** - An alternative to the tool rack, the benchtop toolbox mount allows for the basic hand tools needed for test setup to be secured in a commercially available tool box. Construction will consist of steel channel lined with urethane foam. Rubber donut isolators will be used as standoffs from the bench surface to provide increased vibration resistance.

17. **Extension Cord Reel** - A mounting plate for a reel of 110v extension cord. The integration of this reel will allow the powering of vibrators and accessories that might have a cord that is too short based on their storage/mounting location. The plate will consist of a urethane rubber pad that will fit in between the built in cord reel mount and the vertical bench wall.

18. **Data Acquisition Module Isolation Box** - After the decision to use AstroNova's Daxus data acquisition system, it was necessary to devise a mounting solution for this system that would adequately shield it from the shop environment. The box will consist of sheet metal lined with urethane foam. Rubber donut standoffs will also be used in securing the box to the bench surface. Cutouts in the back of the box will be located for cooling in the enclosed space.

19. **Wiring Conduit** - Since there will be a large amount of wires running from the back of the Daxus unit, it will be necessary to shield them from the shop environment. A wire sheath, constructed of sheet metal or 3D- printed PLA plastic can be epoxied to the bench wall, protecting the bundle of wires inside.

20. **Retractable Air Hose Reel** - Similar in design to the extension cord reel, a vertically mounted pneumatic rubber hose reel will allow for a technician to have an optimal amount of hose length to hook up a pneumatic vibrator to the test bench. The reel will be mounted to the vertical wall by a urethane rubber pad sandwiched between the wall and the built in reel mounting plate.

21. **Urethane Foam Bench Top** - A bench top consisting of a 1 inch thick mat back by sheet metal for rigidity. Not only will this prevent the movement of tools and other equipment on the bench surface from moving during testing, it will also provide a layer of vibration resistance for the operator.

22. **Data Acquisition Module Auxiliary Cooling** - By placing the data acquisition module in an enclosed space, cooling issues may occur. The air holes placed in design 78 may not be sufficient to keep the Daxus cool. Consequently, two readily available commercial computer fans may be mounted above the air holes for increased cooling efficiency.

23. **Fire Extinguisher Mounting Plate** - Similar to design 75 in that it is not necessarily part of the design requirements, the integration of a fire extinguisher adds another element of safety to the bench. Electrical fires are a possibility when working with equipment that draws a high current load. The mount may be constructed using COTS parts such as simple U-band clamps.

24. **Desktop/Computer Tower** - A simple, vibration isolation mount for integrating a desktop computer into the test bench design. Constructed of simple steel channel lined with urethane foam, the mount is secured to the bench top using rubber standoffs.

25. **Retractable Vertical Wall Mount** - Because space is at a premium in VIBCO's manufacturing shop, it may be viable to design the vertical bench wall to retract inside the bench for easy storage and reduced footprint. The wall may be mounted on heavy duty, locking drawer slides for simple movement of the entire bench backing plate.

26. **Vertical Wall Mount for Moisture Filter** - A common by-product of producing compressed air is moisture. The internals of VIBCO's pneumatic vibrators must remain lubricated and free of moisture that might be found in the compressed air feed. A simple sheet metal strap fastened to the vertical wall with self-tapping screws adds increased security versus just the support of the hard air lines.

27. **Pop-Up Bench Top** - As an alternative to separate compartments in the base of the test bench, a bench top that flips open to reveal the interior of the bench may be viable.

A hydraulic damper will allow the entire bench top surface to tilt back, giving access to the interior of the test bench base. The bench top must be slightly smaller in diameter than the bench base in order to avoid clearance problems when the top is tilted.

28. **Bench Tie Down Anchors** - Although the unit is projected to never leave VIBCO's facility, it may be difficult to secure the bench down during shipping if it is ever loaned out to another company/user. A pair of eye hooks/eye bolts welded to the top of the vertical wall offers a place to hook ratchet straps for securing the unit during shipping.

29. **Coiled Air Line** - VIBCO's pneumatic vibrators require an adequate air supply in order to run properly. In order to integrate the numerous air accessories needed to accomplish this, a large amount of brass hard line must be used. However, the properties of brass are less than optimal in a vibration/shock rich environment. Using soft rubber coiled air lines provides the freedom of movement needed to absorb harsh vibrations without failure.

30. **Emergency Air Shut Off Valve** - Similar to the emergency stop button, a simple ball valve mounted before the air supply accessories (filter, regulator, hose reel, ect.) will enable the technician to safely cut the supply of air to a pneumatic vibrator in case of failure.

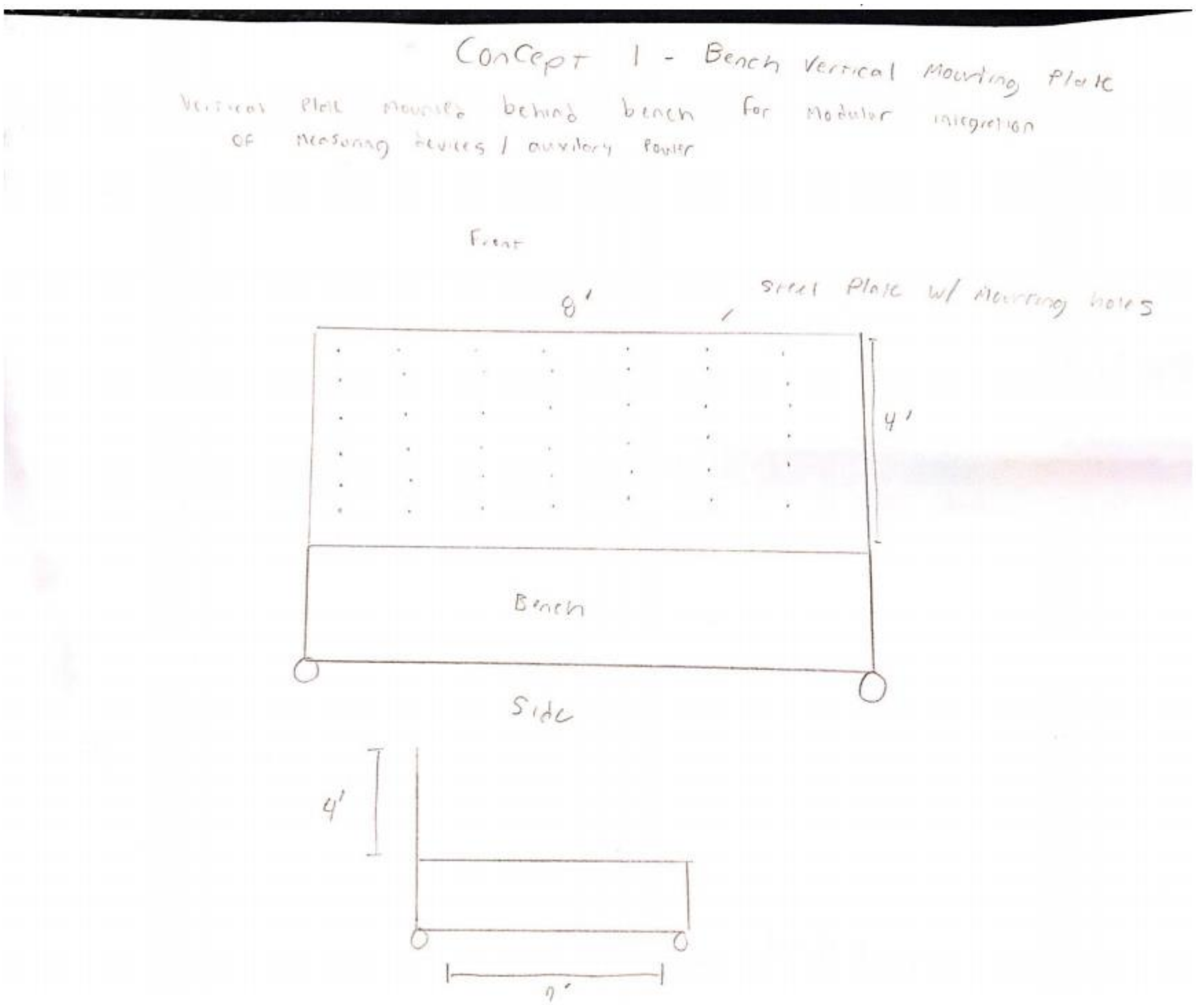

FIGURE 1: BENCH VERTICAL MOUNTING PLATE

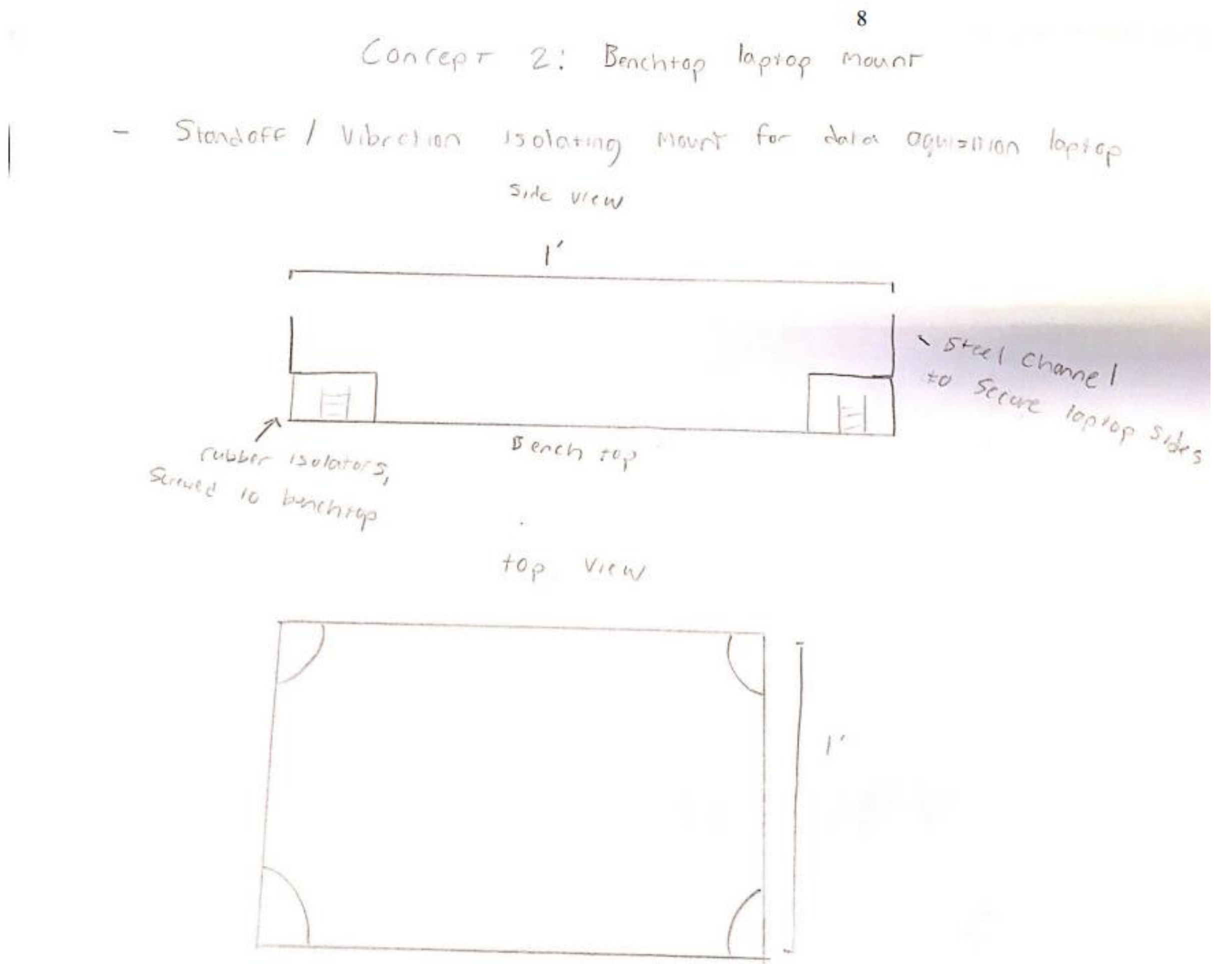

FIGURE 2: BENCHTOP LAPTOP MOUNT

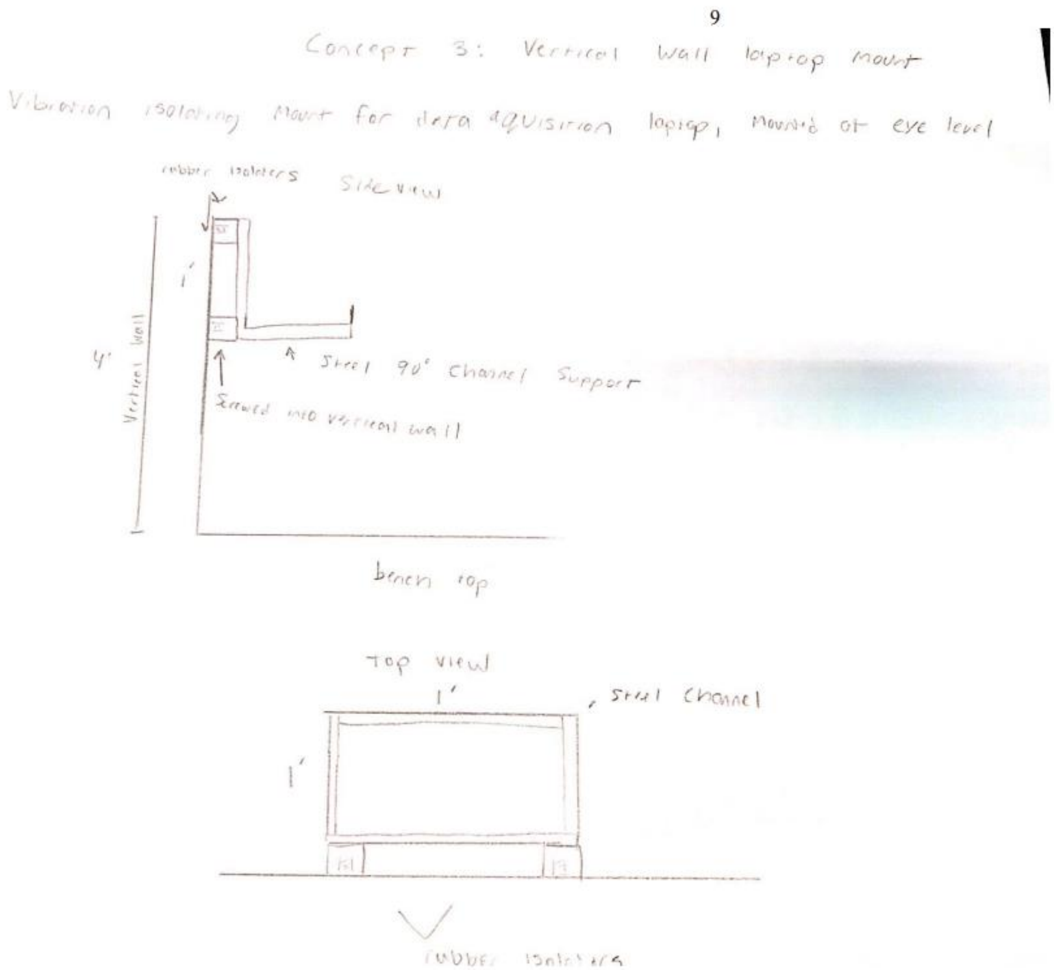

FIGURE 3: VERTICAL WALL LAPTOP MOUNT

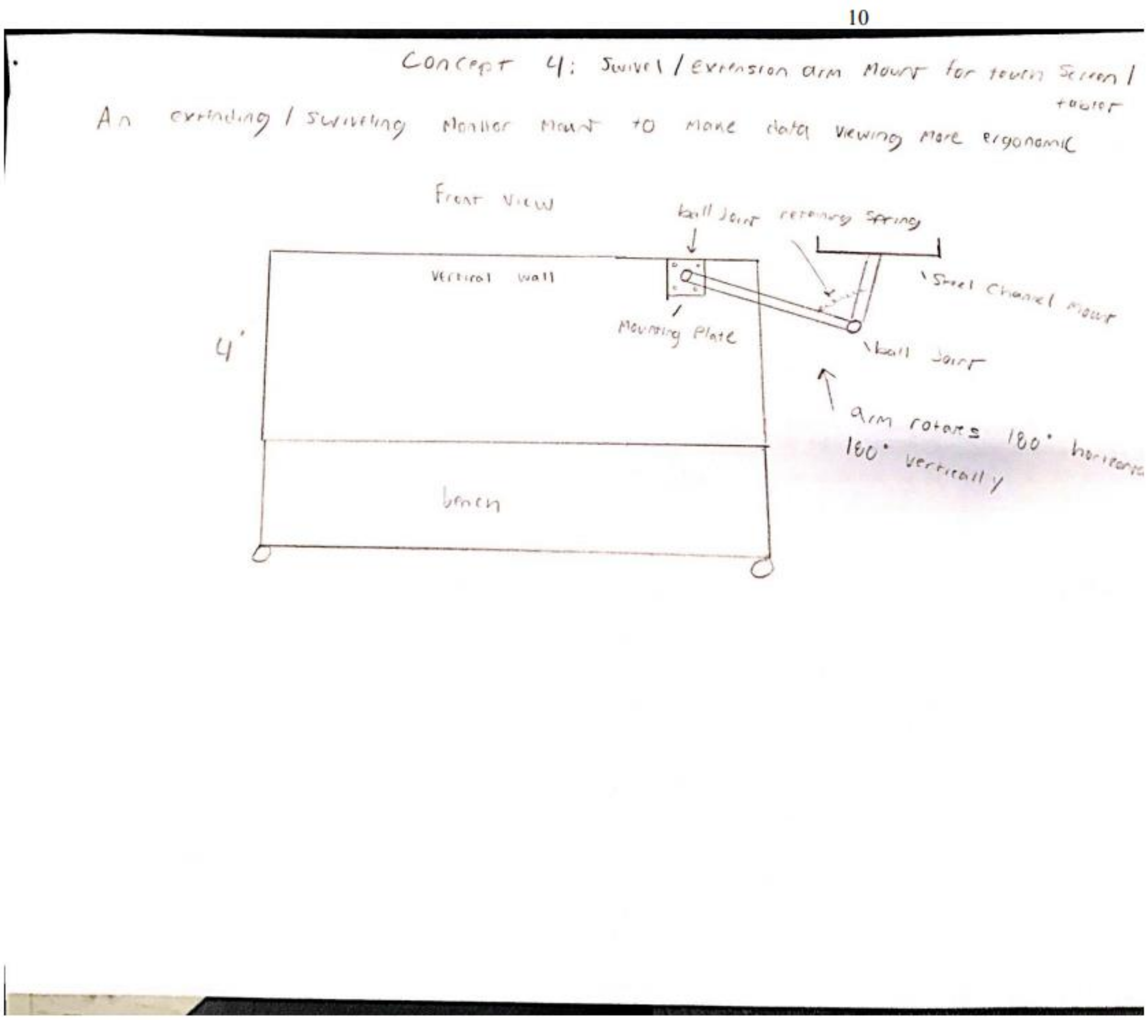

FIGURE 4: SWIVEL/EXTENSION ARM MOUNT FOR TOUCH SCREEN/TABLET

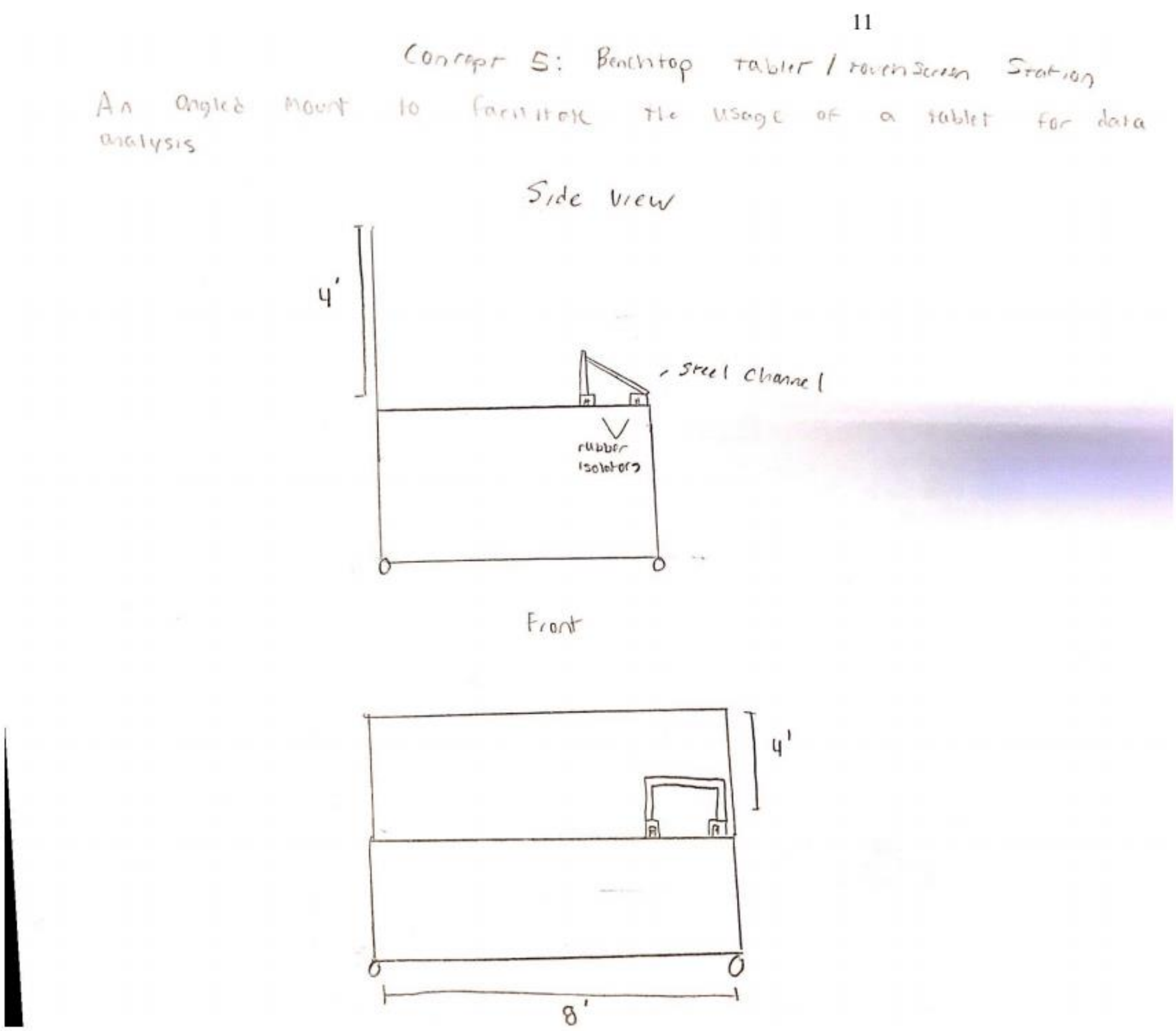

FIGURE 5: BENCHTOP TABLET/TOUCHSCREEN STATION

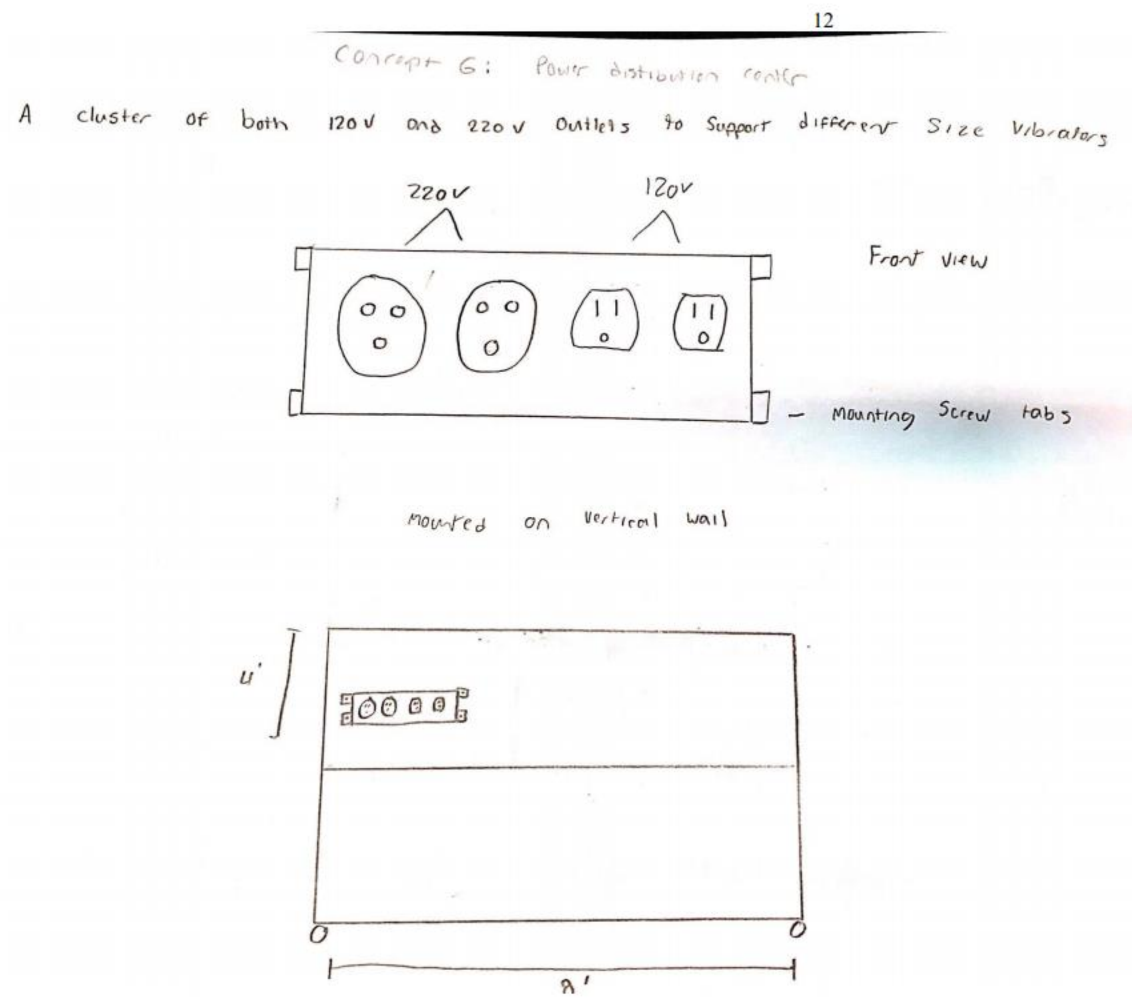

FIGURE 6: POWER DISTRIBUTION CENTER

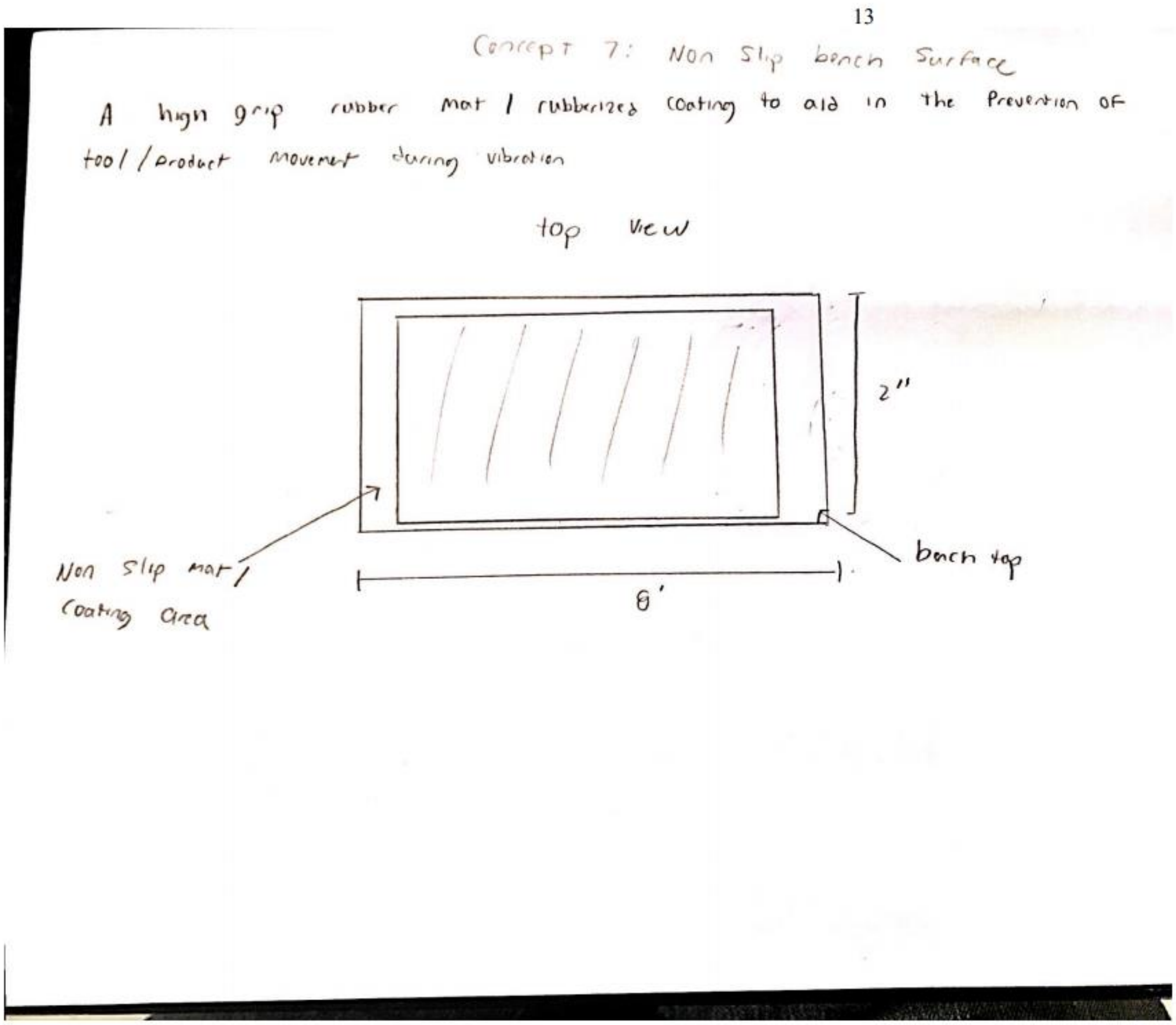

FIGURE 7: NON-SLIP BENCHTOP

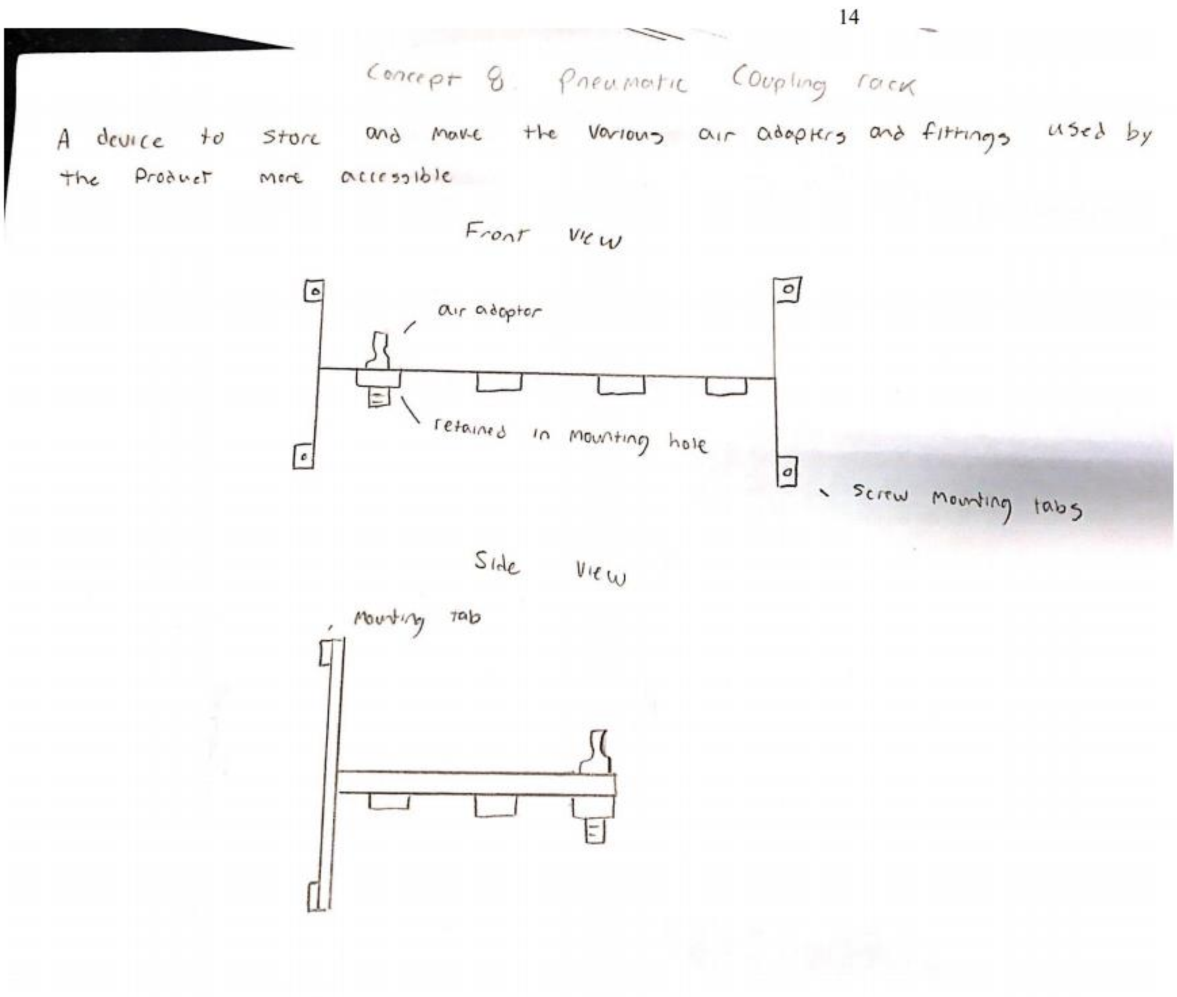

FIGURE 8: PNEUMATIC COUPLING RACK

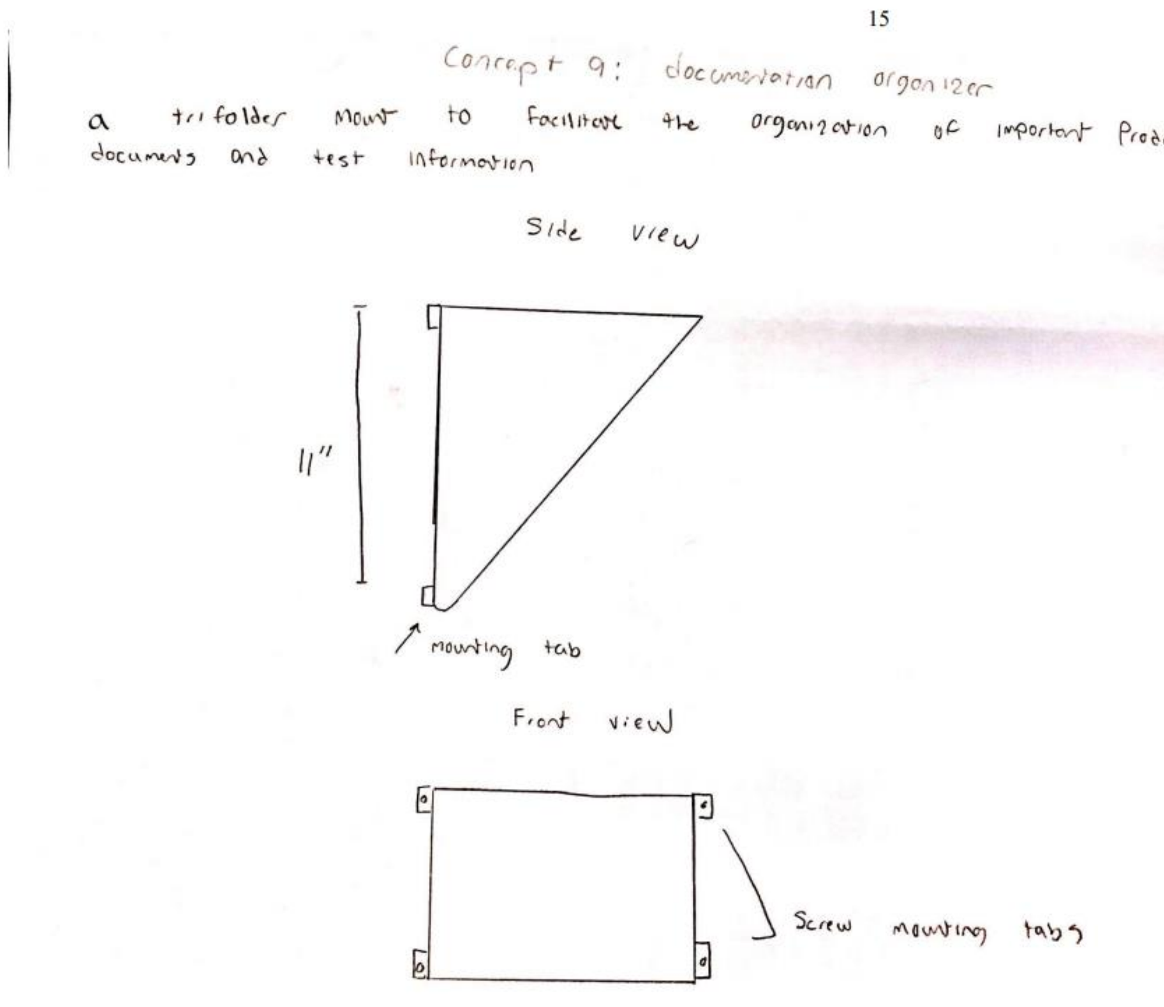

FIGURE 9: DOCUMENTATION ORGANIZER

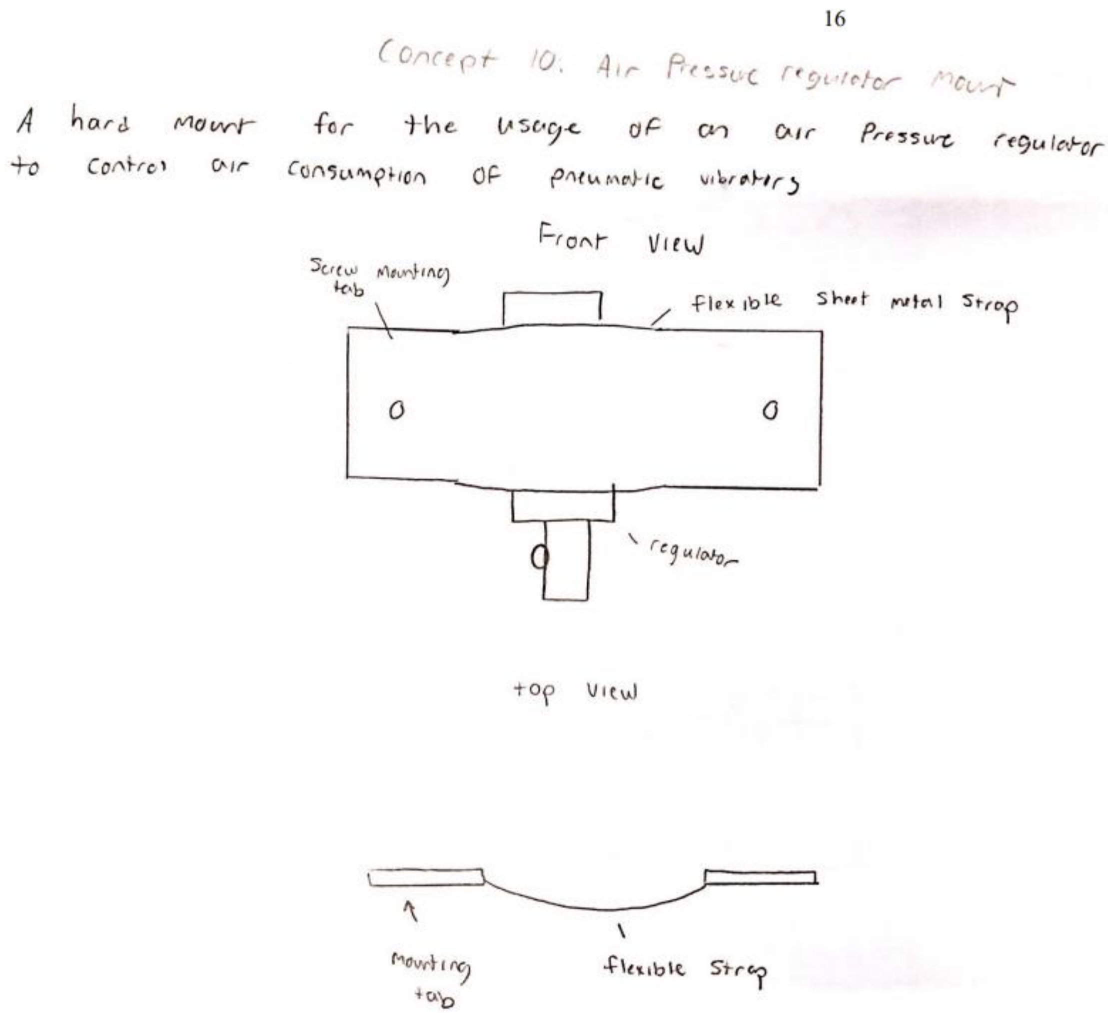

FIGURE 10: AIR PRESSURE REGULATOR MOUNT

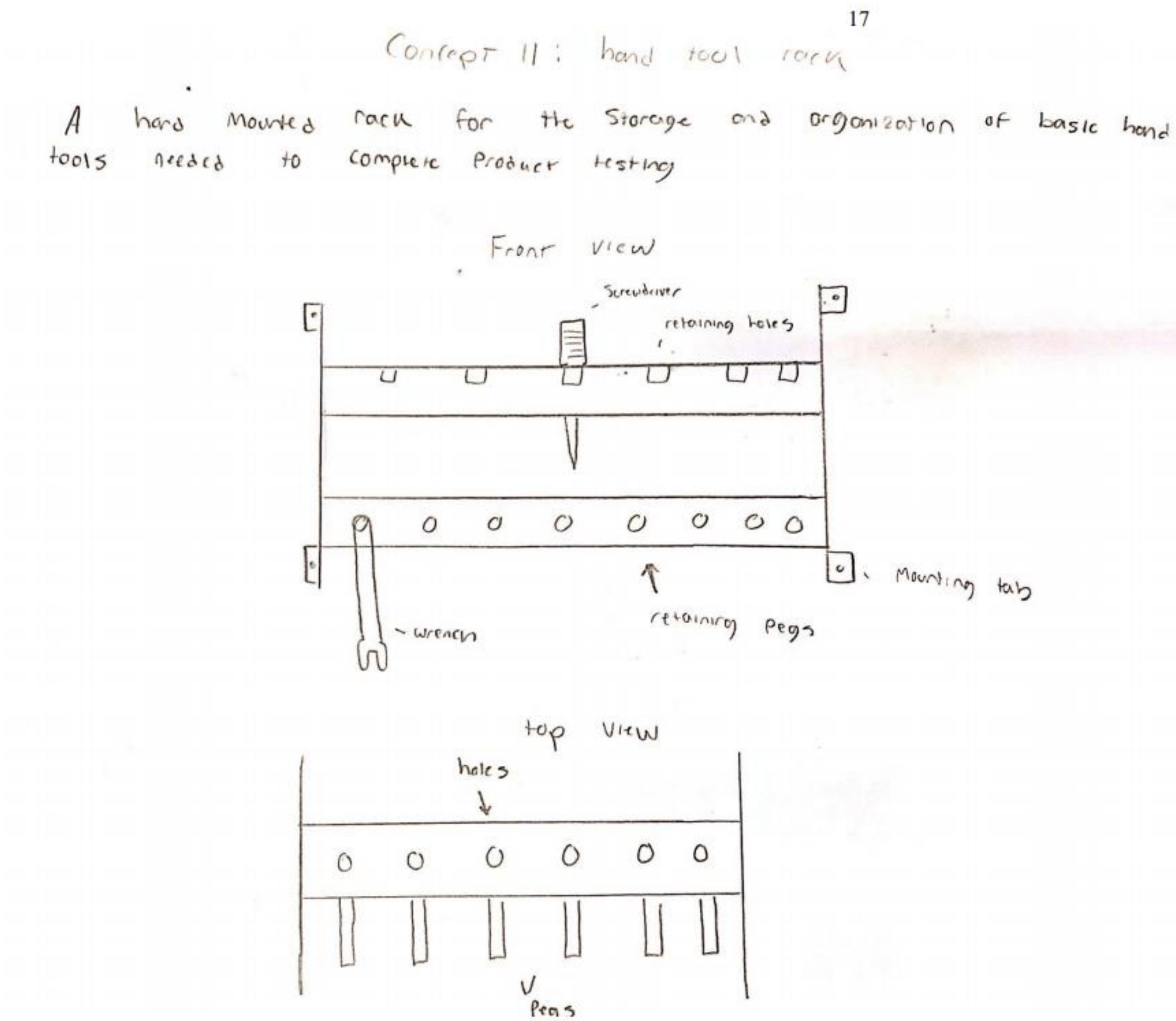

FIGURE 11: HAND TOOL RACK

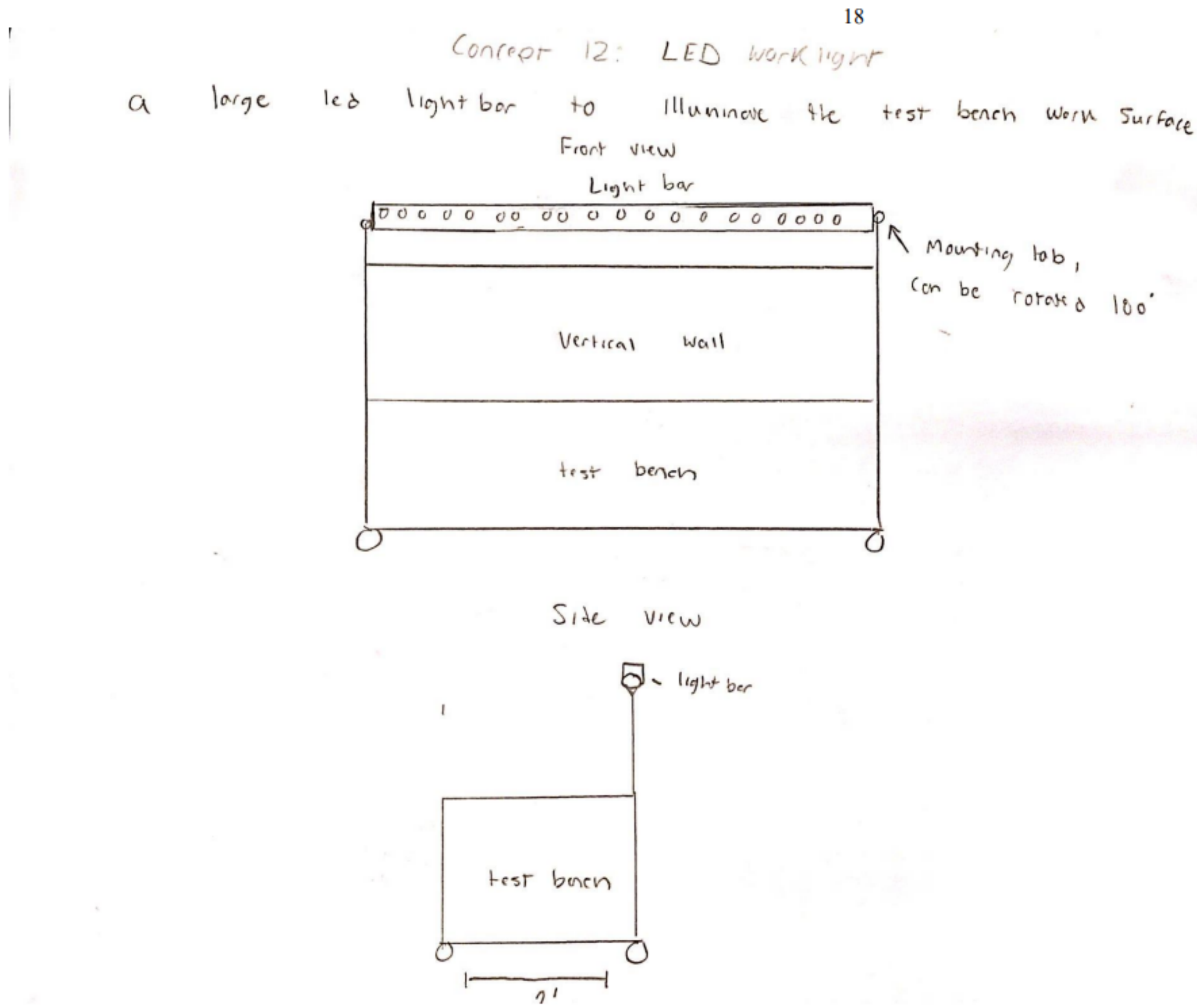

FIGURE 12: LED WORKLIGHT

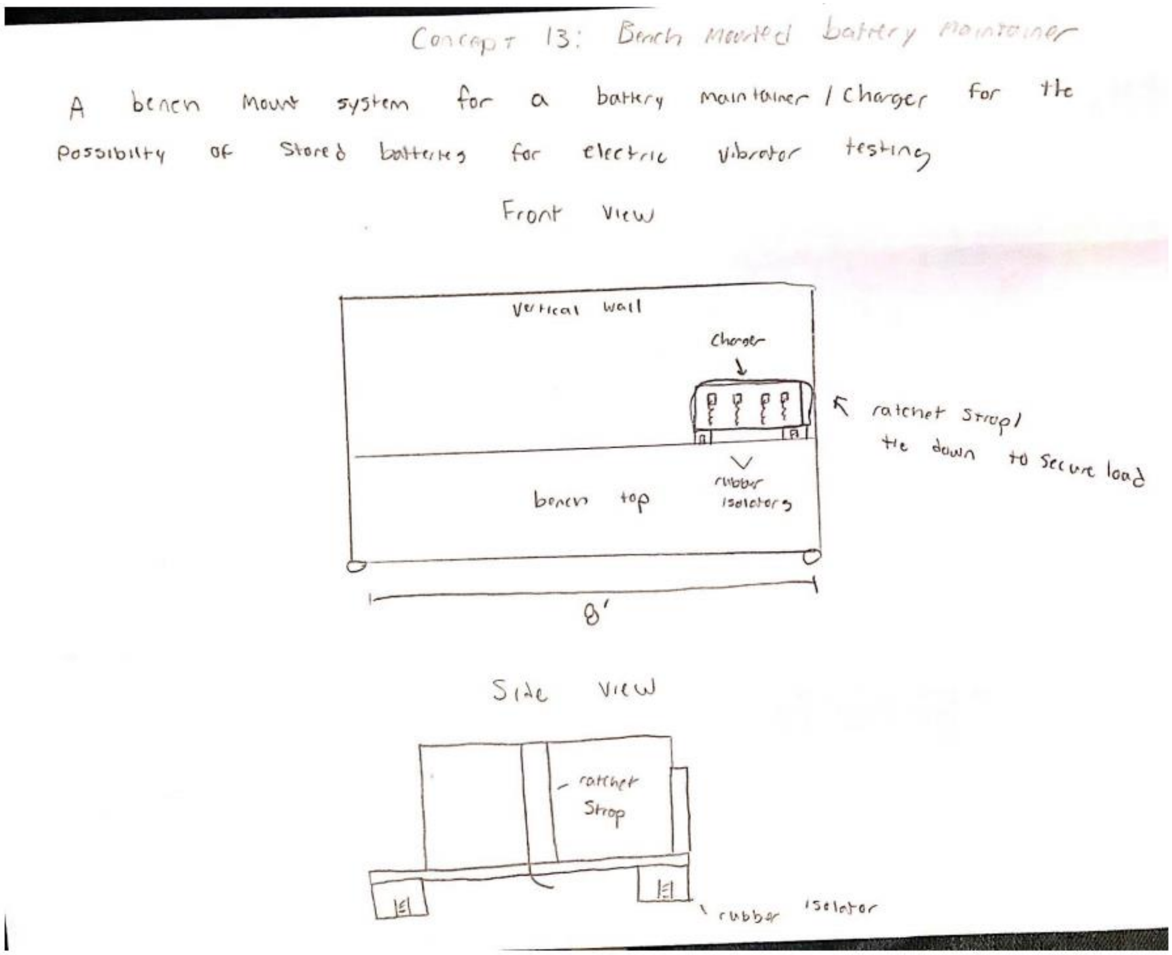

FIGURE 13: BENCHTOP BATTERY MAINTAINER

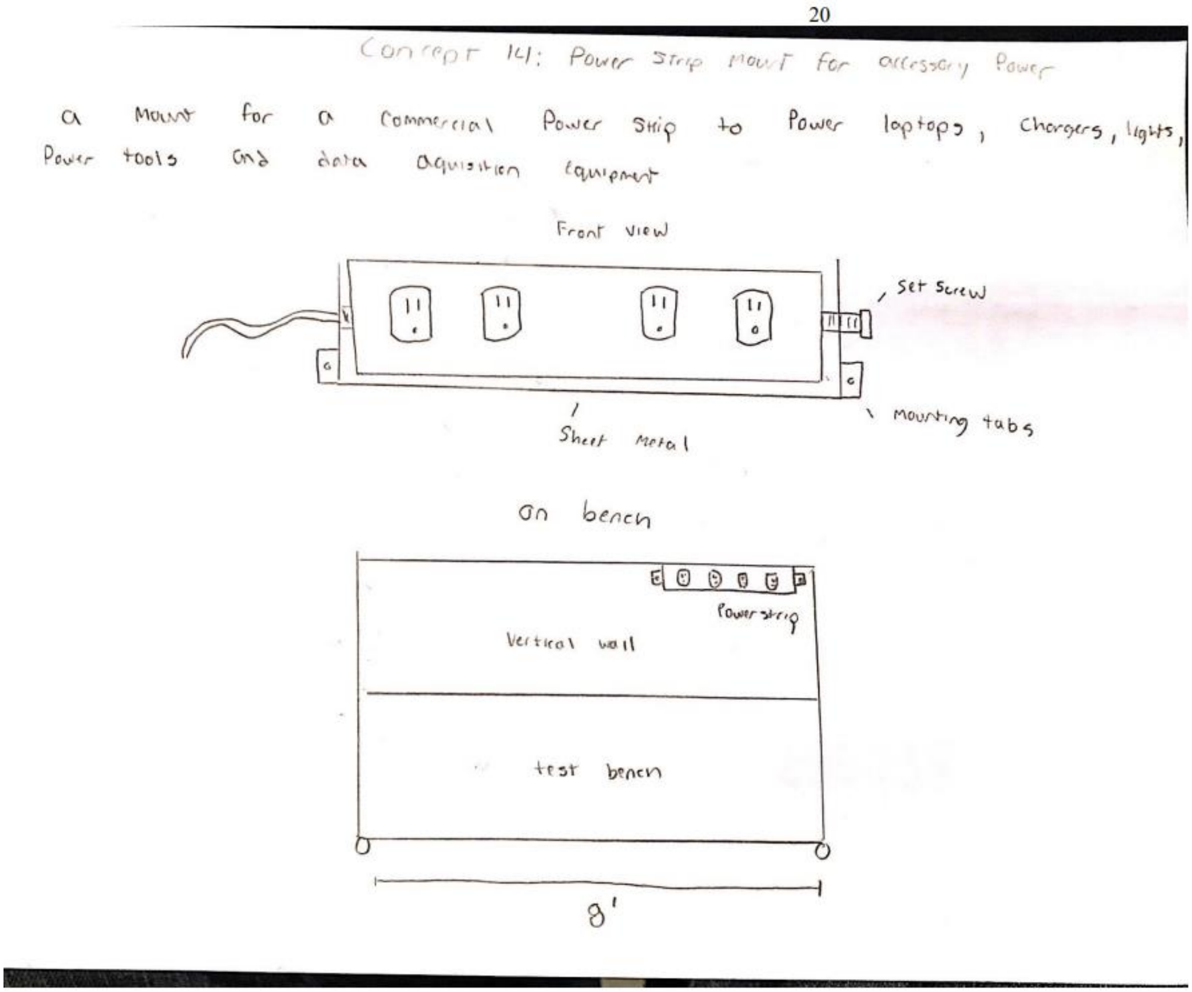

FIGURE 14: POWER STRIP MOUNT FOR ACCESSORY POWER

21

Concept 15: Emergency Shut off Switch

A simple button that will shut down all power to the test bench in case of accident

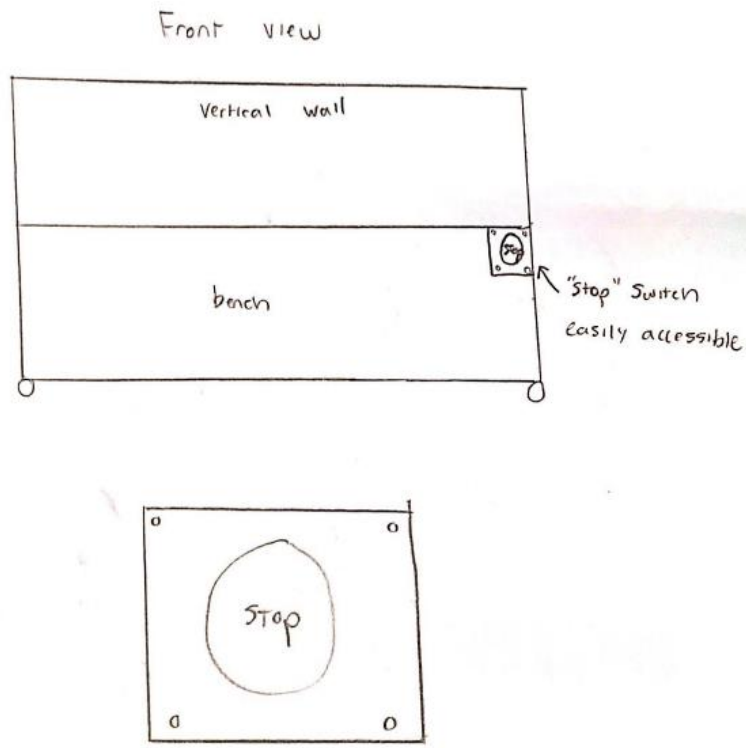

FIGURE 15: EMERGENCY SHUTOFF SWITCH

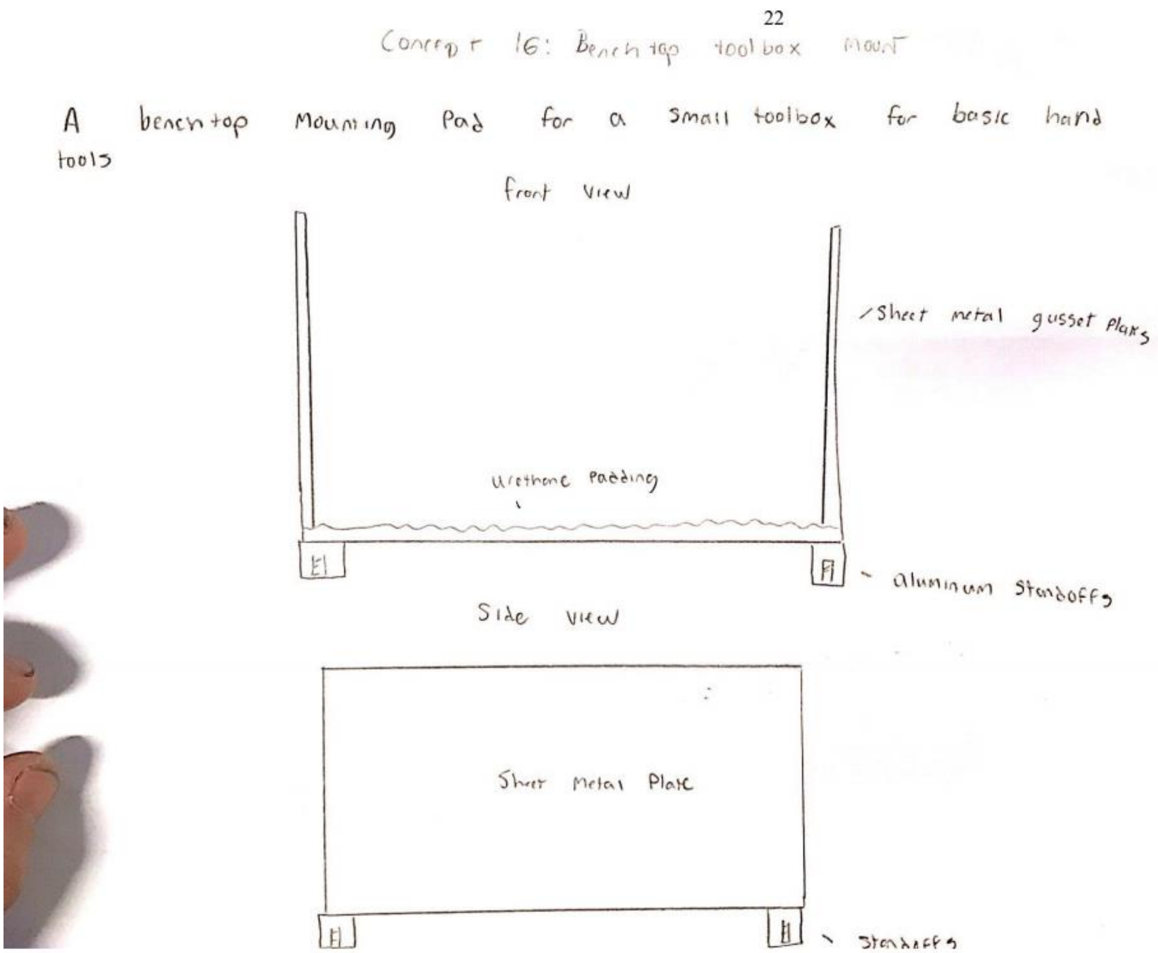

FIGURE 16: BENCHTOP TOOLBOX MOUNT

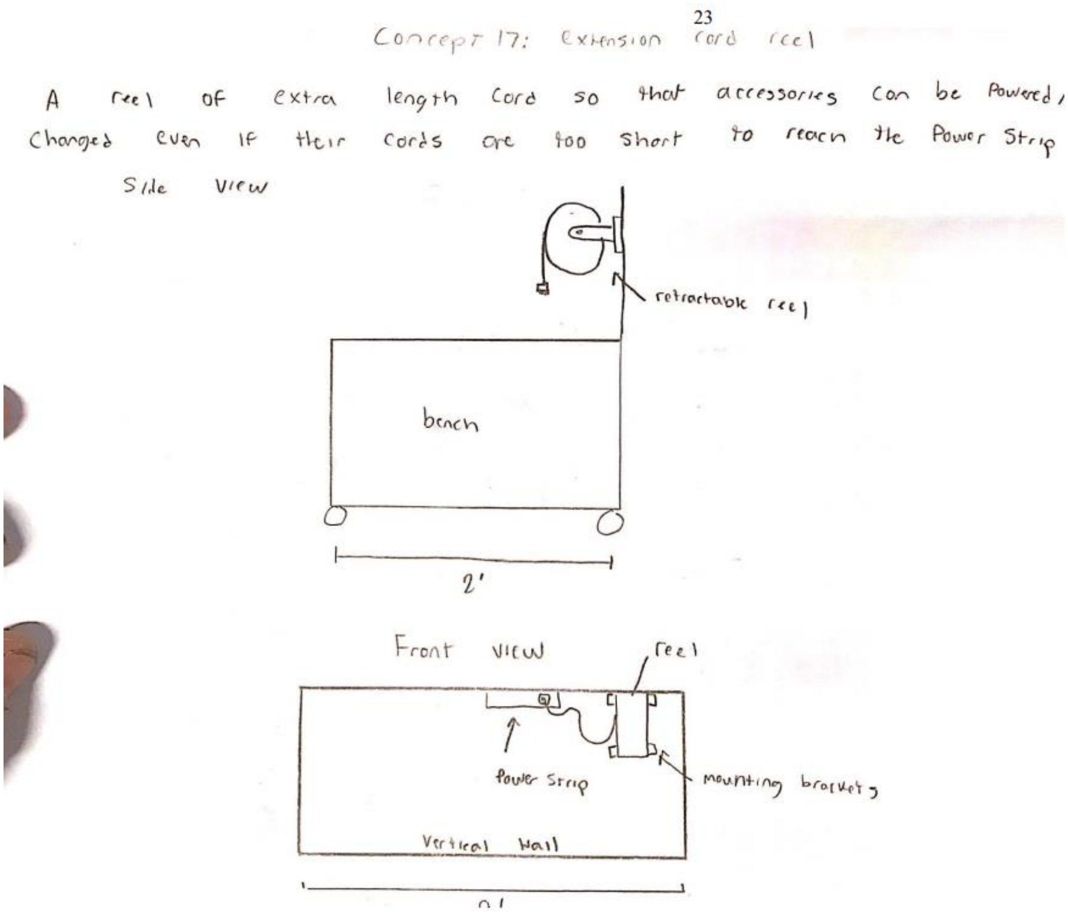

FIGURE 17: EXTENSION CORD REEL

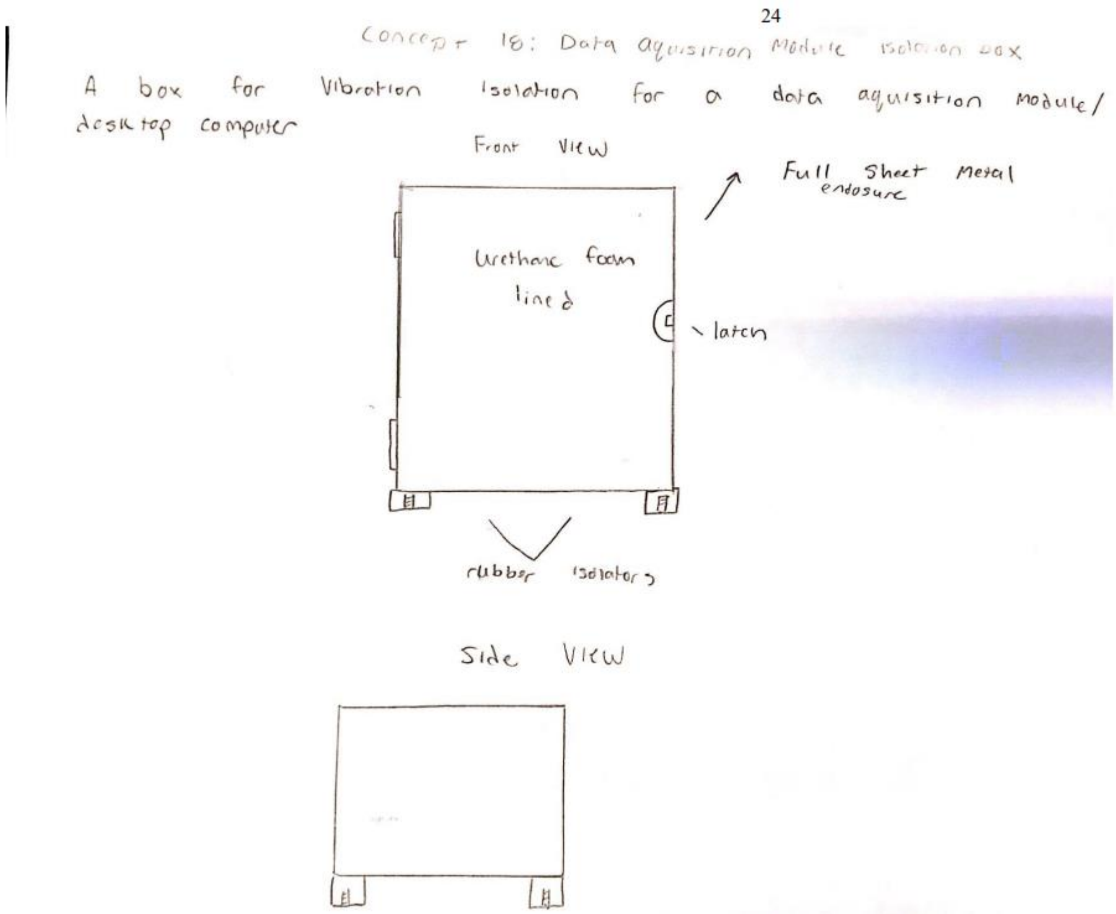

FIGURE 18: DATA ACQUISITION MODULE ISOLATION BOX

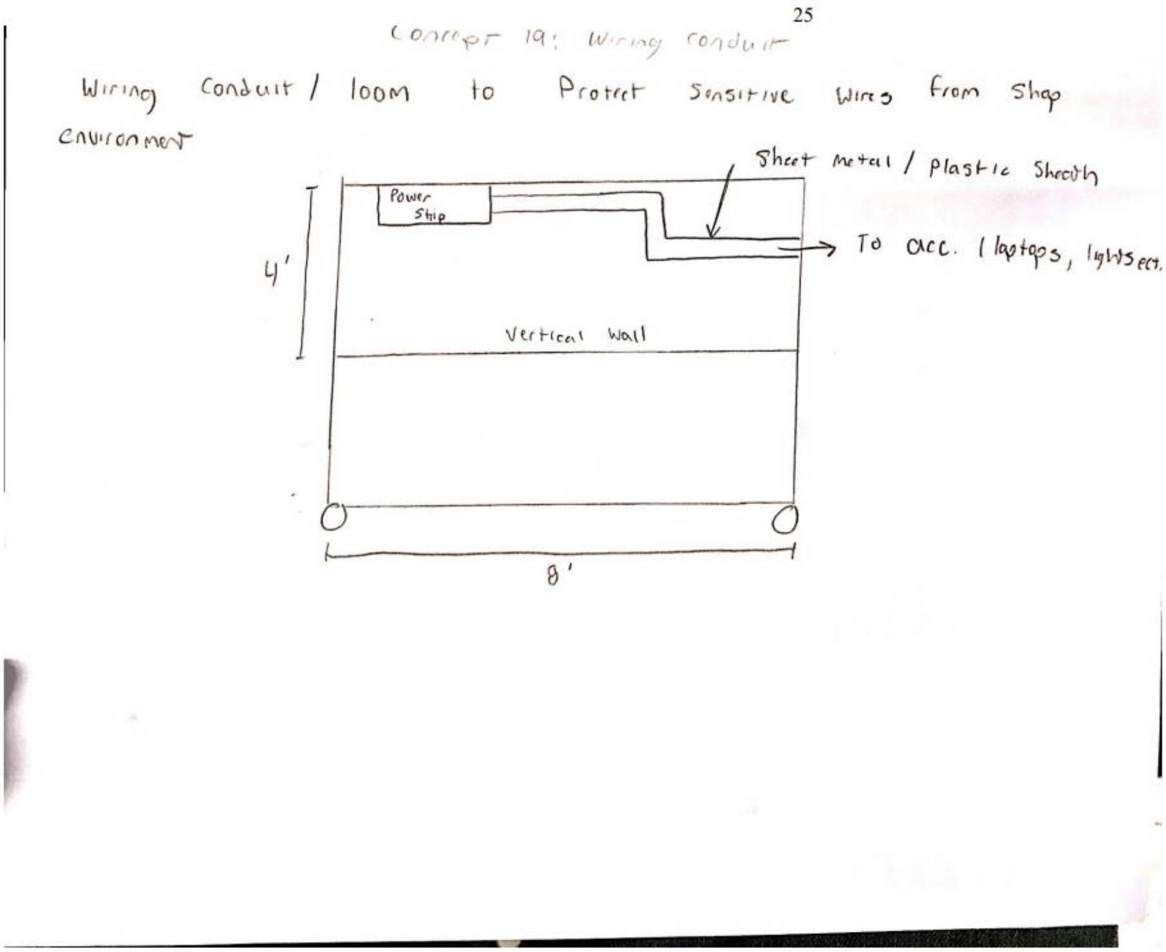

FIGURE 19: WIRING CONDUIT

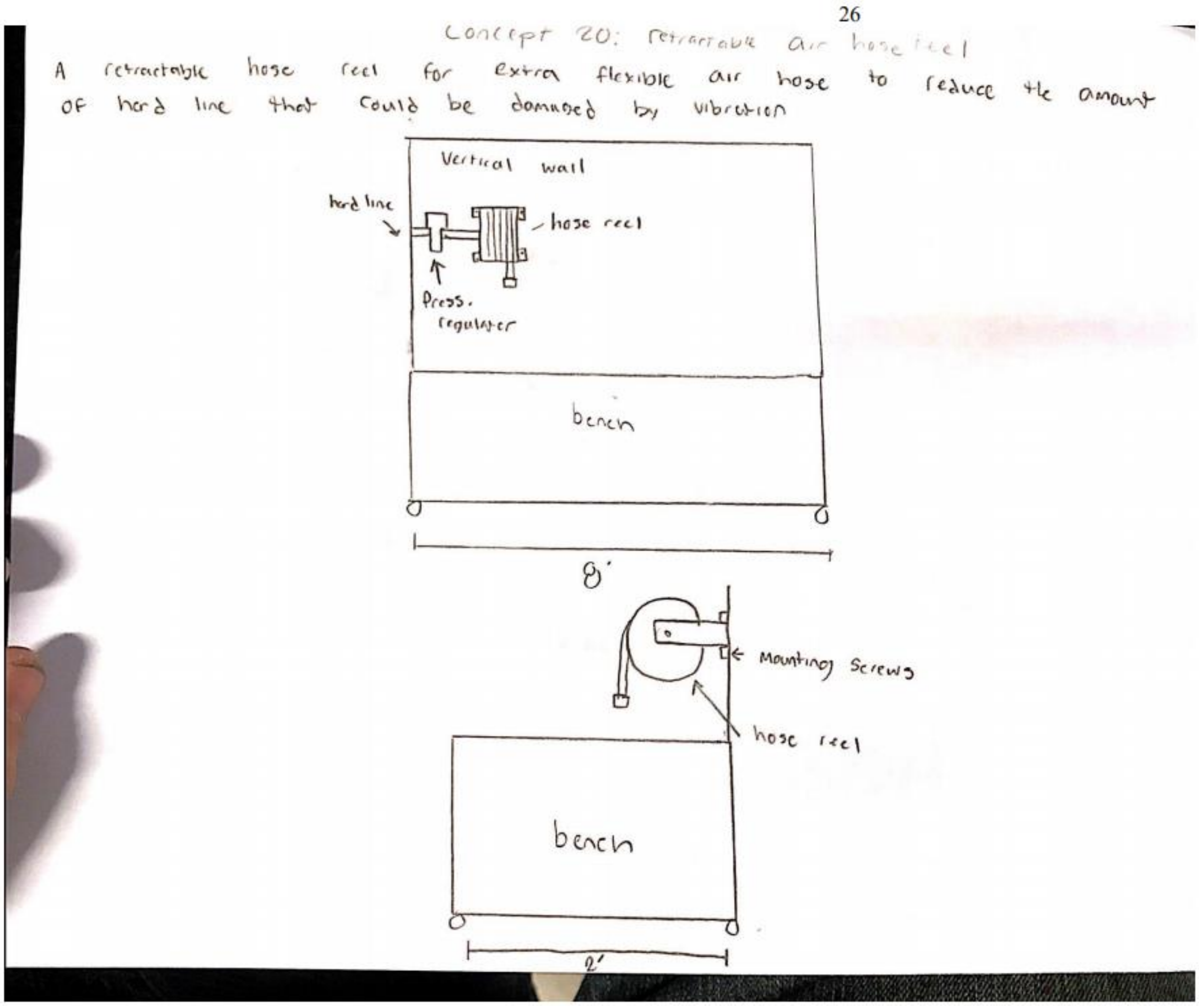

FIGURE 20: RETRACTABLE AIR HOSE REEL

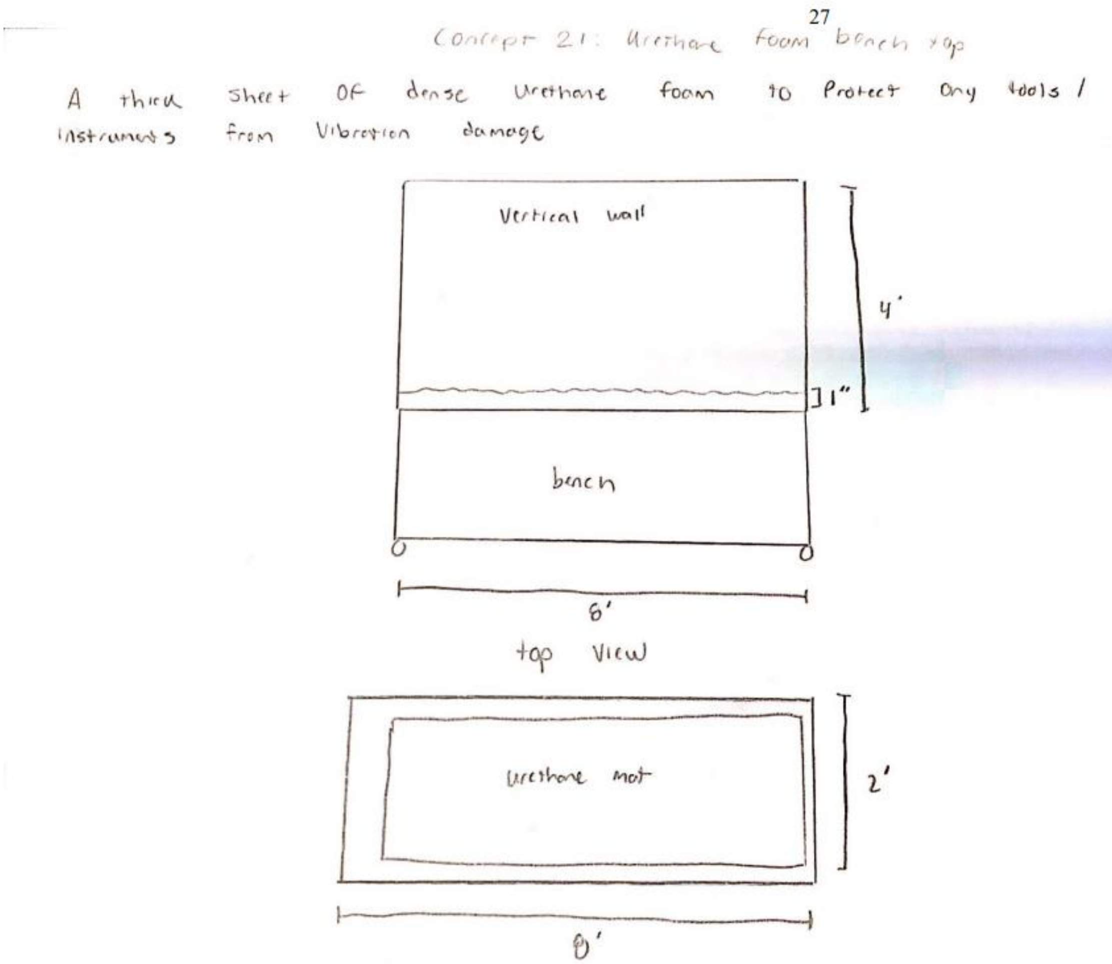

FIGURE 21: URETHANE FOAM BENCH TOP

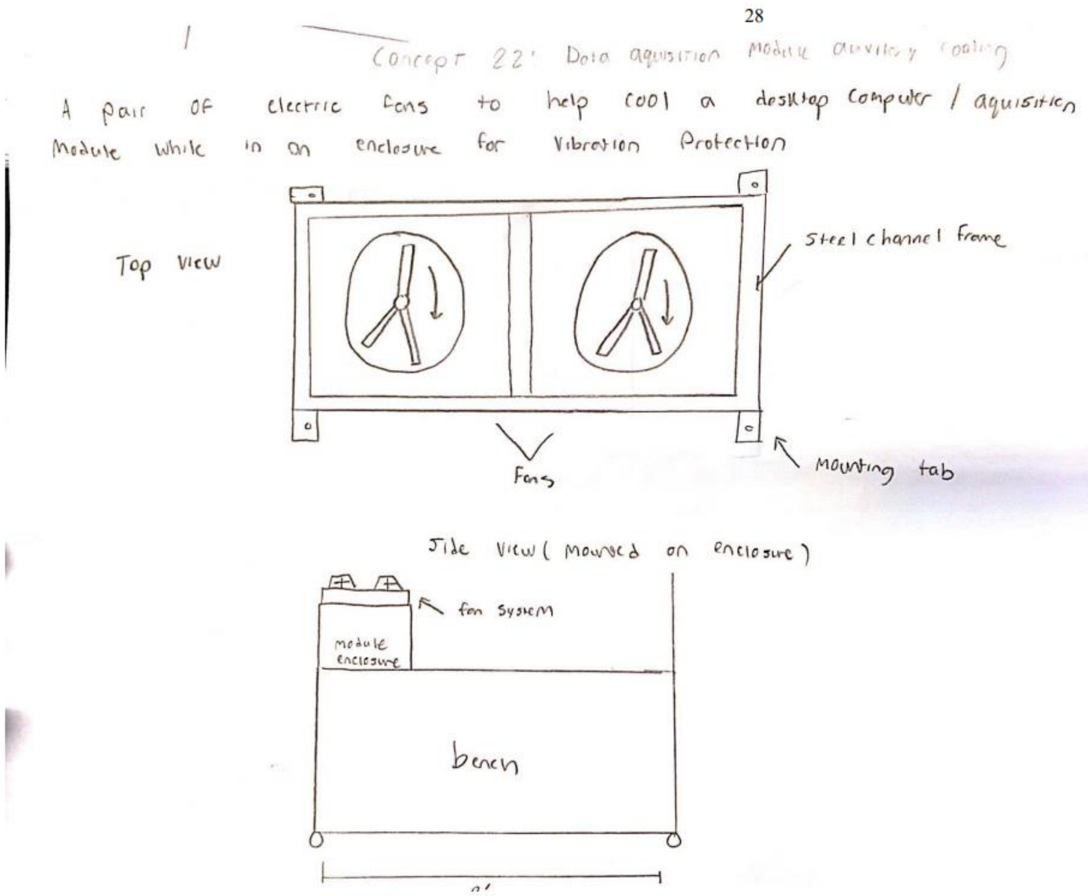

FIGURE 22: DATA ACQUISITION MODULE AUXILIARY COOLING

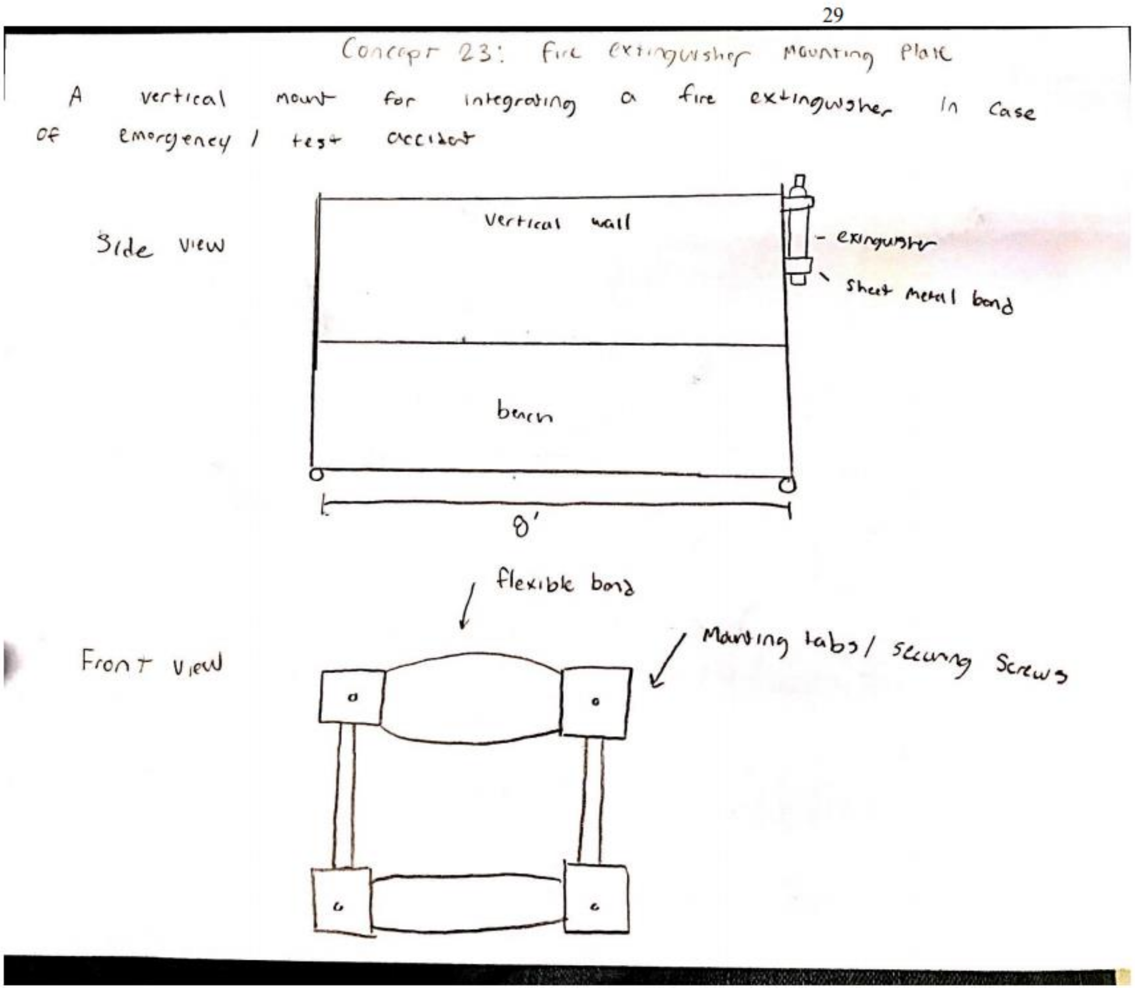

FIGURE 23: FIRE EXTINGUISHER MOUNTING PLATE

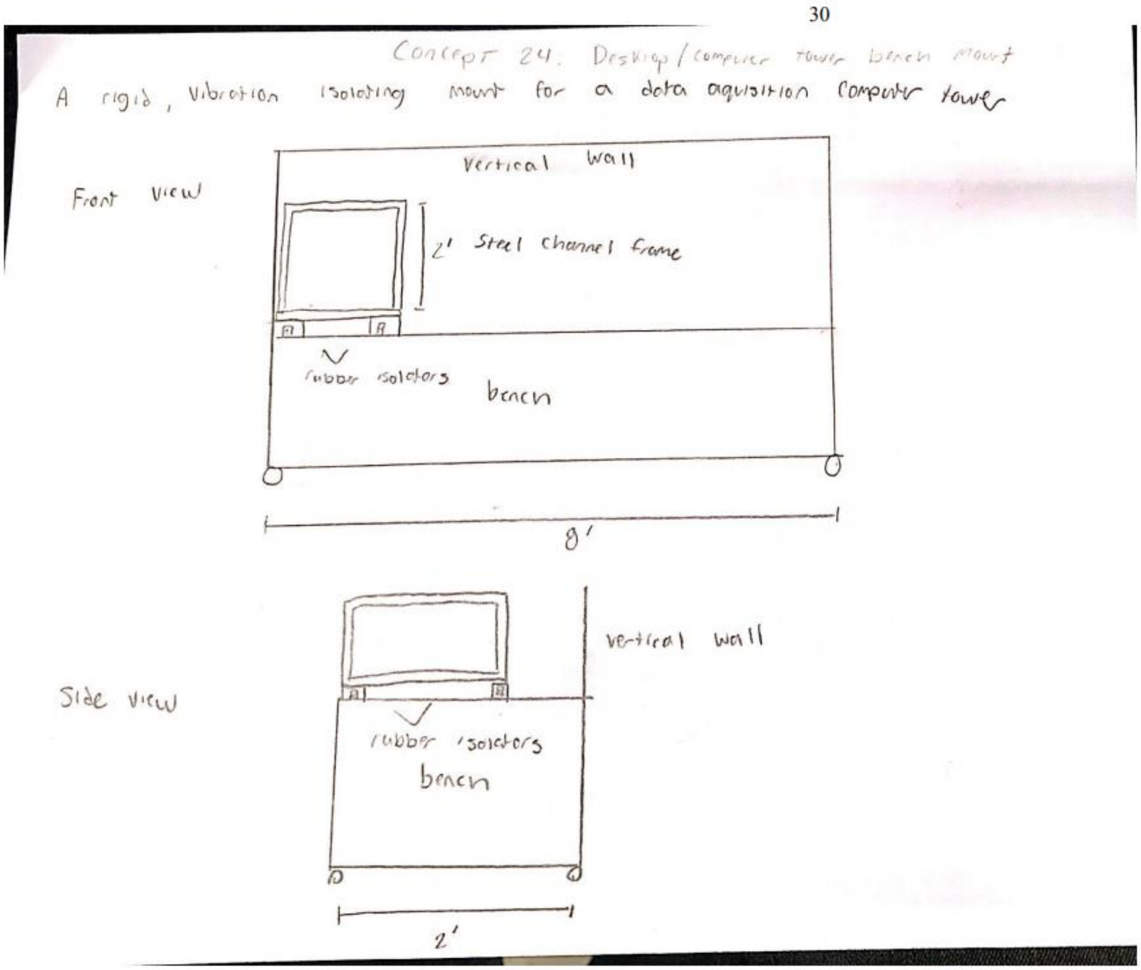

FIGURE 24: DESKTOP/COMPUTER TOWER

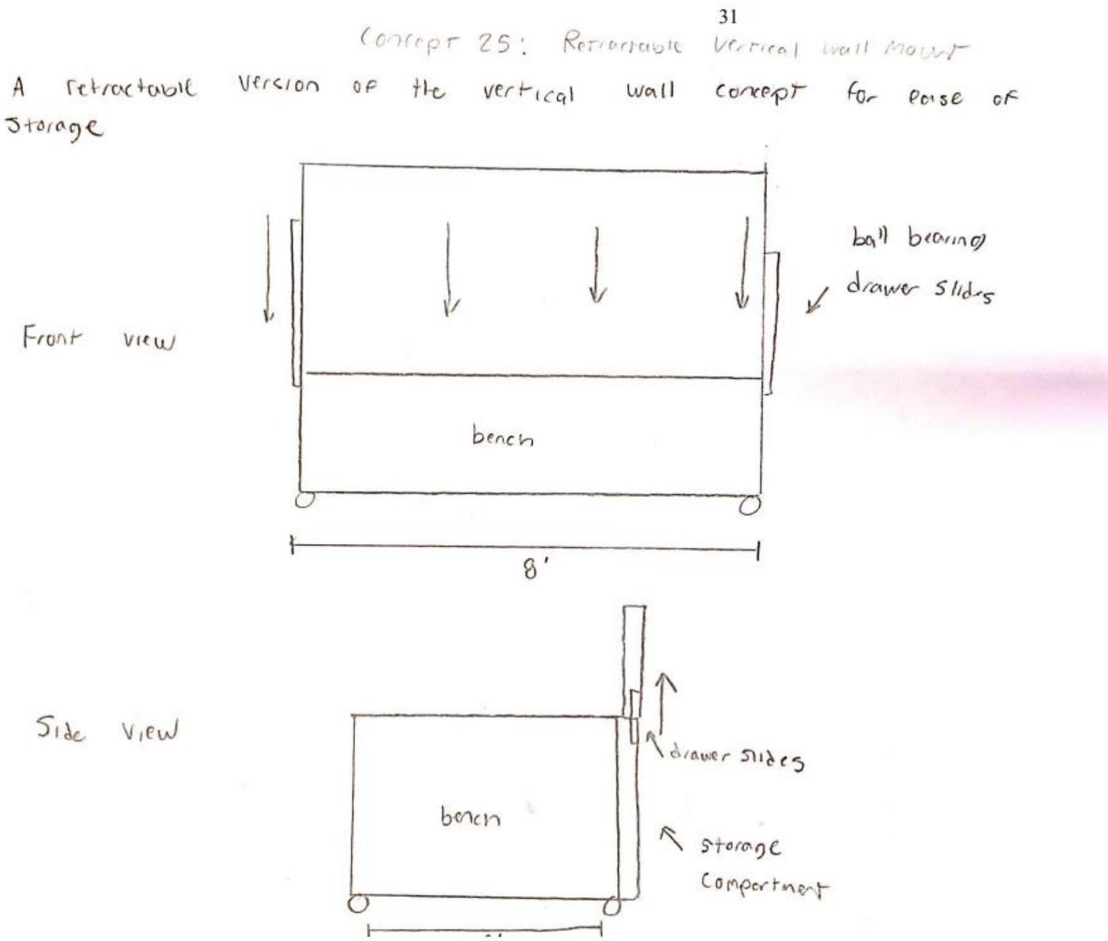

FIGURE 25: RETRACTABLE VERTICAL WALL MOUNT

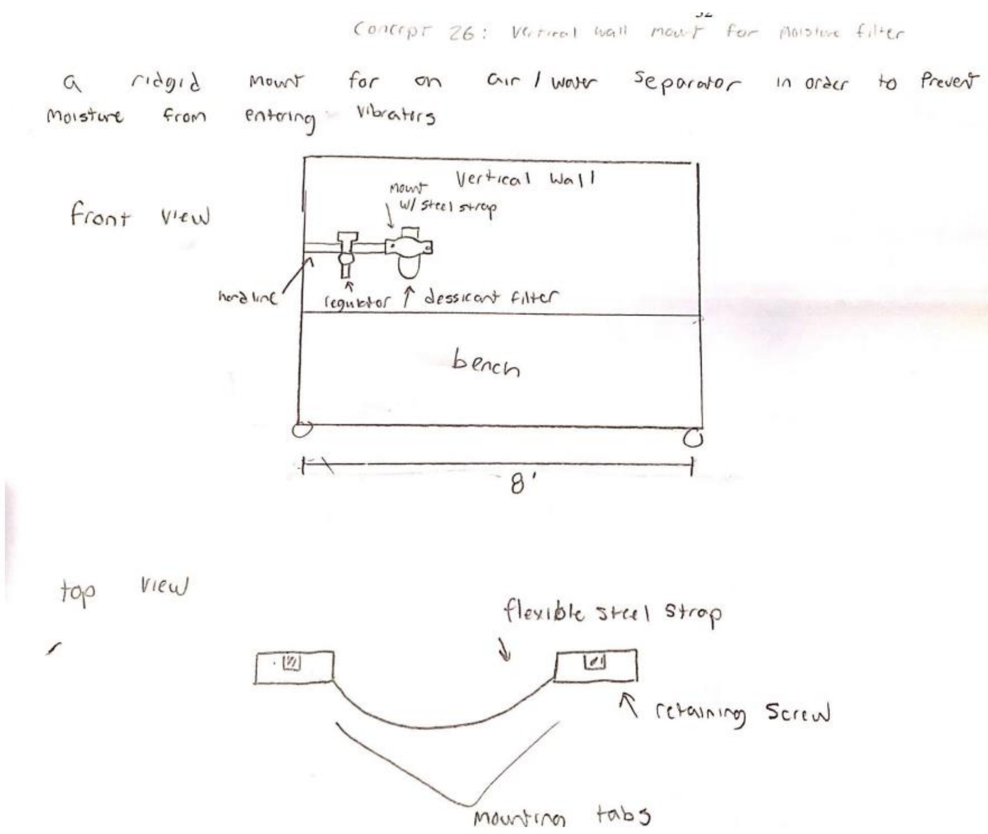

FIGURE 26: VERTICAL WALL MOUNT FOR MOISTURE FILTER

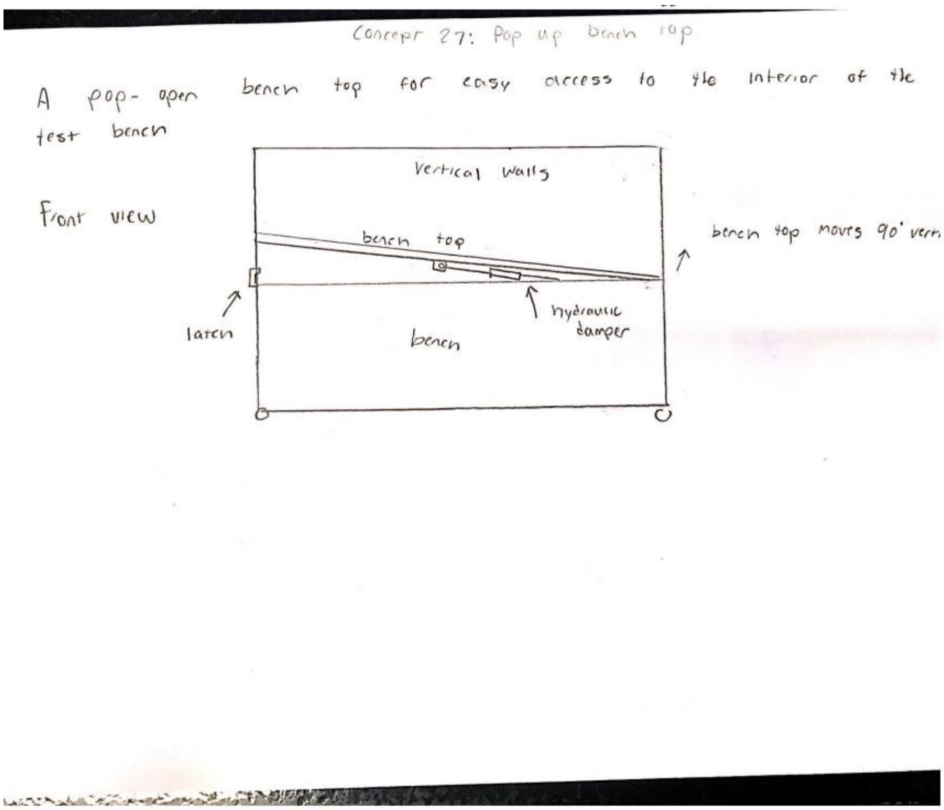

FIGURE 27: POP-UP BENCH TOP

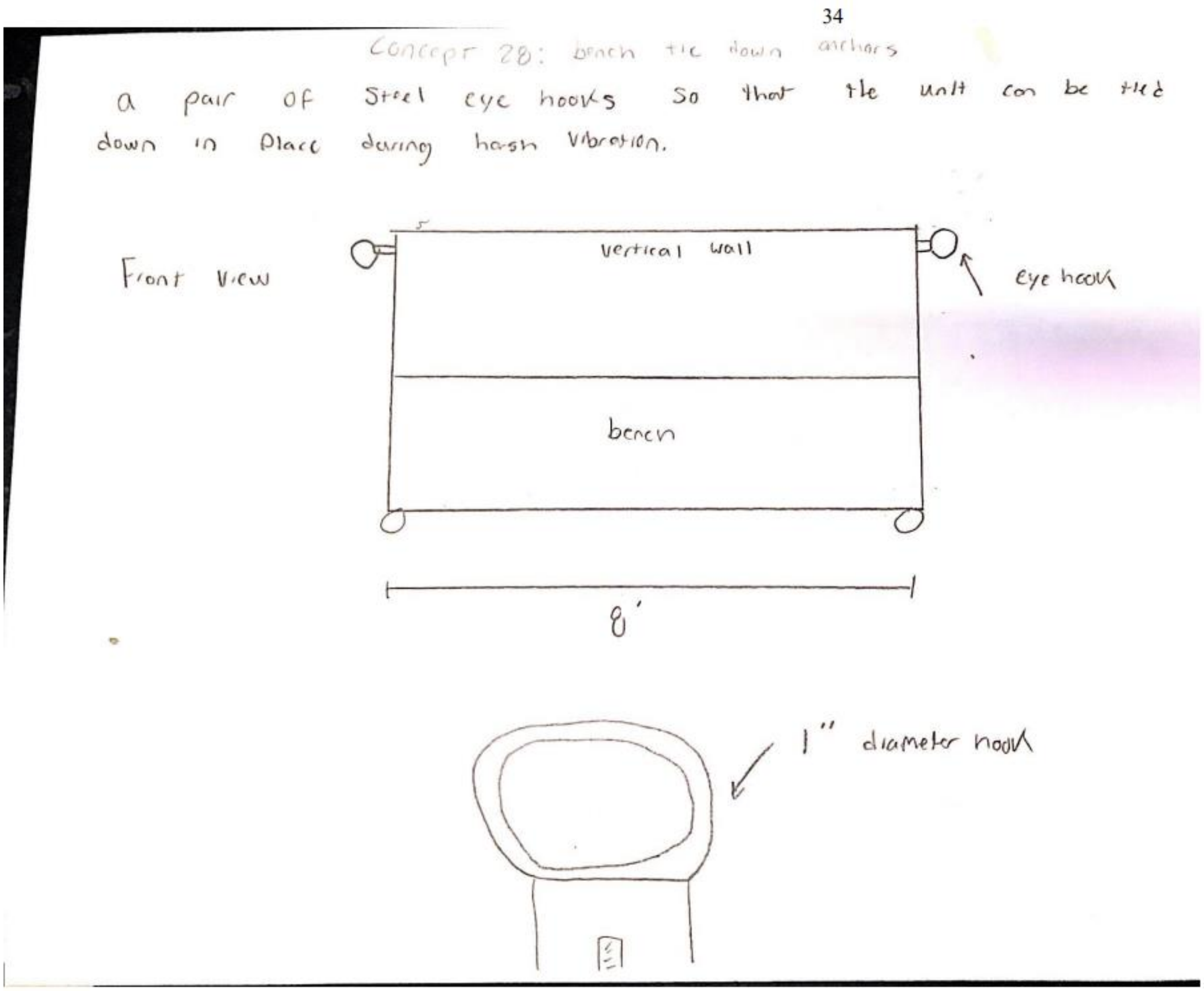

FIGURE 28: BENCH TIE DOWN ANCHORS

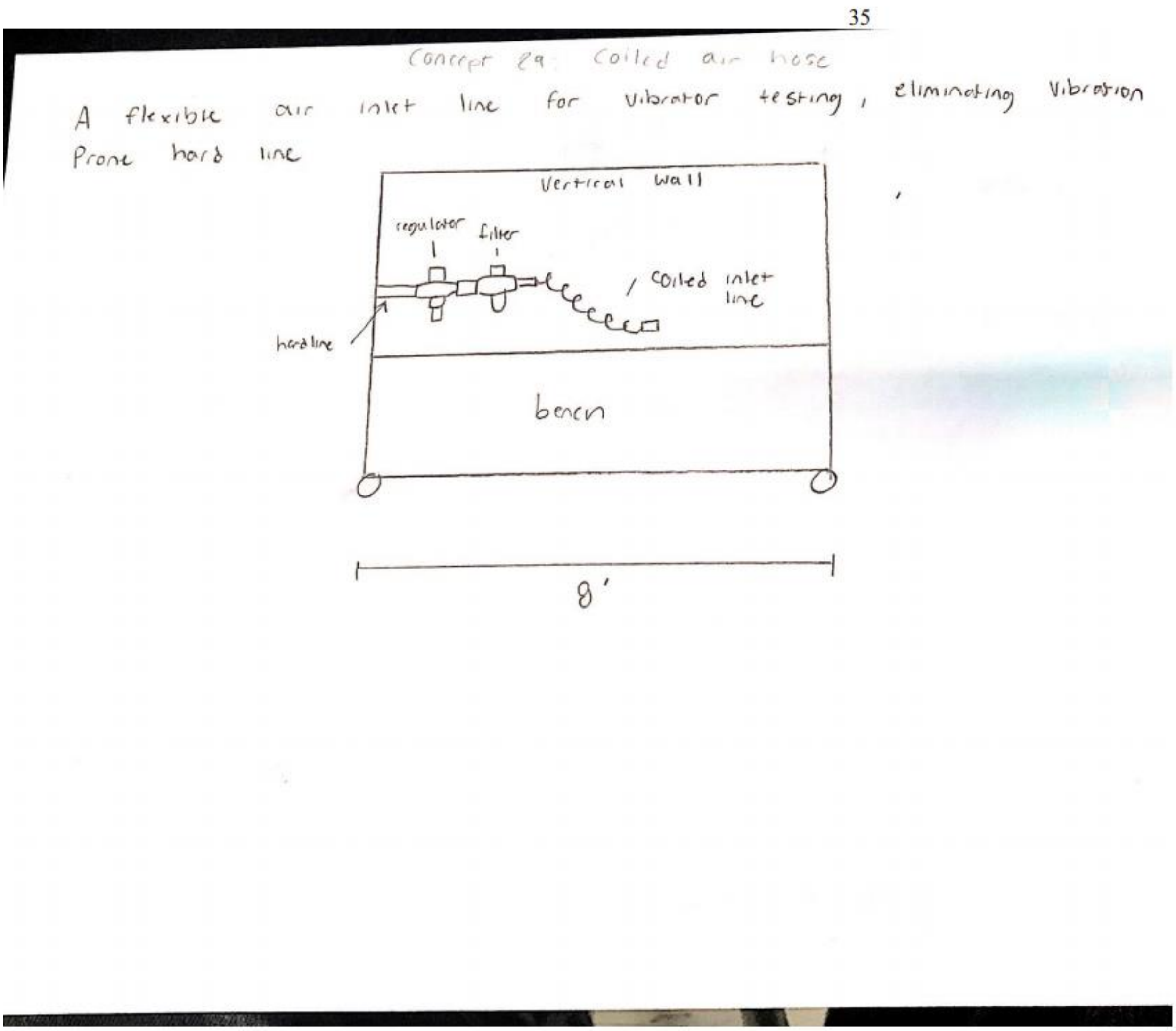

FIGURE 29: COILED AIR LINE

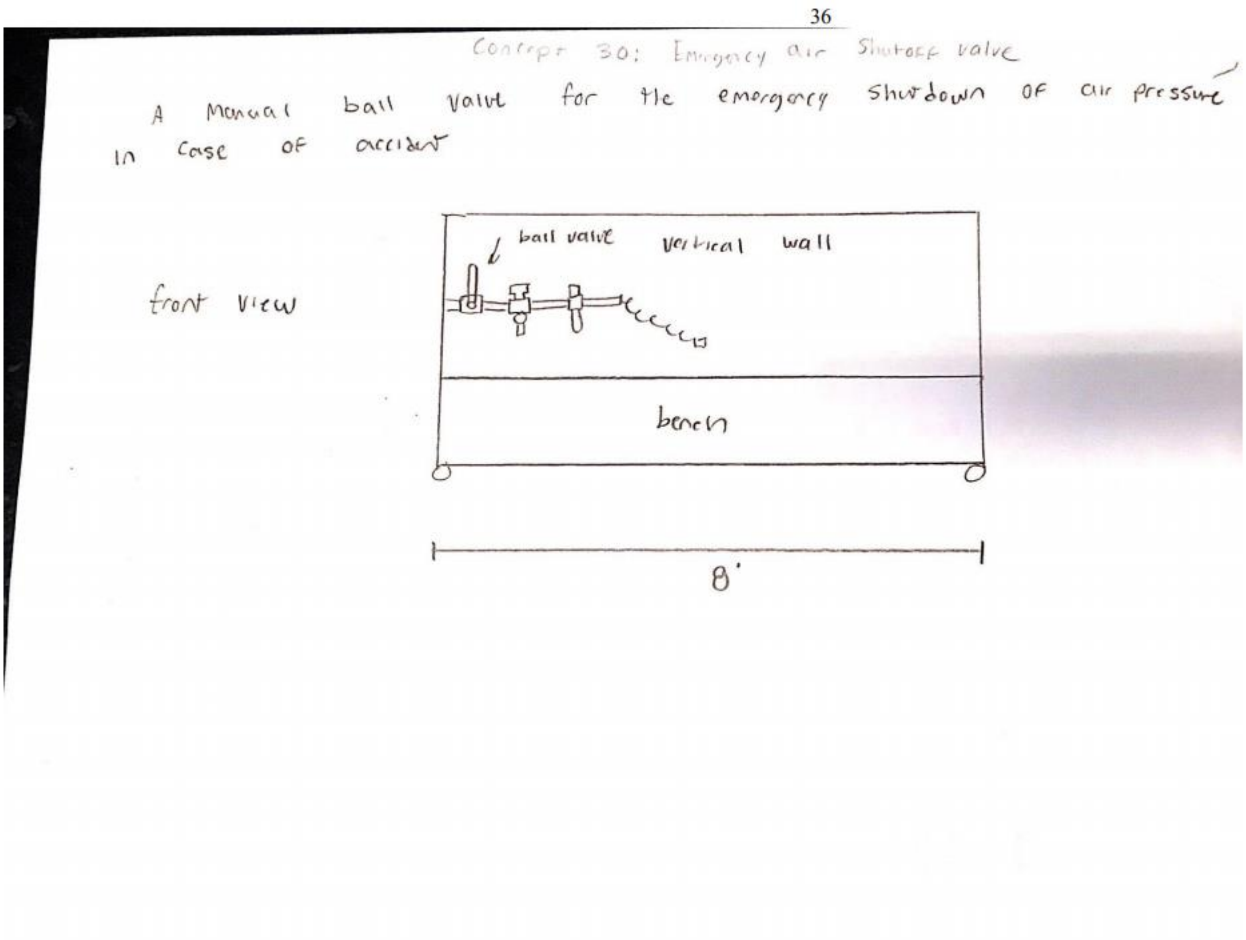

FIGURE 30: EMERGENCY AIR SHUT-OFF VALVE

Stephen Grabarz:

31. **Bench Surface Dimensions - 8' x 2'** - This is the maximum size of the bench we can produce, as specified by VIBCO's engineering team. This size bench would be more than capable of housing all of the components we need. However, it may not be necessary.

32. **Bench Surface Dimensions - 6' x 2'** - This size bench would take up 4 square feet less than the maximum allotted size, and therefore waste less of VIBCO's shop space. However, there would not be as much space for components.

33. **Bench Height – 4'** - The upper surface of the test bench would be 4 feet high.

34. **Bench Height – 3'** - The upper surface of the test bench would be 3 feet high.
We will consult the engineering team to learn which height would be most convenient for them to use.

35. **Main Bench Material – Aluminum** - An aluminum bench would be lightweight, but more susceptible to damage from heavy vibrational loads.

36. **Main Bench Material – Steel** - Steel is much heavier than aluminum, but will likely be used as this will provide the durability required. This is likely the material the bench will be constructed from.

37. **Bench Construction – Bolted** - A bolted construction would allow the bench to be deconstructed, but may be problematic as most threaded fasteners loosen when strong vibrational loads are applied.

38. **Bench Construction – Welded** - A welded bench would be very solid and unable to be loosened by vibration, but would prevent the bench from being deconstructed. This is likely the option we will choose, since it will most likely not be required to be transported very often.

The following eight concepts describe the layout of the legs, supports, and casters that will be used on the bench. The two styles of casters are fixed direction and swiveling. The bench will have either four or six legs. The legs may be supported by one or more trusses for increased bench durability. We will inspect existing tables on VIBCO's shop floor to determine which of these layouts will be optimal.

39. **Four Legs – Four Swiveling** Casters - High portability, but potentially less durability.

40. **Four Legs – Two Swiveling Casters, Two Fixed Casters** - Slightly lower portability, but would potentially give the bench more stability.

41. **Six Legs – Six Swiveling Casters** - A six-leg design would give the bench more rigidity, but may be unnecessary for our purposes.

42. **Six Legs – Four Swiveling Casters, Two Fixed Casters** - This design would give slightly more stability, but may be difficult to move around.

43. **Four Legs – Single Truss (each side)** - The addition of trusses would greatly increase the rigidity of the bench.

44. **Four Legs – Double Truss (each side)** - Two trusses in an "x" shape would further increase the bench's rigidity.

45. **Six Legs – Two Single Trusses (each side)** - Adding trusses to a six-leg design would be extremely rigid, but probably overkill.

46. **Six Legs - Two Double Trusses (each side)** - Similar to concept 14, but with two additional legs.

47. **Six Legs – Two Drawers** - Drawers under the bench surface would provide convenient storage for the operator. However, this design may be difficult to implement.

48. **Six Legs – Two Drawers and Two Cabinets** - These cabinets would add further storage to the bench but may not be necessary. After all, the bench is designed to require as little external equipment as possible.

49. **Six Legs – Two Drawers, Middle Platform w/ Easy Access Storage Containers** These containers are used often at VIBCO and would be very easy to implement on our bench. After further consideration, we will likely omit the drawers and simply add the middle platform to house the containers.

50. **Bench Surface Isolators – Solid Rubber** - Solid rubber mounts to keep the surface of the table isolated from external vibrations and prevent damage to the bench structure.

51. **Bench Surface Isolators – Rubber Air Bags** - These are similar to the solid rubber mounts, but are filled with air. They generally provide optimal dampening, and are already used by VIBCO on their vibrating tables.

52. **Bench Surface – Full Surface Isolated, Four Isolators** - The entire top surface of the bench would be vibration isolated, with an isolator on each corner.

53. **Bench Surface – Full Surface Isolated, Six Isolators** - The inclusion of two more isolators in the middle of the table would increase stability.

54. **Bench Surface – Half Surface Isolated, Four Isolators** - Only half of the top of the bench would be vibration isolated, with four isolators on the corners of the surface. This may be beneficial because the data acquisition equipment do not have to be isolated, and would be mounted on the un-isolated side.

55. **Computer Mounting – Slide Out from Side** - The computer would be mounted in a drawer that slides out from the side of the bench. This would save much space on the bench surface.

56. **Computer Mounting – On Surface** - The computer would simply be mounted on the top surface of the bench.

57. **Backing Plate – One Foot Tall** - A backing plate would prevent items from falling off the back side of the bench.

58. **Data Acquisition Unit Mounting – Below Bench Surface** - The Daxus units would be mounted beneath the surface of the bench, which would save space on the bench surface.

59. **Data Acquisition Unit Mounting – On Bench Surface** - The Daxus units would be simply mounted to the surface of the bench.

60. **Power and Air Supply/Regulator Mounting – Back Edge of Table** - The leads for the power supply and air supply regulator would be mounted on the corner of the bench pointing upwards.

61. **Power and Air Supply/Regulator Mounting – Under Table** - The leads for the power supply and air supply regulator would be mounted beneath the table, pointing outwards. This may save space, but make hooking up the units more cumbersome.

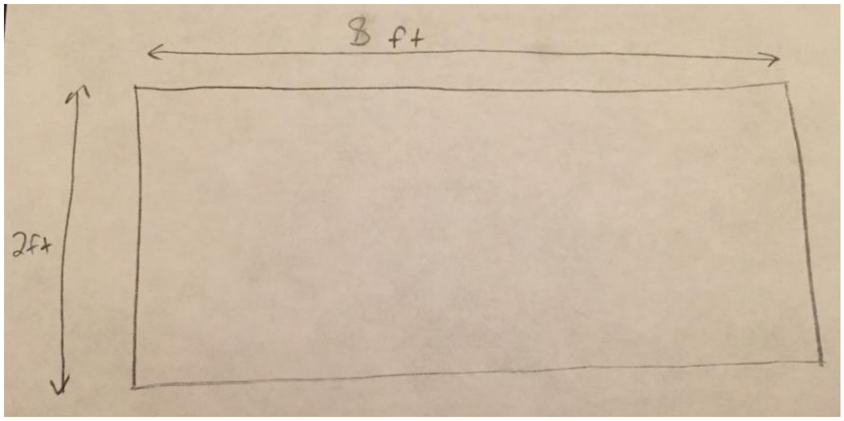

FIGURE 31: BENCH SURFACE DIMENSIONS – 8' X 2'

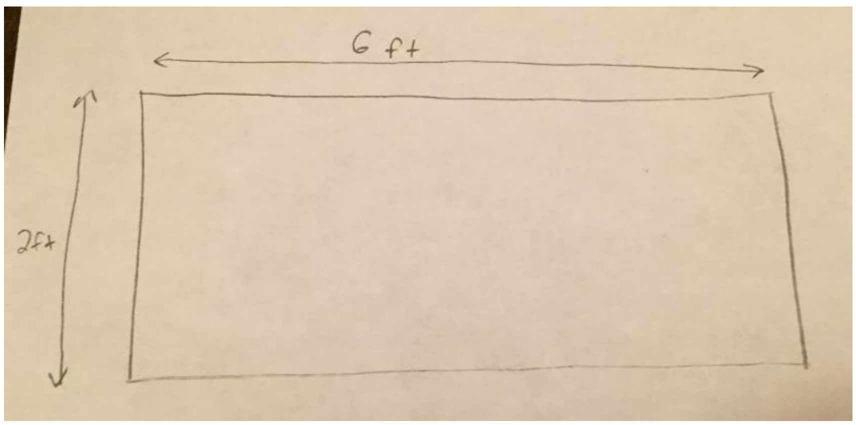

FIGURE 32: BENCH SURFACE DIMENSIONS – 6' X 2'

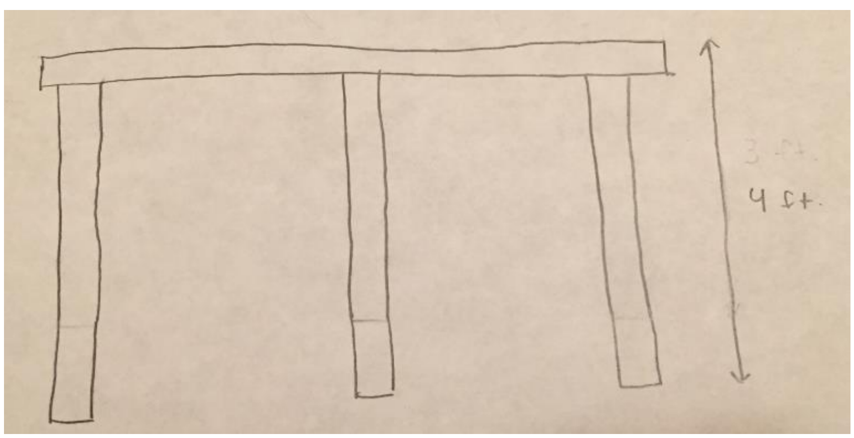

FIGURE 33: BENCH HEIGHT – 4'

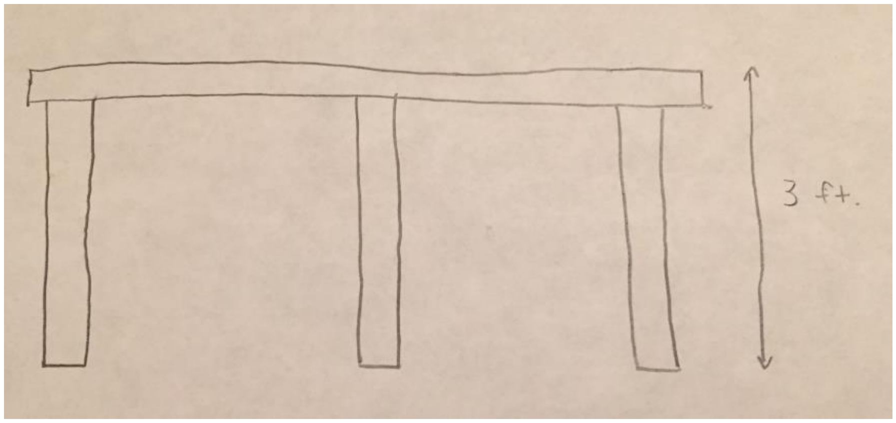

FIGURE 34: BENCH HEIGHT – 3'

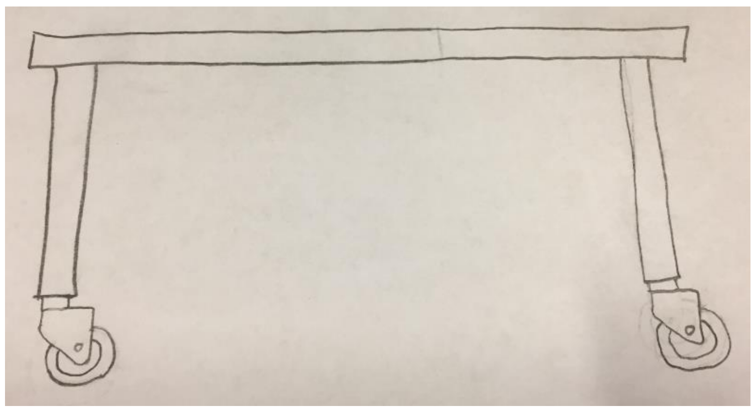

FIGURE 35: FOUR LEGS – FOUR SWIVELING CASTERS

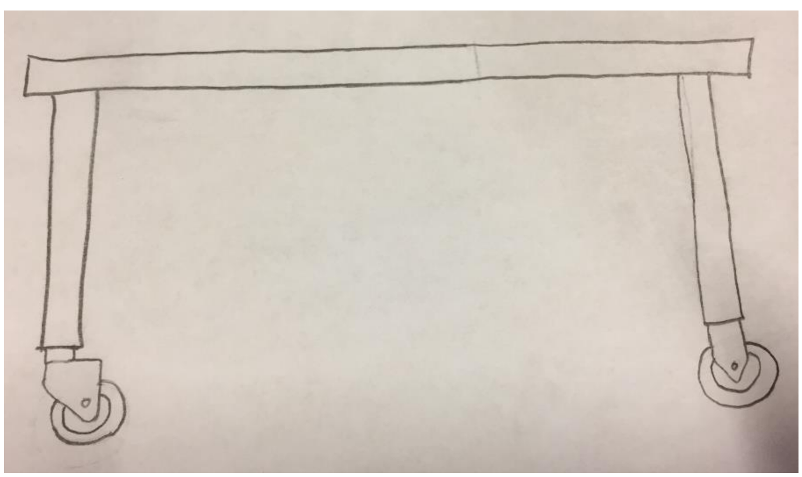

FIGURE 36: FOUR LEGS – TWO SWIVELING CASTERS, TWO FIXED CASTERS

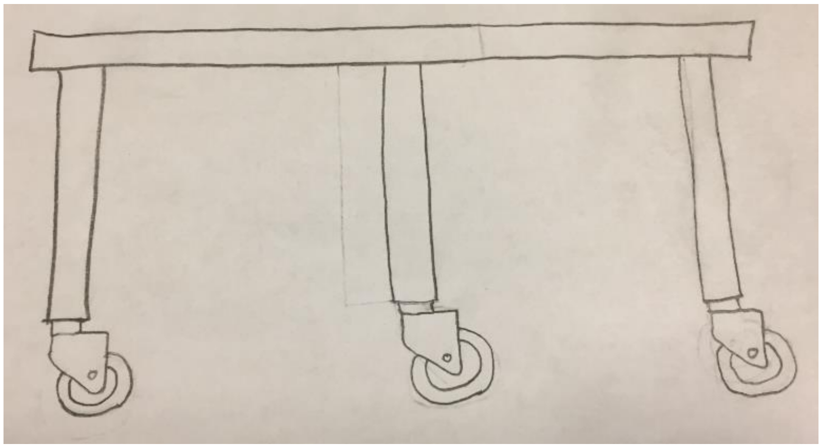

FIGURE 37: SIX LEGS – SIX SWIVELING CASTERS

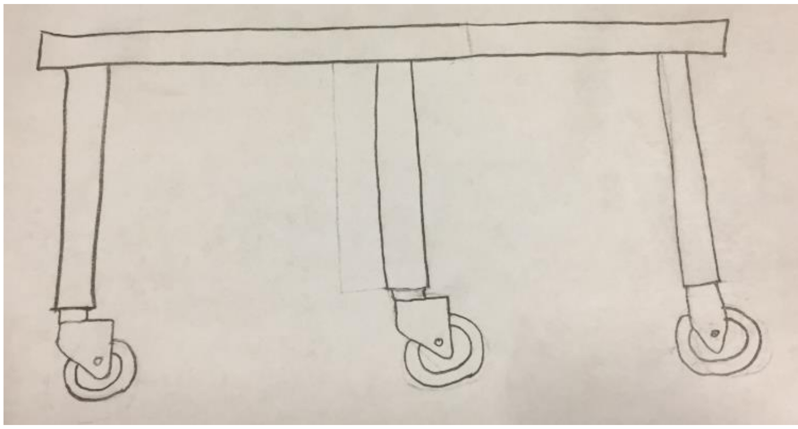

FIGURE 38: SIX LEGS – FOUR SWIVELING CASTERS, TWO FIXED CASTERS

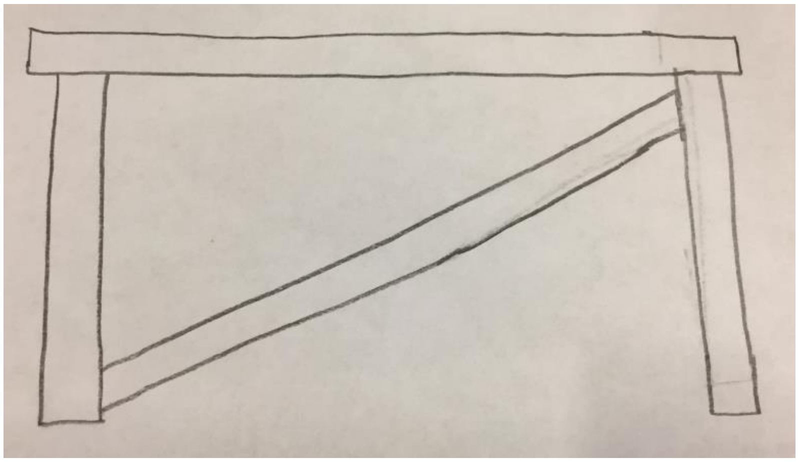

FIGURE 39: FOUR LEGS – SINGLE TRUSS (EACH SIDE)

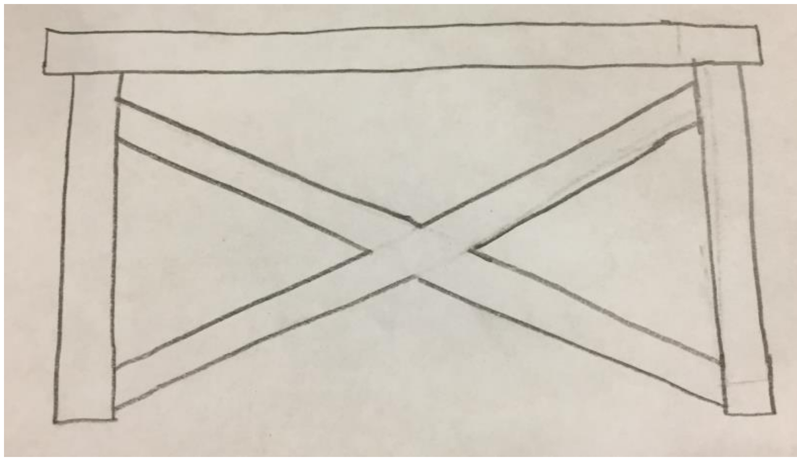

FIGURE 40: FOUR LEGS – DOUBLE TRUSS (EACH SIDE)

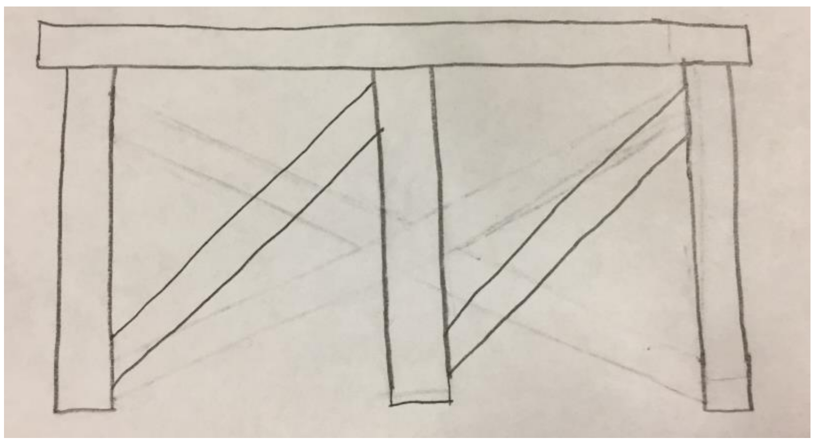

FIGURE 41: SIX LEGS – TWO SINGLE TRUSSES (EACH SIDE)

Six Legs- Two Single Trusses (each side)

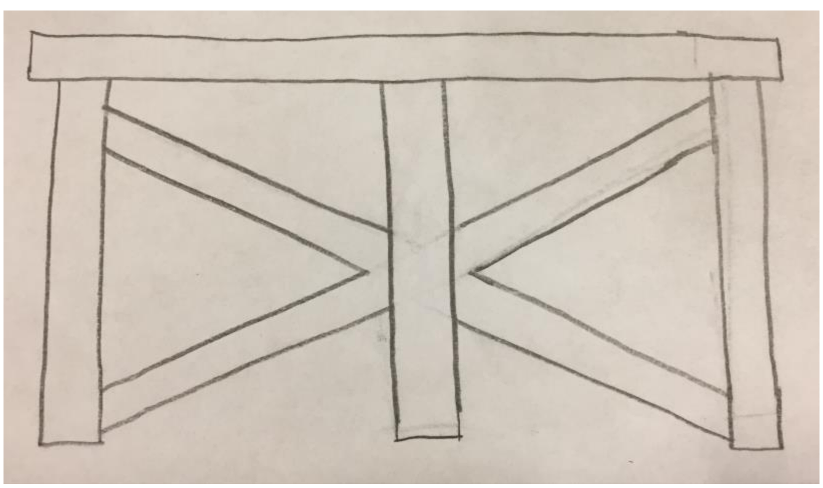

FIGURE 42: SIX LEGS – TWO DOUBLE TRUSSES (EACH SIDE)

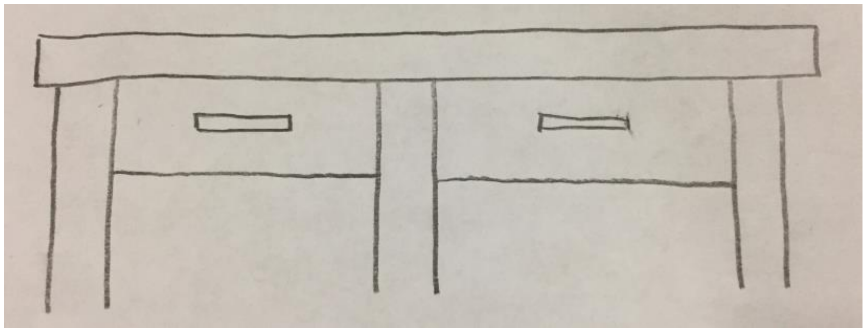

FIGURE 43: SIX LEGS – TWO DRAWERS

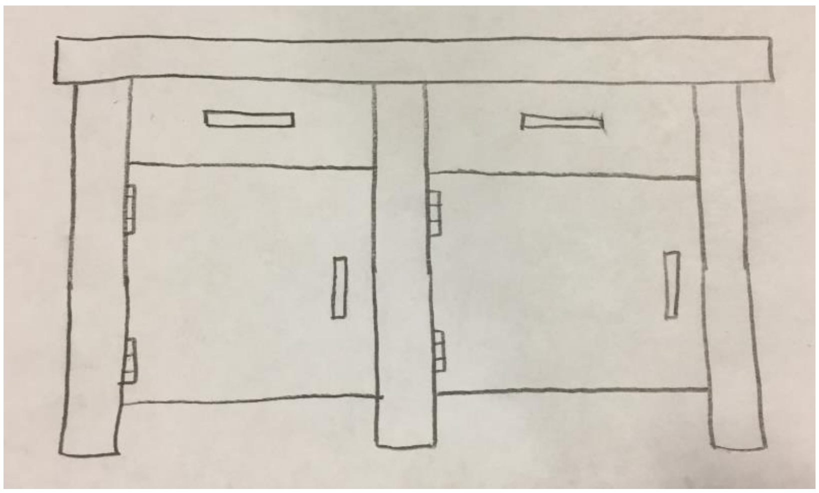

FIGURE 44: SIX LEGS – TWO DRAWERS AND TWO CABINETS

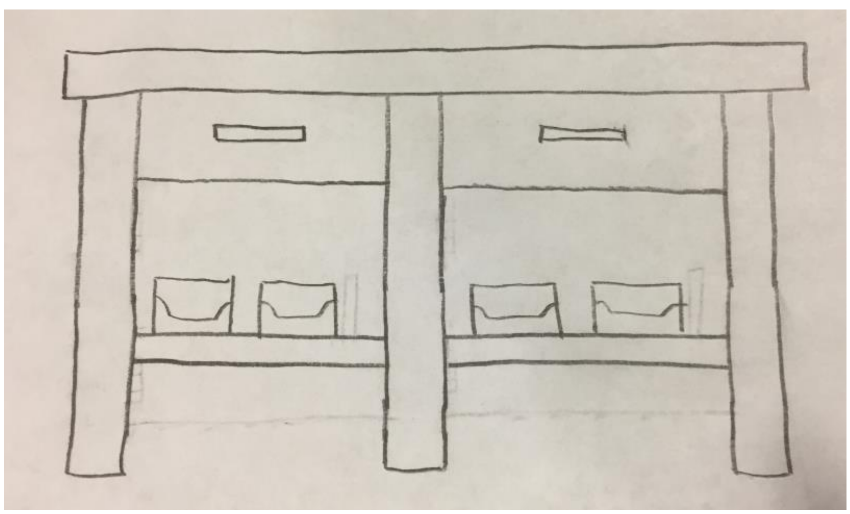

FIGURE 45: SIX LEGS – TWO DRAWERS, MIDDLE PLATFORM W/ EASY ACCESS STORAGE CONTAINERS

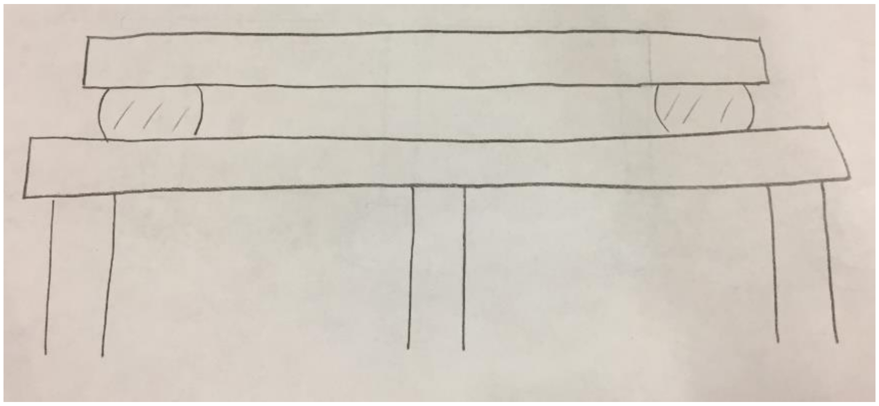

FIGURE 45: BENCH SURFACE – FULL SURFACE ISOLATED, FOUR ISOLATORS

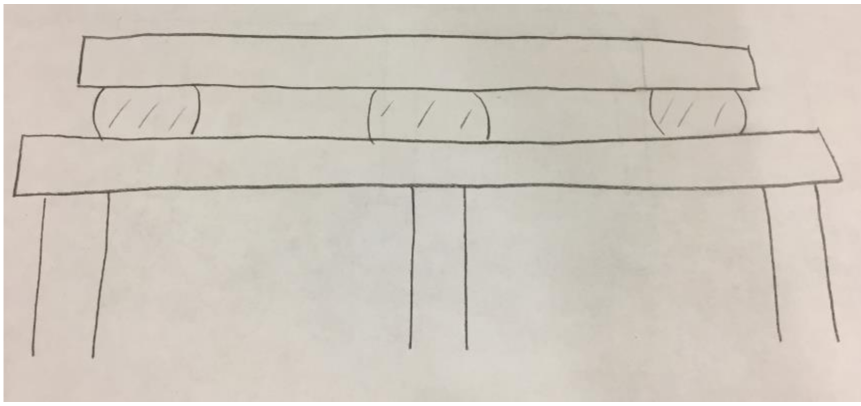

FIGURE 46: BENCH SURFACE – FULL SURFACE ISOLATED, SIX ISOLATORS

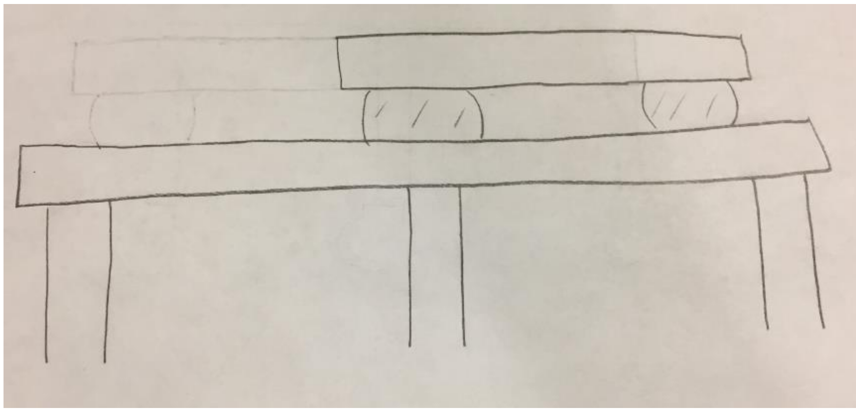

FIGURE 47: BENCH SURFACE – HALF SURFACE ISOLATED, FOUR ISOLATORS

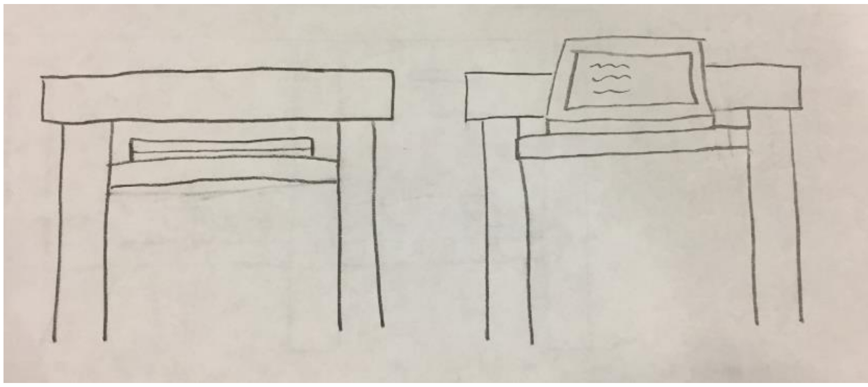

FIGURE 48: COMPUTER MOUNTING – SLIDE OUT FROM SIDE

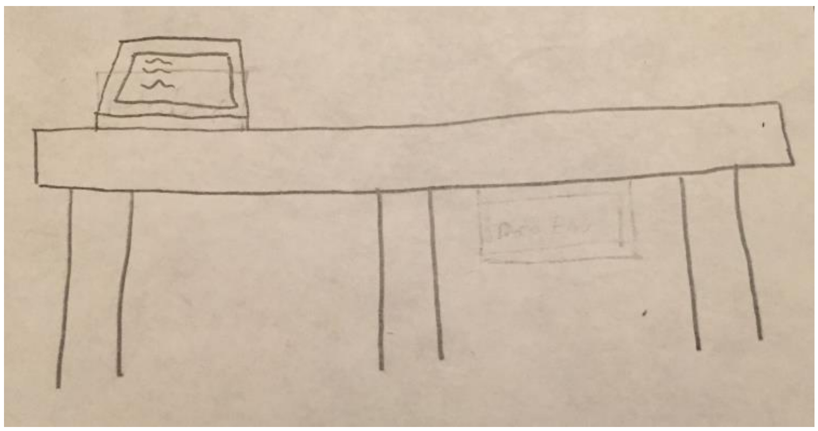

FIGURE 49: COMPUTER MOUNTING – ON SURFACE

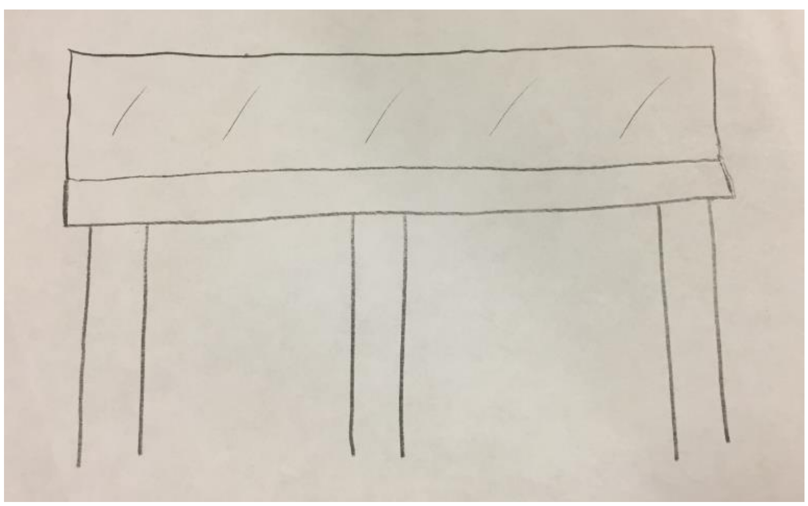

FIGURE 50: BACKING PLATE – ONE FOOT TALL

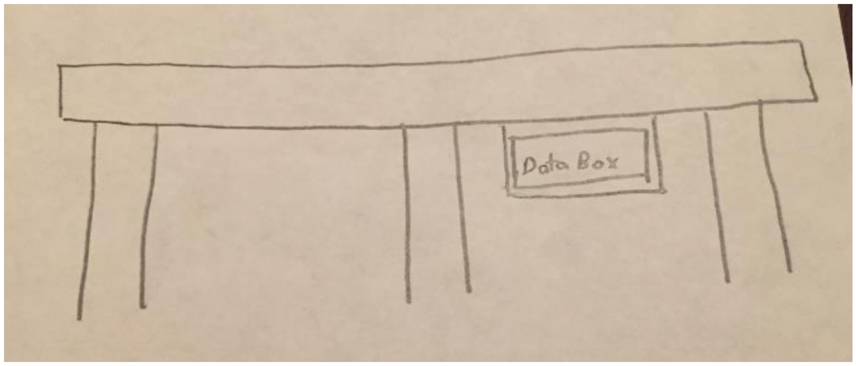

FIGURE 51: DATA ACQUISITION UNIT MOUNTING – BELOW BENCH SURFACE

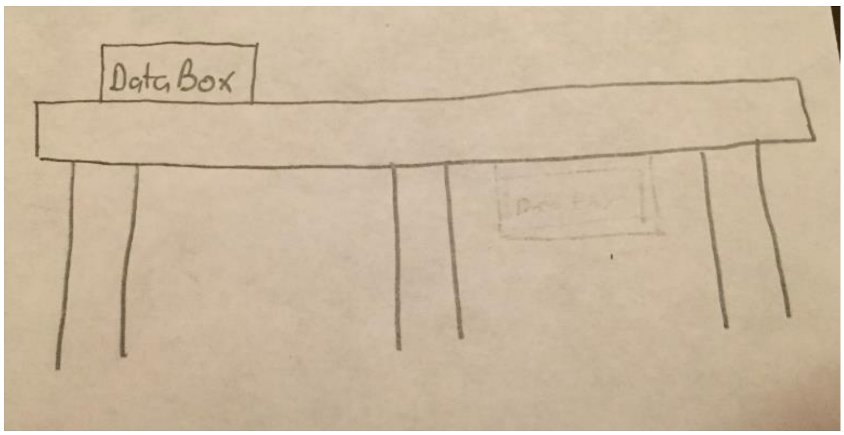

FIGURE 52: DATA ACQUISITION UNIT MOUNTING – ON BENCH SURFACE

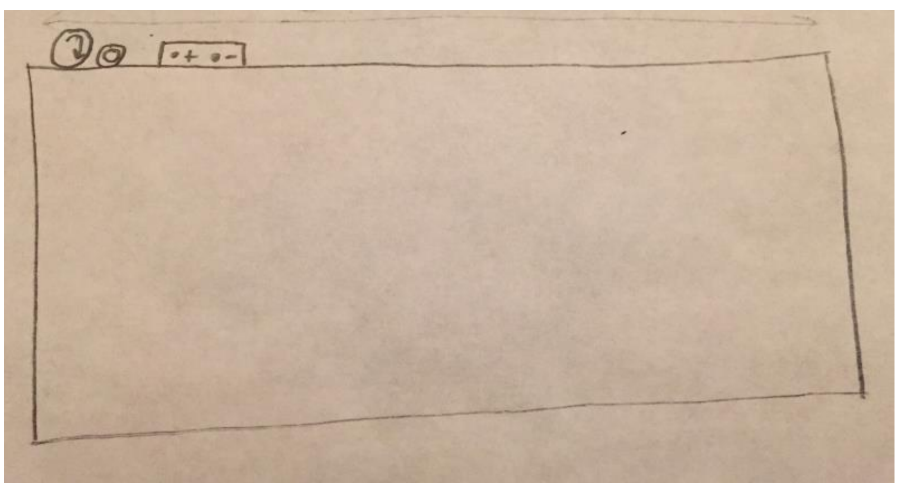

FIGURE 53: POWER AND AIR SUPPLY/REGULATOR MOUNTIN – BACK EDGE OF TABLE

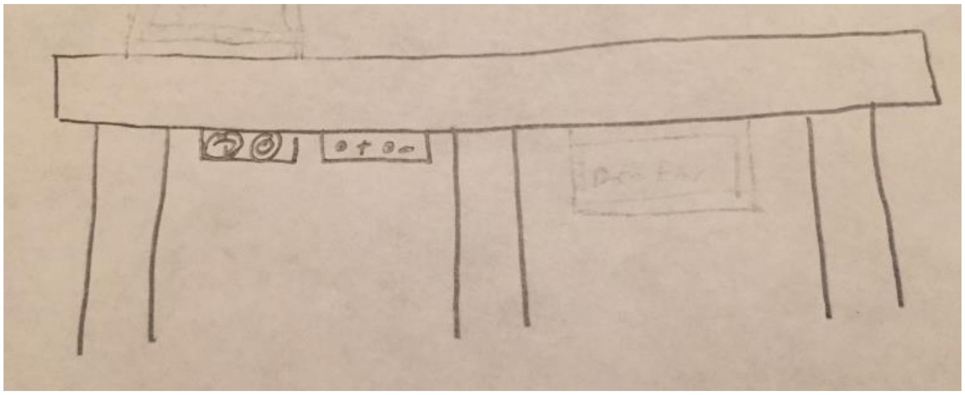

FIGURE 54: POWER AND AIR SUPPLY/REGULATOR MOUNTIN – UNDER TABLE

George Donoyan:

62. **Top-Down Mounting for Vibrator Adaption –** This concept was the original configuration for creating a system of modular plates with which to adapt a large number of vibrators to a relatively compact mounting point. This rendition is the most simplistic and minimalistic in terms of manufacturing ease and is the one that was chosen to be featured on the bench.

63. **Side Bolted Mounting for Adaptor Plates –** This concept incorporates two rails fixed to the bottom of each adaptor plate to slide in between the tabletop mounting rails and be fixed from the side with bolts. After further evaluation it was deemed too impractical because of the need for nuts to be threaded on the bolts under the plates which is a very small space.

64. **Slide on Adaptor Plates with Center Mounting Rails –** This concept features two rails fixed to the bottom of each adaptor plate with some of the inner portion of each rail machined off leaving a step which would slide into a notch machined into the rails mounted to the surface of the bench. This was deemed impractical for unnecessary machining and a lack of a locking system for securing the plate in place.

65. **Slide on Adaptor Plates with Edge Mounting Rails –** This concept features yet again two rails fixed to the bottom of the adaptor plates with the same machining of the previous concept's rails but with the rails located on the outside edge of the plate. These plates would be easier to machine and tight tolerances could ensure a snug fit but the concept was ditched due to lack of a reasonable locking system.

66. **Table Top Flush Mounted Plates with Counter Bored Bolt Holes –** This concept features a cutout of the top surface of the bench with a lip all around the perimeter on the bottom edge of the surface. This cut out area would accommodate an adaptor plate with counter bored threaded holes for mounting to the lip on the table surface and making the entire plate flush with the surface. This concept was not used after further evaluation due to concern for the strength of the lip and the plate not being thick enough

to maintain integrity around the mounting holes considering the holes being counter bored.

67. **Vise/ Clamp Mounted Adaptor Plates –** This concept shows a system of securing adaptor plates by clamping on a strip of metal fixed to the bottom of the adaptor plate. Concept not used because of the area above the metal strip not available to be drilled for bolt patterns.

68. **Table Top Mounted Adaptor Plates Secure by Metal Strips –** This concept is a system of securing the adaptor plates to the surface of the table by using two steel strips laid over the front and back edge of the plates and bolted on either side. This concept was not used because of the need for some sort of spacer on the bolts between the metal strips and the table and having to line up four spacers every time a plate needs to be bolted down would be too tedious for quick operation.

69. **Permanent fixture on Table Top with all Bolt Patterns Machined –** This concept employs a portion of the bench surface machined with all the bolt holes needed for all the vibrators. This would further increase the speed of affixing units for loaded testing but the concept was unused because of the dimensions of the bench top as a single piece of steel would be very difficult to machine accurately and would be a very expensive machining job.

70. **Slide In Table Top Plates –** This concept features adaptor plates with a groove machined into both sides which would slide into a notch machined into the sided of a cut out portion of the bench surface. Tight machining tolerance would ensure a snug fit but the concept was not used because of the nature of the environment the bench would be operating in. Dirt or debris could constantly get into the notch in the bench surface and cause issues removing and installing the plates.

71. **Accelerometer Mounting Points on Supporting Rail's Center –** This concept shows possible mounting points for accelerometers to collect VPM data. This positioning directly in the center allows for the most accurate data to be collected. This concept will be employed in the final product.

72. **Accelerometer Mounted Direct to Adaptor Plates –** This concept incorporates an accelerometer individually affixed to each adaptor plate with an easily accessible plug on a short length of wire for quick connecting and disconnecting of the sensor. After further analysis, concept not used for concern of debris entering the plug after numerous connections.

73. **Split Washer Mounting with Bolts for Concept #2 –** This concept showcases concept number two but with split lock washers added for extra resistance against vibration loosening.

74. **Support Rails Welded to Bench with Studs for Top Down Securing –** This concept features two support rails for the adaptor plates with studs inserted into the surface. An adaptor plate is slid over the studs and secured from the top with nuts. This concept was not used for concern of the studs shaking loose under excessive vibration from some of the more powerful formats.

75. **Accelerometers Mounted Directly to Supports in Concept #14 –** This concept shows accelerometers mounted to the outside center of the support rails in concept number 13.

76. **Bench Layout –** This concept shows a foam lined box with an open top for unloaded testing on the left side of the bench and a section for the mounting fixture used during loaded testing on the right side.

77. **Sliding Mount Rails on Sliders for length Adjustment –** This concept is one of the more unique concepts in that it does not employ a plate but two sliders with different sized holes threaded in symmetrically on each slider. One slider is fixed and the other is adjustable to accommodate different length bolt patterns. This concept was not used due to a few of the bolt patterns and bolt sizes being inconveniently large for such a device.

78. **Base Plate Welded to Table Top with Depression for Accelerometer –** This concept incorporates a base plate welded all around to the top of the bench with a depression in the center for permanent mounting of an accelerometer. The base plate also features studs for mounting an adaptor plate and securing from the top with nuts. This concept was not used because after further research, most of the accelerometers suitable for our application do not have a desirable form factor to fit within a small depression in the base plate.

79. **Base Plate Fixed to Table with Welded Nuts for Bolting –** This concept features a base plate fixed to the bench top with holes cut out on the bottom of the bench surface for nuts welded to the base plate to fit through. This allows for adaptor plates to be bolted down to the base plate from the top down.

80. **5-Sided Enclosure for Unloaded Testing –** This concept shows a 5 sided box lined with urethane foam to be used for unloaded testing. The box also includes a nylon strap with an accelerometer for measuring VPM's of tested units and a dB meter for noise level testing. This concept will be used in the final product minus the dB meter as noise level testing requires a soundproof enclosure.

81. **Soundproof Cabinet Mounted Under Bench for dB Testing –** This concept shows a two door cabinet with soundproofing for conducting noise level testing. This concept could be used but is a last priority in the completion of the bench.

82. **Adaptor Plates Secured with Small Work Holding Clamps –** This concept features small work holding clamps commonly used inside CNC machines to clamp adaptor plates down to the surface of the bench. This is one of the best concepts in terms of speed of changing out adaptor plates, but was not used due to concern of small enough clamps being able to provide enough clamping force under heavy vibration.

83. **Adaptor Plates Held by Mitee-Bite Clamps to Welded Rails –** This concept shows two rails welded about 3 inches farther apart than the length of an adaptor plate and held in place by brand name Mitee-Bite clamps. These are a heavy duty adjustable clamping system commonly used for work holding during CNC machining.

84. **Adaptor Plates Secured to Rails by Strap Bolt Clamps –** This concept shows an adaptor plate secured to two side support rails by strap bolt clamps, a heavy duty clamping system with high holding force.

85. **6-Sided Enclosed Box for Unloaded/ dB Testing –** This concept shows an enclosed box with a lid for carrying out unloaded tests and dB testing.

86. **Nylon Strap Mounted Accelerometer –** This concept shows a method of temporarily fixing an accelerometer to a vibrator for unloaded testing of VPM's. The accelerometer is mounted to a nylon strap to fit over any size or shape of vibrator. This concept will be featured in the final product.

87. **Inline Flow Meter Placement for Flowrate Measurement –** This concept shows an electronic data acquisition capable volumetric flowrate sensor for measuring airflow to the pneumatic units.

88. **Adaptor Hoses for Pneumatic Vibrator Inlets –** This concept shows different adaptor hoses with a quick disconnect air fitting on one end and various sized NPT fittings on the other end for adaptation to different units.

89. **Battery Configurations for 12 and 24 Volt DC Power Supply –** This concept shows two different configurations for batteries to allow for a 12 and 24 Volt DC power supply for all the DC powered units to be tested.

90. **Relay Circuit for switched 12 and 24 Volt Power –** This concept describes a simple circuit with heavy duty relays and a switch for changing between 12 and 24 Volt power on demand.

91. **Data Acquisition Unit Used for Data Collection and Recording –** This concept describes a data acquisition system with a digital to analog converter for reading analog signals and amplifying and conditioning them for processing by a local or remote PC.

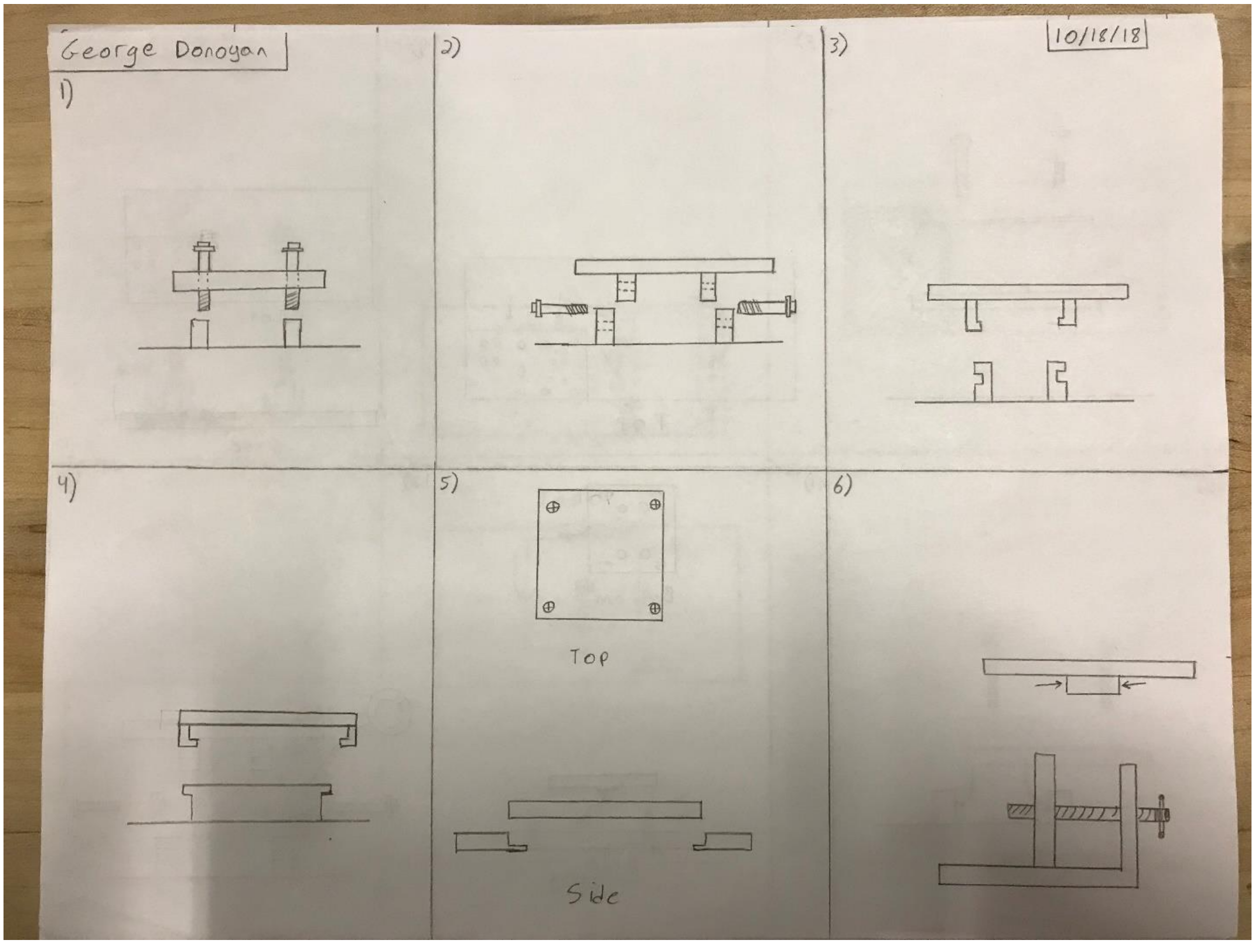

FIGURE 55: GEORGE DONOYAN CONCEPTS 1-6

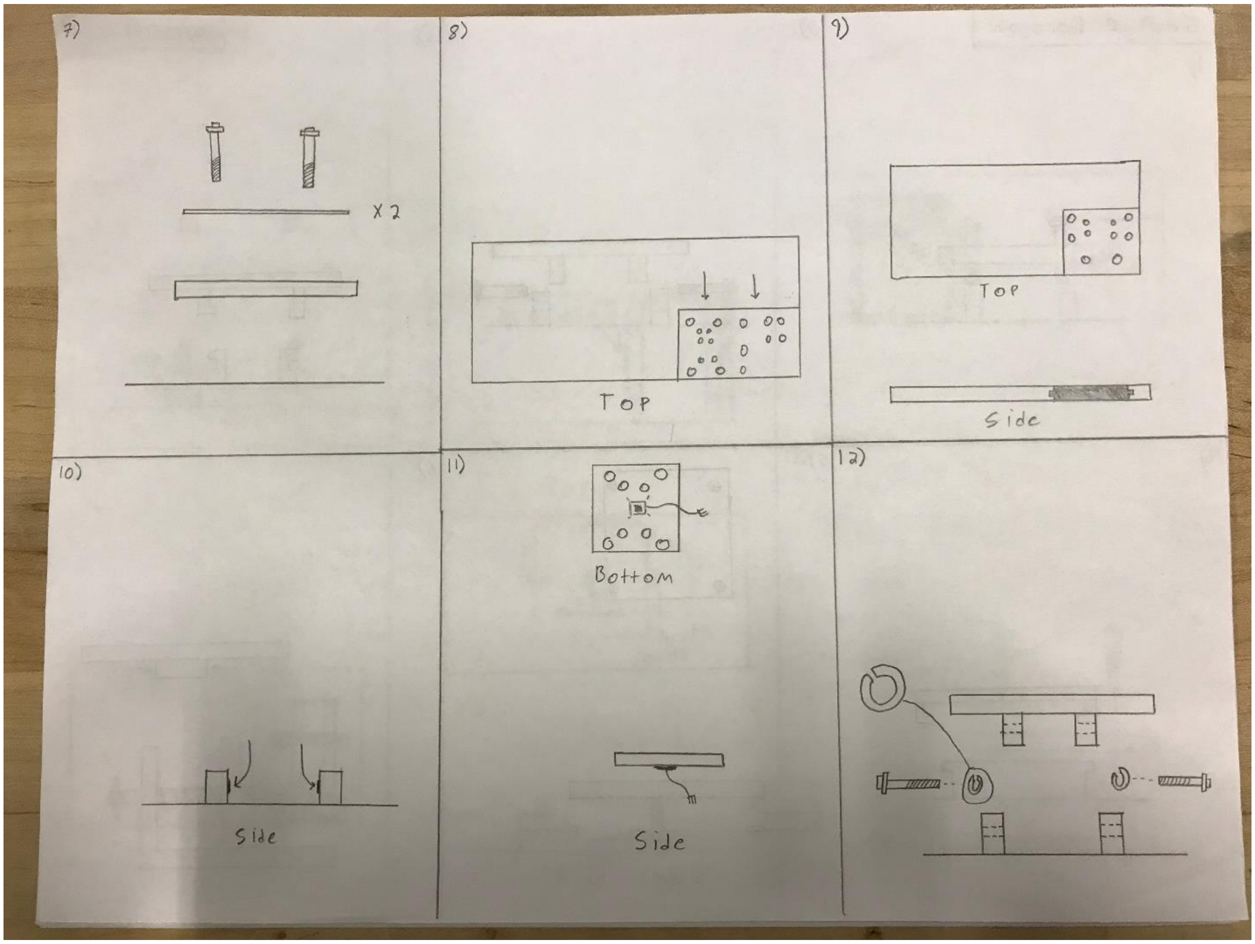

FIGURE 56: GEORGE DONOYAN CONCEPTS 7-12

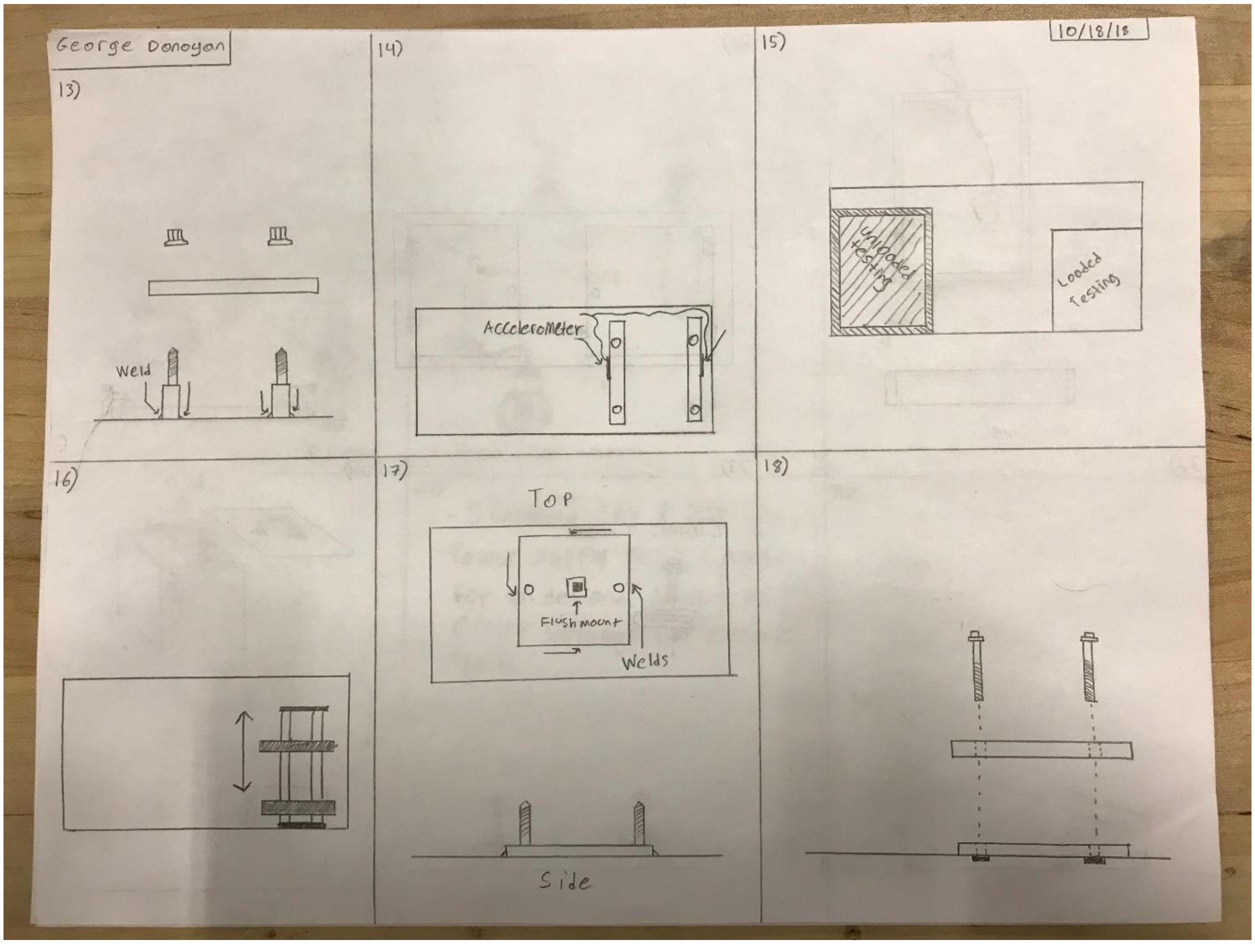

FIGURE 57: GEORGE DONOYAN CONCEPTS 13-18

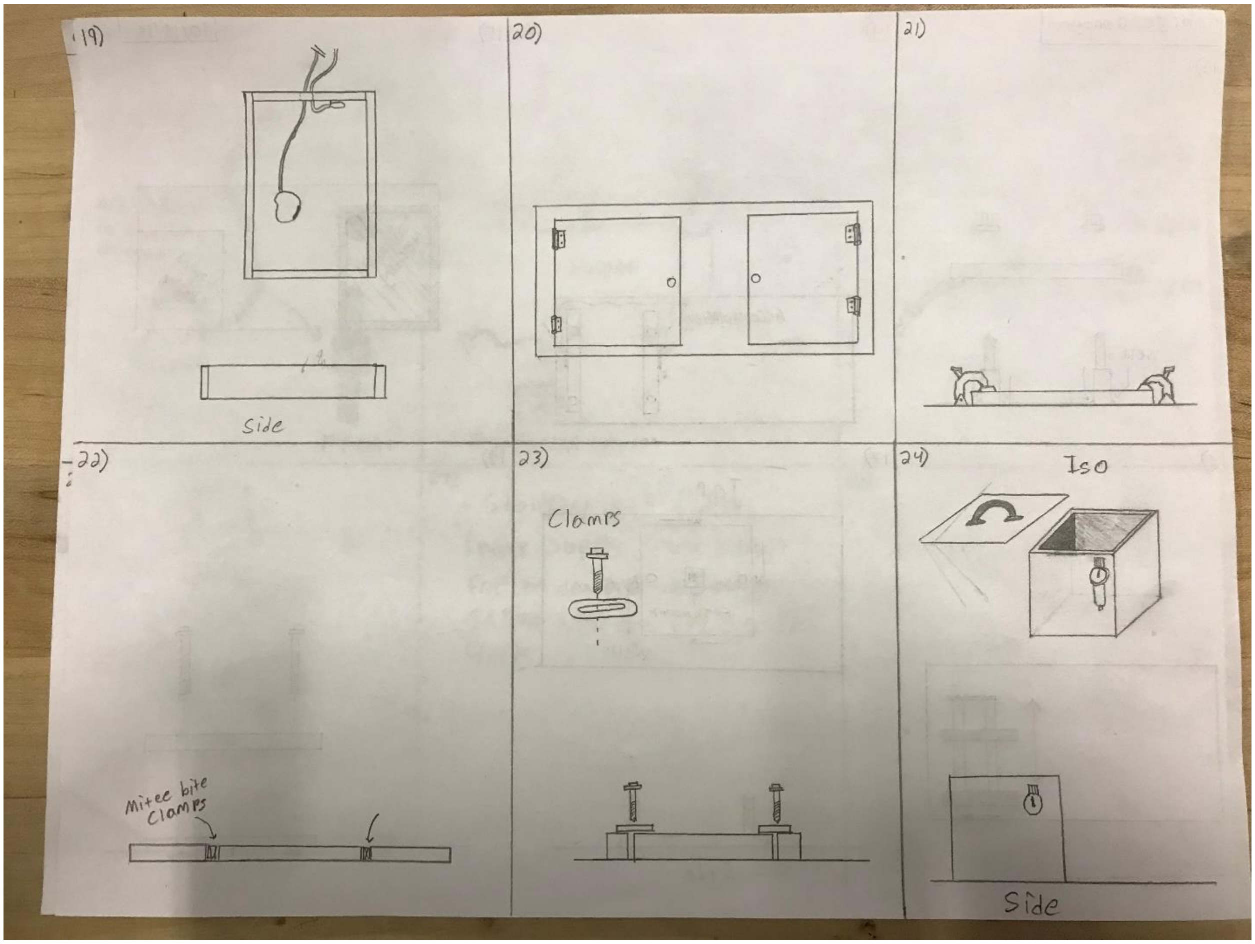

FIGURE 58: GEORGE DONOYAN CONCEPTS 19-24

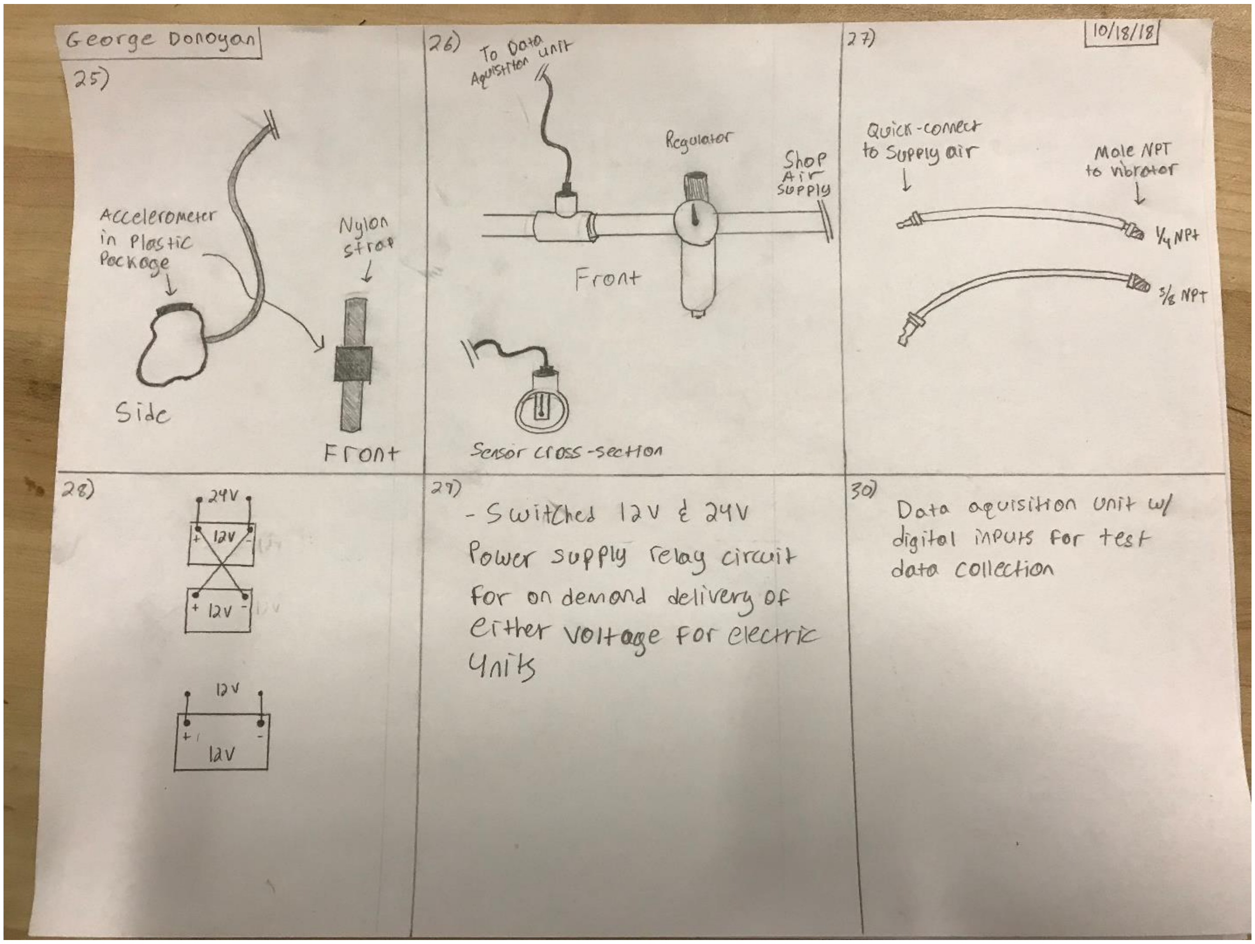

FIGURE 59: GEORGE DONOYAN CONCEPTS 25-30

Quality Function Deployment (QFD)

A Quality Function Deployment (QFD) analysis is typically used to compare a new design to existing designs, relating design specifications and parameters to one another to determine the financial viability of the products. Because our project is being custom-designed for a single customer, there is essentially no market or competition. It will never be mass-produced since it is so specialized for VIBCO's application, and is consequently useless to any company or purpose other than VIBCO's engineering team. Therefore, our QFD focused more on comparing different design concepts we generated to determine which will be most beneficial to the operation and efficiency of our test bench.

The first part of our QFD analysis is the requirements that the customer, VIBCO, set for us to accomplish. These requirements were then given a weight out of five in regards to overall importance. As shown, the most important customer requirements are ease of use, ease of maintenance, and adaptability. These requirements are absolutely essential in order to maximize VIBCO's engineering team's productivity while using the test bench.

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats")
1	9	8.6	3.0	Cost
2	9	5.7	2.0	Weight
3	9	14.3	5.0	Ease of use
4	3	14.3	5.0	Ease of maintenance
5	9	11.4	4.0	Durability
6	9	11.4	4.0	Simplicity
7	9	11.4	4.0	Ease of transportation
8	9	14.3	5.0	Adaptability
9	9	8.6	3.0	Efficient use of space

FIGURE 60: QFD CUSTOMER REQUIREMENTS

The next part of our QFD analysis is listing the quality characteristics of the test bench. These are certain dimensions and quantifiable elements of the bench. The values of these characteristics are the basis of how well the customer requirements are to be met. Each characteristic is meant to be maximized, minimized, or set at a specific value, which is represented by the row above them. The triangular grid above the characteristics represents the relationship between each characteristic, or in what way each one affects each other. The meaning of the symbols seen in this region can be found in the QFD legend, provided below.

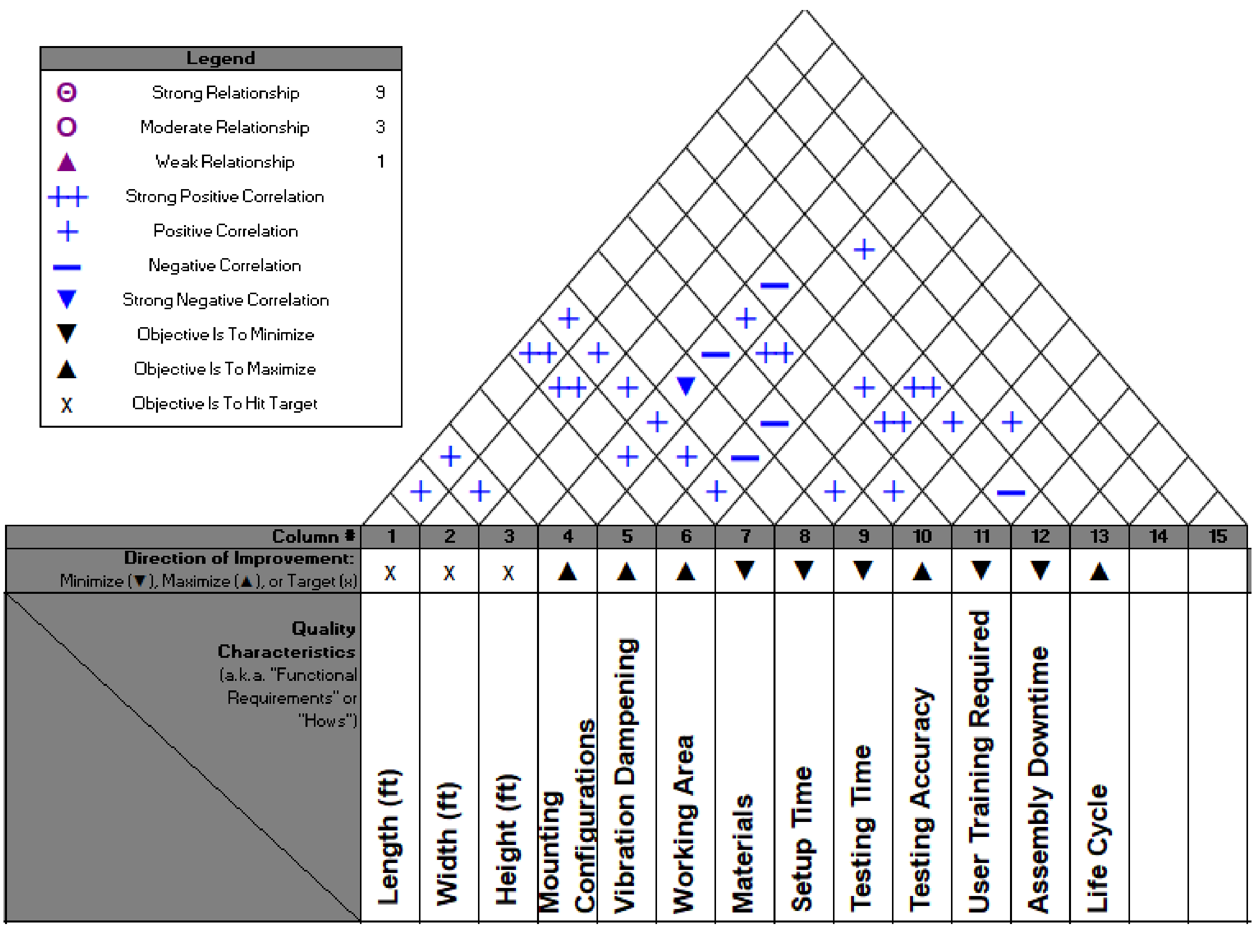

FIGURE 61: QFD FUNCTIONAL REQUIREMENTS

The main body of the chart relates the functional characteristics to the customer requirements. The two parameters are rated on how strong the relationship, if any, is between them. This is denoted using the symbols found in the legend. These relationships are used, along with each customer requirement's weight, to calculate the relative importance of each functional characteristic, and also the estimated difficulty of implementing each characteristic to the given specification.

				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	x	x	▲	▲	▲	▼	▼	▼	▲	▼	▼	▲
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Length (ft)	Width (ft)	Height (ft)	Mounting Configurations	Vibration Dampening	Working Area	Materials	Setup Time	Testing Time	Testing Accuracy	User Training Required	Assembly Downtime	Life Cycle
1	9	8.6	3.0	Cost	Ο	Ο	Ο				Θ				▲		Ο
2	9	5.7	2.0	Weight	Θ	Θ	Θ			Ο	Θ						
3	9	14.3	5.0	Ease of use				Θ	▲	Ο		Θ	Θ	▲	Θ	▲	
4	3	14.3	5.0	Ease of maintenance	▲	▲	▲		▲								Ο
5	9	11.4	4.0	Durability					Ο		Ο			▲			Θ
6	9	11.4	4.0	Simplicity				▲				Θ		Ο	Θ		▲
7	9	11.4	4.0	Ease of transportation	Ο	Ο	Ο				Θ						
8	9	14.3	5.0	Adaptability				Θ				Θ			▲	Ο	
9	9	8.6	3.0	Efficient use of space	Ο	Ο	▲	Θ		Θ			Ο			Ο	
10																	
				Target or Limit Value	8 Feet	2 Feet	~3.5 Feet									No downtime	Indefinite
				Difficulty (0=Easy to Accomplish, 10=Extremely	1	1	1	4	3	3	4	6	6	5	4	2	3
				Max Relationship Value in Column	9	9	9	9	3	9	9	9	9	3	9	3	9
				Weight / Importance	151.4	151.4	134.3	345.7	62.9	137.1	265.7	360.0	154.3	60.0	254.3	82.9	182.9
				Relative Weight	6.5	6.5	5.7	14.8	2.7	5.9	11.3	15.4	6.6	2.6	10.9	3.5	7.8

FIGURE 62: QFD BODY

The final part of this QFD analysis is the comparative analysis. This is normally where the design concept is rated, based on the customer requirements, against other competitive products on the market. However, since our project has essentially no competition or comparable products, several of our design concepts were compared. As shown on the chart, the current testing process at VIBCO is very ineffective for satisfying the customer requirements, but several of our concepts can make a drastic improvement. The clamp-fastened mounting plate system is also clearly our most promising concept based on this chart.

Competitive Analysis
(0=Worst, 5=Best)

Current Testing Process	Nylon Strap VPM reading	Vertical Mounting Systen	Clamp Fastened Mounting Plates		
4	3	5	4		
1	5	3	4		
2	5	5	5		
2	4	5	5		
2	4	5	4		
2	4	5	5		
2	5	3	5		
1	5	5	5		
2	5	3	4		

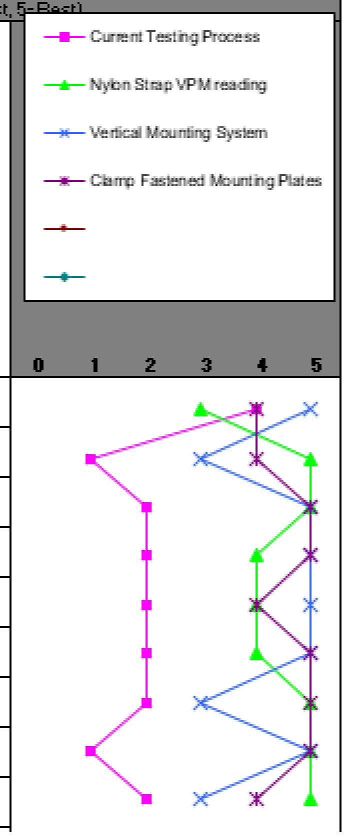

FIGURE 63: QFD COMPETETIVE ANALYSIS

Design For X

Throughout the process of designing this engineering test bench, considerations were made to take many aspects of the design’s ease of use, maintenance, safety, manufacturability, reliability and cost effectiveness into account. Designing this bench with an approach taking all these factors into account was a significant task as designing specifically for each property can sometimes have detrimental effects on another.

Designing for manufacturability, reliability and cost effectiveness were definitely top priorities in the design process. VIBCO already has a standard design method for vibrating tables and workbenches, so naturally, design cues would be taken from each product and combined into one as the engineering test bench is essentially an isolated vibrating table and a workbench put together. In the interest of manufacturability, A36 angle steel was specified for the majority of the bench’s construction. Angle steel is commonly used in structural applications and was selected for its raw strength, availability, cost and ease of working/ welding. The VIBCO fabricators are also very familiar with using angle steel which was another factor in that decision. The joints of the bench wherever two lengths of steel met at a ninety degree angle were designed as lap joints rather than cut and notch joints. This kept the design simplistic and eliminated the need for meticulous cutting of small amounts of steel off the ends of each angle, greatly reducing the time needed to prepare the lengths of angle for fitting and welding. A36 hot rolled, pickled and oiled steel plate was specified for the bench tops. Pickling and oiling is a finishing process which removes milling marks from the plate via an acid bath and greatly increases the corrosion resistance of the plate. This improves the aesthetics and smoothness of the surface which will eventually be worked on. The aforementioned bench tops were waterjet cut by ERW Inc. in Putnam, CT as VIBCO does not have the machine capabilities to work with large pieces of plate steel like the top for the non-isolated portion of the bench.

Designing for ease of use, maintenance and safety were also of high importance in the design process. The bench design incorporates a number of features with these qualities in mind. The top plates of the bench feature filleted corners to mitigate any chance of loose clothing becoming caught on the corners of the bench which can lead to injury in an industrial environment. These filleted corners also lessen the risk of injury should anyone accidentally fall towards a corner of the bench or sharply strike a corner with their body. The non-isolated top plate was also designed with a one inch overhang on all sides to reduce the need to stand so close to the bench and risk contact of an operator's shins with the lower support bracing around the perimeter of the bench. This overhang also has a superficial function of making the bench more aesthetically pleasing in the event that the bench is shown to groups that come to have a tour of VIBCO's manufacturing floor. The isolated section of the test bench was mostly designed with ease of manufacturability and assembly in mind, which can be observed in the CAD drawings of the bench. The first top plate layered on top of the angle steel legs has accommodations for the specified Firestone brand Airmount isolators and the middle section of the plate has been cut out to reduce weight. This plate is attached to the non-isolated section by a simple fillet weld along a length of angle steel acting as a support. The top plate is affixed to the top of the Airmount isolators simply by flush mounted flathead screws sized appropriately to the tapped holes in the end plates of the mounts themselves. Maintenance with this design will hopefully be kept to zero maintenance in terms of the physical structure of the bench itself, unless an accident were to happen during transportation of the bench or an event of that nature.

The modular mounting plate system, which was designed with the intention of fitting as many vibrators as possible to the bench within reasonable size and weight constraints, keeps the design themes used for the bench consistent. The foremost priority was keeping the plates easy to interchange with each other, should the need arise to test multiple different types of vibrators that do not have bolt patterns machined into the same plate. A36 structural steel was again specified for these plates in the interest of cost and strength, since some of the compatible vibrators output very large amounts of force. The plates are bolted down to two rails which are permanently affixed to the isolated tabletop via cap screws and made out of the same A36 steel. In focus of ease of manufacturing, the plates are simply plain steel sheets with through holes machined and tapped into them in the bolt size and footprint of the vibrators to be attached. An effort was made to keep vibrators of the same product line or family together on each plate for ease of operation and to reduce the total number of adaptor plates needed.

Project Specific Details & Analysis

This project was relatively unique because it involved designing and building a product to be used exclusively by one company. There is no potential for resale or mass manufacturing. This gave us the unique advantage of being able to correspond with VIBCO's engineers directly to create a product catered to their exact needs.

Another advantage of designing our product for VIBCO exclusively was that we were able to use their product catalog to help us during the design process. For example, we were able to use it extensively when designing the modular mounting plates. The mounting flange dimensions and hole sizes were readily available in the catalog for adaptation to our design. If this bench was intended to be used by companies other than VIBCO, this portion of the design process would be much more difficult because of discrepancies in the different companies' mounting systems.

We also had the unique ability to survey VIBCO employees and inspect their shop to make decisions about the design of the bench. For example, we studied VIBCO's existing vibration tables extensively and incorporated many design elements into our own design. We have also asked various VIBCO employees about aspects of the bench that would maximize usability, such as the height- working on surfaces that are too tall or too short can cause considerable inconvenience for the user. After all, our goal has been to make the bench as user-friendly and easy to work with as possible.

Fabrication of the test bench was able to be carried out in-house by VIBCO's own fabricators. This was ideal because they are very experienced in building vibratory structures. Dave Waldeck, VIBCO's head fabricator, was able to evaluate our design and make numerous suggestions for changes to make the fabrication process as smooth as possible. When the test bench is finished, it is sure to be a well-built product that will be in use for many years at VIBCO.

Our test bench has been designed with maximum simplicity in mind. This means that it will be so simple to use that eventually, any employee working on VIBCO's shop floor will be able to perform tests with the bench, without the need for lengthy training or knowledge.

Detailed Product Design

The evolution of our design from concept to a final rendition ready for assembly was a lengthy task, as many minor and some major changes were made along the design process. Some of these changes came by recommendation of the VIBCO engineers and fabricators based on their extensive knowledge of their own product, and some came naturally after finishing parts of the design and evaluating how well that portion would work with and affect the design as a whole.

A major portion of our capstone project was the structural design and layout of the test bench itself. This bench was a new design to VIBCO in that it would be combining both a standard non isolated workbench and an isolated vibrating table into one with the design mindset that the bench would be used for engineering testing and diagnosis, not assembly of final products.

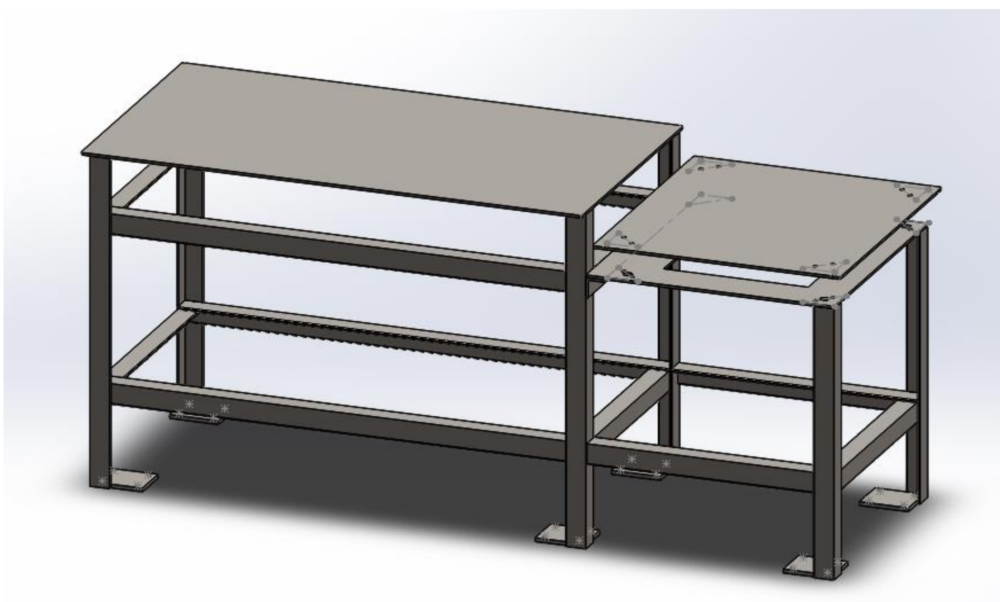

FIGURE 64: DIMETRIC VIEW OF FINAL BENCH DESIGN

Pictured above in fig. 64 is a dimetric view of the final revision of the test bench. The isolated vibrating table is located on the right side and the corners where the Firestone Airmount isolators would be sandwiched between the two steel plates can be seen. Support frames are spaced ten inches off the ground around the entire perimeter of the bench and in between the isolated (appendix 1,2) and non-isolated (appendix 3) portions. The angles serving as the support frames are oriented to allow the placement of storage buckets under the bench should the need or want arise. The six footpads of the bench are drilled and tapped to affix heavy duty casters with individual brakes to allow the entire table to be moved with as little effort as possible. The steel angles are 2”X2”X0.25”, the non-isolated table top is 48.5”X26”, the isolated bottom plate is 24”X24” and the isolated top plate is 26”X24”

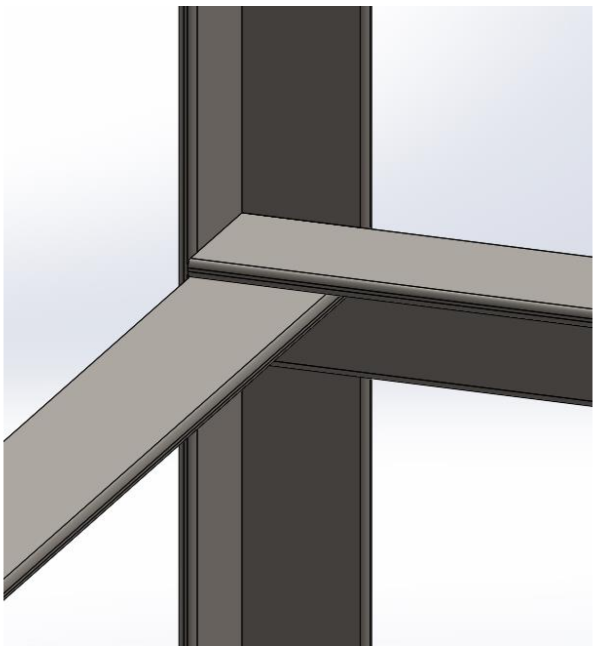

FIGURE 65: CLOSE UP OF LAP JOINT

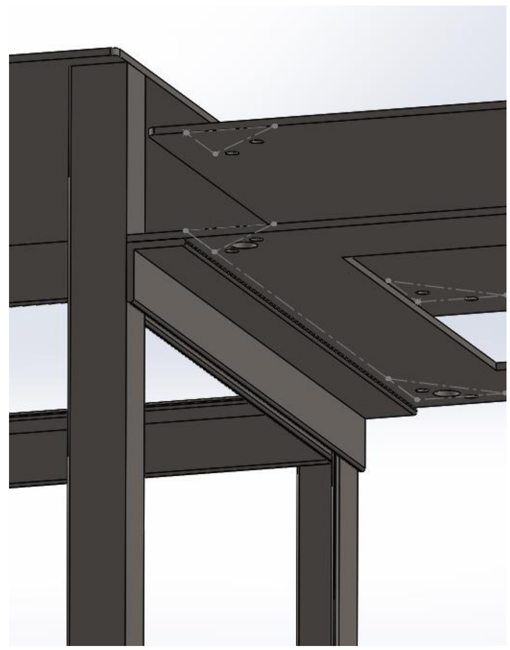

FIGURE 66: ISOLATED SECTION SUPPORT

Fig. 65 shows a close up view of the lap joints that were selected in favor of the cut and notch method of joining angle steel. This kept the design simplistic because none of the steel angles required any notched at the ends to be cut and precisely fit up to each other. The lap joining method involves setting one length of angle steel in the “lap” of another and welding the seams closed. Fig. 66 shows the method by which the isolated tabletop was joined to the main non isolated table. The bottom plate of the isolated table is simply laid on top of the angle welded to the side of the non-isolated table and affixed with a filled weld along the bottom seam.

The modular adaptor plate system (appendix 4,5) used to mount vibrators to the isolated table for loaded testing was a design inspired by the current methods of limited loaded testing at VIBCO. VIBCO does currently manufacture mounts for their vibrators but they do not possess a singular mount that can accommodate all of the products from an entire line of vibrators due to the differences in bolt sizing and spacing. With this in mind, we designed three modular mounting plates that combined can mount over 95 models of vibrators produced by VIBCO.

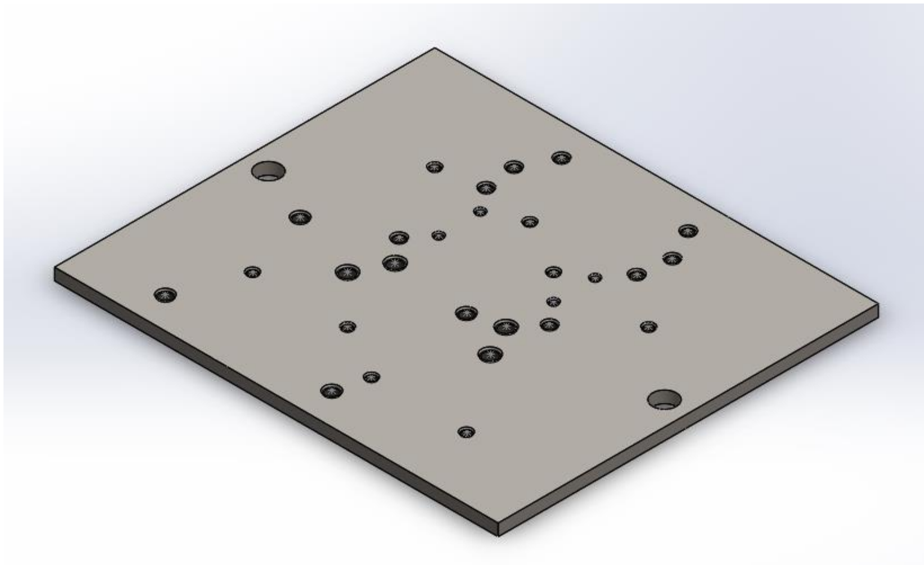

FIGURE 67: SMALL ELECTRIC UNITS MOUNTING PLATE

Fig. 67 as shown above depicts the modular mounting plate for a variety of VIBCO's popular small electric units. This particular mounting plate accommodates 25 different units all powered by 120V AC. The two ¾" through holes on either side allow the plate to be bolted temporarily to the mounting rails which are affixed to the isolated top plate. The high sensitivity accelerometer we selected to collect vibration information for this project will be affixed to one of the mounting rails under the adaptor plates. By mounting the accelerometer to a rail, we eliminate the need for the accelerometer to be unmounted and remounted to adaptor plates every time a plate change is needed. The ¾"-10 bolts affixing the mounting plates to the plate rails hold with enough force that vibration is seamlessly transferred to the rails for an accurate force and VPM measurement.

FIGURE 68: ASTRONOVA DAXUS DXS-100 DATA RECORDER

The data acquisition system we chose to use for this project was a DAXUS DXS-100 system manufactured by AstroNova Test and Measurement division located in West Warwick, Rhode Island. The unit was generously supplied to us for the duration of the project and features two of their universal data acquisition cards for a total of eight independent measurement channels. Each channel can measure up to 250 Volts RMS and and can be set up to read a DC bridge for strain gages, IEPE transducers like accelerometers, thermocouples, and RTD sensors. This was more than ideal for our application as we would need most of the capabilities that this data recorder provided and as an added incentive, this system incorporated all of those capabilities into one. The unit is also WI-FI capable for remote monitoring and carries an onboard hard drive for recording data without a laptop, although recording to a PC is preferred.

Engineering Analysis

The main load-bearing part of the test bench is the mounting plate system. These plates must be securely fastened in order to provide an accurate simulation of the loads the various vibrators will experience. Our mounting plates are to be fastened to the bench surface using a rail system with two ¾ inch grade 8 bolts.

The maximum load to be applied to these mounting plates will be around 7000 lbf, which is the approximate output from the larger piston vibrators, as well as the larger CCF series vibrators. The total load will be distributed across the two bolts:

$$P = \frac{P_{tot}}{N_{bolts}} \quad (1)$$

The maximum load experienced by each bolt will be about 3500 lbs.

According to Shigley's Engineering Design, the textbook used in our MCE 301 class, the tensile stress area, A_t, of ¾ inch bolts is 0.334 in^2. The minimum proof strength, or stress that the bolt can handle before deforming plastically, for Grade 8 bolts is 120 ksi. To find the tensile stress applied to each bolt (not accounting for preload), the applied load is divided by the tensile stress area of the bolt:

$$\sigma_t = \frac{P}{A_t} \quad (2)$$

The calculated tensile stress that the bolts will experience is 10.48 ksi. This is significantly lower than the rated proof strength of 120 ksi. Therefore, these bolts will have no problem supporting the heavy vibrational loads that will be applied, with a very large margin to account for a high preload to keep the bolts securely fastened.

The bolts that will mount the units themselves to the mounting plates will be fastened according to the specifications given in VIBCO's product manual.

Fatigue stress in the mounting plates should also be considered. As described in Materials Science and Engineering, the textbook used in our CHE 333 class, fatigue strength is the tendency of a metal to gradually break down, and eventually fail, as a result of repeated loadings. Because the nature of vibratory loads is rapid alternating loadings, this could potentially be an important factor in the material used for the mounting plates. In the future, Finite Element Analysis (FEA) can potentially be used to investigate the long-term effects of the testing process on the mounting plates.

One of the most important pieces of the data acquisition element of the project is the accelerometer output. Although the PCB 356A15 accelerometer was not difficult to connect and interface with the Daxus data acquisition unit, the output data is still in a fairly raw format. Since we are using the accelerometer as a way to monitor vibration force and speed, a math channel was set up using the Daxus software to derive the required parameters from the raw output.

The accelerometer outputs raw acceleration as a simple voltage measurement to the Daxus unit. According to the specifications found in PCB's product catalog, 100 mV corresponds to one g of acceleration.

Since the raw output is in volts, it is easy to convert to millivolts and then to g's. Using a math channel, a simple equation was used to find the output of the vibration in pound-force:

$$F = ma \tag{3}$$

The accelerometer output acts as our acceleration value in the equation. Using the measured weights of the total isolated vibrating mass (vibrator plus mounting plate), the vibrational force can be calculated using this equation. Note that the weight is divided by acceleration due to gravity and acceleration is multiplied by acceleration due to gravity. Therefore, the weight of the assembly times the acceleration in g's results in a value of pound-force (lbf).

Build / Manufacture

From the beginning of our design process, our group prioritized using materials and manufacturing processes that were already in use by VIBCO and their fabrication team. Since the proposed design featured more complex manufacturing methods such as welding and machining, both VIBCO's ownership and engineering team suggested that the bench build be performed in-house or outsourced. Although our team has some experience with the above methods, our skills are not up to par with VIBCO's fabrication team. Supplied with state-of-the-art equipment and decades of expertise, VIBCO assured team 4 that they would be the right choice to produce an accurate and completely professional looking bench with minimal material waste. With the possibility of the bench used as a display piece for plant tours or advertising, an aesthetically pleasing assembly quality was considered a must and our individual skills were simply not up to the task. As a result of this decision, some of our designs were based on existing products found throughout the shop floor at VIBCO. Not only would this ease the load on the fabrication team by providing them with familiar manufacturing methods and designs, the specification of commonly used materials at VIBCO would save costs and delivery times.

Although VIBCO fabricates a majority of their products in-house, some parts are outsourced to other manufacturers. For example, many of the thick steel plates that are used in the construction of vibration tables are too large to machine on site using their tooling. As previously discussed in earlier in the "Design for X" section of the report, VIBCO put the team in contact with ERW inc. to perform waterjet machining of the benchtop plates. After the bench structure is MIG welded together, it will be primed and painted in the standard VIBCO color scheme (orange/black). After welding, machining and painting processes are finished by VIBCO and ERW, team 4 will step in to tackle the final bench assembly and mounting of data acquisition hardware. This includes installing the tabletops, mounting plates and casters, all of which are performed with simple hand tools. Since this will be a one-off unit that is projected to have a long life cycle with the company, there are no plans in place for mass production. However, since our design incorporates features present on many existing VIBCO products, production of several benches would flow seamlessly into the current manufacturing system at work.

Cutting of A36 channel to lengths specified in bench drawings	Fillet welding of bench structure using lap joints	Waterjet machining of A36 hot rolled, pickled and oiled plates for bench tops	Machining of A36 mounting plates and plate mounting rails	Priming and final painting of bench structure-excluding table tops	Final assembly of bench-installing Airmounts, tabletops, mounting rails and casters using flathead cap screws and grade 8 hardware

Start → → → → Finish

FIGURE 69: MANUFACTURING PROCESS MODEL

Testing

When considering methods of testing our project, Team 4 determined that the testing should be split into two parts- the structural construction of the test bench itself and the data acquisition system and sensors.

For the physical portion of the testing, a test matrix was written. However, since the fabrication process at VIBCO was delayed, the bench was not completed at the time of this report. Therefore, the table contains no results. Proposed solutions are given should the completed test bench fail any of the given testing criteria.

TABLE 2: TEST MATRIX

Part	Parameter	Result	Resolution if results do not meet expectations
Bench Dimensions	Bench was fabricated to all specified dimensions	N/A- Bench not complete at time of test	Contact VIBCO's fabricators for rebuilding
Casters	Casters roll freely but do not compromise bench stability under load	N/A- Bench not complete at time of test	Contact VIBCO's fabricators for rebuilding, possibly select different casters
Mounting Plates	All specified units attach to mounting plates properly	N/A- Plates not complete at time of test	Redesign plates if design error, contact ERW if manufacturing error
Air Mounts	Air mounts inflate to proper design height	N/A- Bench not complete at time of test	Purchase different air mount if defective

Isolated Surface	Isolated surface does not interfere with non-isolated section with vibrational load	N/A- Bench not complete at time of test	Redesign bench to allocate more space between isolated and un-isolated sections
Accelerometer	Output force and vibration speed values to Daxus that are within reasonable range of theoretical catalog values	Pass- test apparatus with SPR-20 read +/- 2 lbf and +/- 200 vpm of catalog value	Move mounting location of accelerometer, Revise math channel, return unit for recalibration
Current Clamp	Output current draw values to Daxus that are within reasonable range of Kill-A-Watt Readings	Fail- current readings as much as 24 times that of Kill-A-Watt readings	Return current clamp to AstroNova for replacement or recalibration
Thermocouple	Output temperature readings to Daxus that can be verified using a control temperature	Pass- readings verified with water at boiling point	Return thermocouple for recalibration or purchase alternative unit

There was much more to be tested on the electronics side of the project. First, the current clamp was tested. This was an important test since Richard DeAlmeida had initially told us that it was potentially out of calibration. Current draw from several different devices was measured using the current clamp interfaced with the DAXUS. It was also measured using a Kill-A-Watt device as a theoretical result. The test results are tabulated below.

TABLE 3: CURRENT CLAMP TESTING

Device	Kill-A-Watt Reading	Clamp Reading	Factor
Vibrator (SPR-20)	0.54 A	8.8 A	16.3
Phone Charger	0.18 A	9.5 A	52.8
Laptop Charger	0.59 A	13.8 A	23.4
Nintendo DS Charger	0.05 A	2.7 A	54.0

The results clearly show that the current clamp was outputting very inconsistent and inaccurate values. As a result, we decided that if a current clamp is used for the test bench, a brand new unit would be the best option to consider.

The next item that was tested was the thermocouple. Initially, when we first set up the thermocouple for use with the DAXUS, it seemed to be working. However, the reading was much too small and clearly not accurate. We took the DAXUS unit to AstroNova for inspection, and there was a software bug found that was causing the problem. With that issue fixed, the real testing could be performed. A pot of water was boiled and then measured using the thermocouple. Ideally, it should have read 212 °F. The DAXUS software displayed about 199 °F. This discrepancy is most likely due to the cooling of the water when it was being transported from the stove to the testing area. We were satisfied with this result, and later testing of the VIBCO SPR-20 unit showed accurate running temperatures.

Finally, it was time to test the centerpiece of the test bench: the accelerometer. The X acceleration channel was used for a frequency counter, which was in turn used to calculate the VPMs of the unit. The Z acceleration channel was multiplied by the weight of the unit and mounting bracket to calculate the vibration force. The running current and voltage of the unit was temporarily recorded using a Kill-A-Watt, since the current clamp was not working properly. The test was run three times.

TABLE 4: SPR-20 TESTING

	Vibration Force	VPMs	Volts*	Amps*
Catalog Value	15 lbs	1600 vpm	115 V	0.50 A
Trial 1	12.8 lbs	1756 vpm	122.2 V	0.54 A
Trial 2	12.7 lbs	1752 vpm	122.2 V	0.54 A
Trial 3	12.9 lbs	1759 vpm	122.3 V	0.54 A

The results of the test were conclusive. The VPM reading was consistently around 1750 VPM, which is slightly higher than the catalog value of 1600 VPM. However, the method currently used by VIBCO to calculate the catalog values is inaccurate, and the new value is likely more accurate. The vibration force was reading about 12.8 lbs. This is slightly lower than the catalog value of 15 lbs. The current consistently measured 0.54 A, which was very close to the given value of 0.5 A. The voltage was about 122 V AC, as expected.

This testing should be repeated when the test bench has finished fabrication and it can be performed on the isolated section. Also, the current clamp will have to be retested in the future.

Redesign

A significant effort was made throughout this design process to recognize any errors or potential issues and remedy them before the final bench design was settled upon. The final product of our design was a system that VIBCO fully intends on using to benefit their business, so it was of utmost importance than the final design of the bench be the most fully optimized and usable rendition possible.

During the design process, the bench went through three major revisions and a host of minor changes in between each revision. Each change made to the bench further improved the ease of use, safety and ease of manufacture/ assembly of the bench.

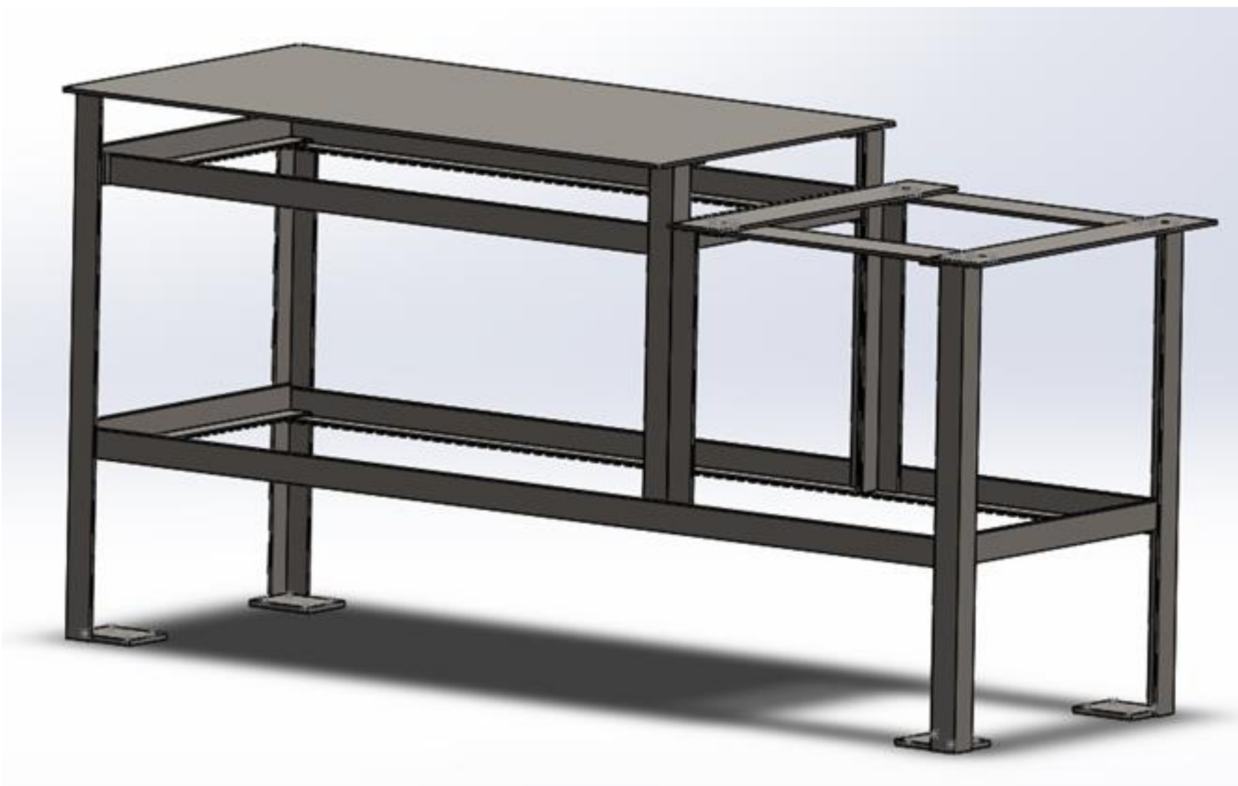

FIGURE 70: REVISION ONE OF TEST BENCH DESIGN

Pictured above is the first revision of the test bench design. Compared to the view of the complete test bench in the Detailed Product Design section, it is clear that major changes have been made. Some of those changes include the sizing of the angle steel brought down from 3”X3”X0.25” to 2”X2”X0.25” upon recommendation from the VIBCO fabrication team that the 3” angles were overkill to support the kind of weight and work this bench would be seeing. This significantly reduced the weight of the bench which would make it easier to roll around on caster wheels. Another more obvious change was the extension of two legs down to the ground where the non-isolated and isolated sections of the bench came together. This placed the bench on 6 legs instead of four, increasing its rigidity and increased the chances of the bench welding together perfectly straight to mitigate any rocking back and forth in the final design. The four flat bars seen in the above image on the served as rigid mounting points for the Firestone air mounts but were also later removed in favor of a one piece plate machined by ERW Inc. with the center cut out to reduce weight and increase easy accessibility to the Airmounts and pneumatic lines under the table for adjusting air mount pressure or servicing. A few of the minor changes include adding fillets to the overhanging corners of the bench to decrease the chance of injury should an operator or bystander accidentally strike a corner of the bench. Any joints where two lengths of angle iron met at a ninety degree angle were also changed to lap joints instead of the original idea of cut and notch joints to decrease the amount of prep work, specifically cutting, before the bench was to be mocked up and welded together. Support plates in the corners of the angle irons at the top of the bench were also removed upon recommendation by the fabrication dept as they were deemed unnecessary of the adequate thickness of the bench tops themselves.

The modular plate system used to mount vibrators for loaded testing also underwent one significant revision before manufacture as an interference issue was discovered on some of the plates between a vibrator mounting hole and the mounting hole for the plates themselves.

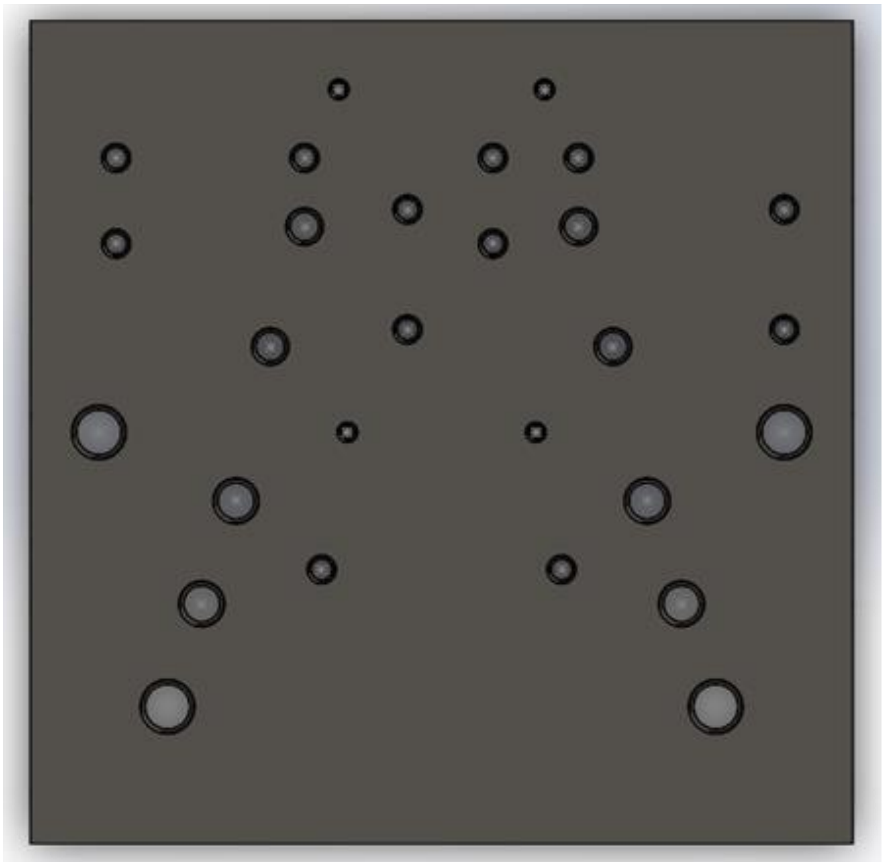

FIGURE 71: OLD REVISION OF SMALL ELECTRIC UNITS MOUNTING PLATE

As mentioned above, the figure shows the interference issue between the ¾”-10 plate mounting hole and a vibrator mounting pattern as the pattern for the vibrator is located almost vertically in line with the plate mounting hole which would not work due to the fact that the plate mounting rails run vertically under both sides of the mounting plates. This would not allow bolts to be threaded through the plate in that location as they would bottom out on the mounting rail. To remedy this issue, the plates were increased in size from 12”X12” to 14”X12” in order to move the patterns and clear the way for the vibrator mounting bolts and ass some more space throughout the entire plate to add a few more bolt patterns and space the patterns out a little more evenly. Lastly, another small change made to the plates was reducing the diameter of the plate mounting holes just slightly to eliminate any side to side play when mounting the plates and ensure a square mount every time.

Project Planning

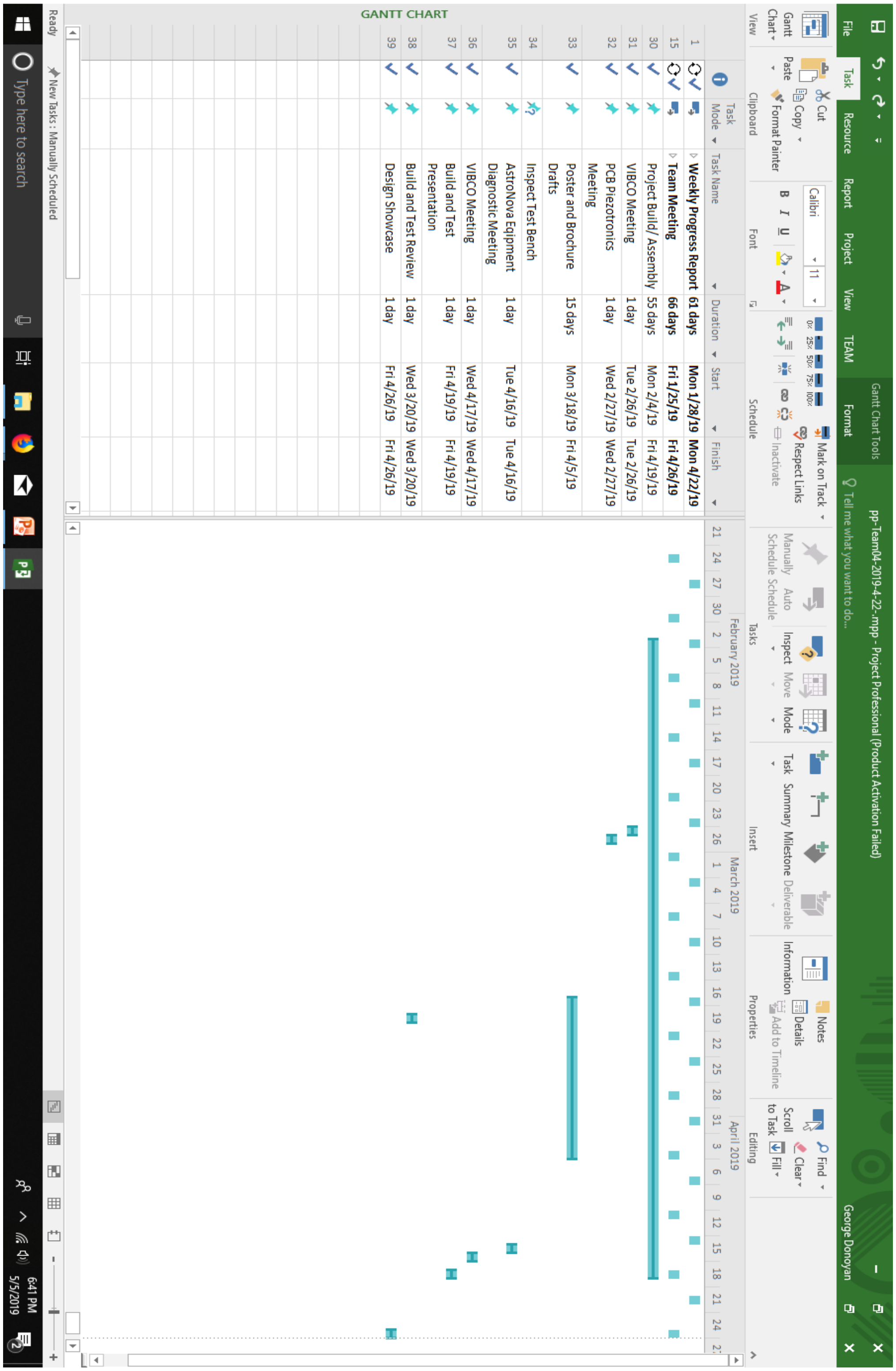

FIGURE 72: GANTT CHART

Since the design requirements set by VIBCO focused on the measurement and recording of several selected variables including force, vibration and air consumption, our group had to shift some of our focus from the overall physical design of the bench to data acquisition. The design requirements for the footprint of the bench and other physical characteristics were extremely broad as the only two constraints are the eight by two foot length and diameter, as well as the ability to test loaded and unloaded units.

Coming into the project, our group members had little to no experience in sensor integration and the accompanying programming/software needed to turn raw data into easily understandable numbers with engineering units. Software such as LabView was considered but was eventually dismissed due of our lack of experience with the program. Not only would we have to spend time and resources learning how to utilize the software, our equal lack of knowledge in the field of sensors/ transducers would have caused numerous problems in trying to integrate a viable user interface. Research on the measurement of vibration and force output dominated most of our literature and patent searches that were completed by early October. VIBCO's representatives stressed the importance of a simple and intuitive system for data recording as additional employee training would cost them in both time and money. The task of creating our own data acquisition system using commercially available software and COTS parts seemed near impossible given our time constraints. The creation of a suitable data acquisition system that is effective enough for the untrained person to use is so complex that it could be its own Capstone project.

Additional meetings with VIBCO engineers drew the conclusion of outsourcing our data acquisition needs. Our team reached out to notable data acquisition firms National Instruments and the locally headquartered AstroNova in the hopes that we could use one of their dedicated data recording systems and software suites at a reasonable cost to the company. The decision to outsource our data acquisition needs strongly influenced our design concepts. After making this decision, the expanse of our design ideas was reduced greatly because our group only had to focus on integrating a purchased data acquisition suite instead of creating our own from scratch. As a result, our listed design concepts are focused mainly on integrating data acquisition systems, the mounting plates needed to accommodate all of VIBCO's product range and vibration isolation of sensitive systems.

Throughout the back half of the second semester, the data acquisition system was constantly tested and retested as we purchased more sensors to integrate with the AstroNova data recorder and their software and great success was achieved in these tests. The raw angle steel and cut plates for our finished bench design was ordered and assembly work began although it was never finished before the end of the semester. Multiple meetings were scheduled and carried out with both AstroNova and VIBCO regarding completion of the project and any technical issues that needed expertise beyond our scope of knowledge to rectify as well as PCB Piezotronics whom which we purchased a high sensitivity tri-axial accelerometer from.

Financial Analysis

The financial analysis for the project can effectively be separated into four parts: cost of the test bench structure, data acquisition equipment, sensors, and labor/advising costs.

TABLE 5: TEST BENCH COST

Component	Cost
46.5 feet of 2”x2”x0.25” angle steel	@$1.95 per foot→$90.80
¼” table top plates+ ERW machining	$469.95
(6) heavy duty casters	@$30.00 each → $180.00
(4) Firestone Airmount isolators	@$70.00 each → $280.00
TOTAL COST	**$1,020.75**

TABLE 6: DATA ACQUISITION EQUIPMENT COST (PROVIDED BY ASTRONOVA)

Component	Cost
AstroNova Daxus DXS-100 with 2 UNIV-4 Modules	$10,755.00
(3) ADP- I IEPE adaptors	Component included in package cost
ADP-T thermocouple adaptor	Component included in package cost
MR-411 current clamp	Component included in package cost
TOTAL COST	**$10,755.00**

TABLE 7: SENSORS COST

Component	**Cost**
PCB Piezotronics 356A15 high sensitivity tri-axial accelerometer	$1065.00
PCB Piezotronics accelerometer cable	$137.00
Perfect Prime K-type thermocouple	$10.00
Klein Tools AC line splitter	$15.00
Generic voltage probes	$5.00
TOTAL COST	**$1,232.00**

TABLE 8: LABOR AND ADVISING COSTS

Component	**Cost**
VIBCO fabrication team labor- 8 hours	@$30.00 an hour → $240.00
Student labor- 30 weeks, 10 hours per week per group member	@$20.00 an hour per undergrad student→ $6,000.00
AstroNova advising time- 6 hours	@$30.00 an hour → $180.00
TOTAL COST	**$6,420**

TOTAL COST OF PROJECT: $19,427.75

Operation

Since one of the primary objectives of the project was to reduce the need for specialized training, user interactions with the bench and the data acquisition equipment will be minimal. Apart from the bolting of vibrators to adaptor plates and swapping out adaptor plates if required, there should be no need for the end user to assemble/disassemble anything related to the main structure of the bench. Installation of vibrators to the mounting plates only requires the hardware that VIBCO supplies with each unit. A standard set of SAE ⅜" drive sockets and spanner wrenches are the only tools necessary for mounting. The various transducers that interact with the Daxus unit will never need to be moved or maintained after initial installation, excluding the thermocouple. The accelerometer will be fixed to the bench surface via a stud mount on the plate mounting rails. Since the mounting rails can remain stationary while the plates are interchanged, the position of the accelerometer will remain the same during install of different vibrators/ adaptor plates. The current clamp will remain hooked on the supplied line splitter and should only be removed for cleaning or maintenance, wherein the clamp can simply be hooked back on the splitter by the end user without the use of tools. The only transducer that must be moved during the mounting of vibrators is the thermocouple since it must be attached directly to the outer surface of a vibrator for accurate readings. Team 4 developed a simple but effective solution to this mounting problem. The end user must use small strips of electrical tape to secure the thermocouple to the vibrator housing. After testing, the sensor can be easily removed without damage to the vibrator.

During testing, Team 4 developed a set of derived data channels using the Daxus software. Our settings can be exported to any computer that has the AstroNova software installed. The end user will have full access to this software after VIBCO's purchase of a Daxus DXS-100 unit. Once the program files are displayed on a PC, tablet or laptop computer, all the user must do to begin recording test data is power on the vibrator. Team 4 prioritized minimal user training to operate the test bench and interaction with the Daxus software represents the greatest learning curve of any of the design features. While the user may not be required to create/modify data channels, they must be able to input certain data to complete the force/speed tests accurately. As discussed in the Engineering Analysis section of the report, our equation for force measurement requires the total vibrating mass of the system. Since this mass will be different due to changes in vibrator and mounting plate mass, the user must know the total mass and input the value into the derived math channel. In future work, team 4 in collaboration with VIBCO plans to create a comprehensive data sheet with the measured weights of the majority of VIBCO's product line along with mounting plate weights. Using this data sheet, the end user must only be required to input a single number into the math channel, greatly reducing the risk for errors. The Daxus user manual will also be supplied to VIBCO if troubleshooting must occur.

Maintenance

Given the construction of the bench, maintenance demands of the structure should be very minimal. Other than periodical cleaning and lubrication of the casters, shop floor hazards will have very little effect on the bench other than dust/dirt accumulation. The most vulnerable components to shop hazards will be the Daxus unit and the related sensors. Although the Daxus unit is relatively well sealed, it will not tolerate heavy dust or liquid intrusion like most pieces of electronic equipment. As a result, the Daxus unit should be cleaned with compressed air after each testing session. The majority of sensors that interact with the Daxus are not user serviceable. In the event of malfunction or breakage, they must be returned to the manufacturer for repair or replacement. The construction of the bench also ensures cost returns for VIBCO in the event of disposal or obsolescence. If disposed of, a majority of the bench components are recyclable. The steel channel and plates can be dismantled and reused for other projects at VIBCO or scrapped for a small cash return. Electronic components such as the Daxus and sensors can be disposed of at any electronics recycling center. Given the Daxus unit's reliance on proprietary software, it is clear that the Daxus will most likely be the reason for disposal. It is unclear how long AstroNova plans on supporting the unit and its software, providing tech support and software updates. If the unit cannot interface with newer computers, it will become useless.

Additional Considerations

The VIBCO Engineering Test Bench will have a positive economic impact. Internally, using the test bench will allow for easier and quicker testing of products, saving precious time and keeping the production line moving. An easier and more accurate testing method will also ensure that the VIBCO products tested with it will be fully working and defect-free. This means customers will not have to deal with exchanging defective units or finding a different supplier; they will be able to use their VIBCO products on the job issue-free.

The bench will not have any societal or political impact, as it will only be used internally at VIBCO Vibrators.

Similarly, there is no need for ethical considerations, as the project does not concern the general public, only VIBCO.

The Engineering Test Bench will provide a positive impact on workplace ergonomics. One of the most important requirements given to us by VIBCO was that the bench needs to be as easy to use as possible. We designed it to be a comfortable height and with a simple mounting plate interchange system. These features will definitely increase the ergonomics of the VIBCO testing process. The bench will also positively affect safety. More thoroughly tested products are much less likely to fail and cause potential workplace accidents.

Finally, our project will not have any substantial environmental or sustainability impacts. The raw materials and manufacturing processes used to produce the test bench are environmentally friendly.

Conclusions

After two semesters of work, Team 4 has successfully designed an Engineering Test Bench that VIBCO Vibrators will be putting to use in the future. The Design Specifications that we generated have been strictly followed throughout the process.

One thing that was made quite clear as the project progressed was the difficulty of selecting data acquisition equipment and sensors. The process of researching and comparing different sensors was very confusing and time consuming. Many types of sensors can be purchased with a wide variety of specifications such as measuring range and excitation. We are very grateful to have been able to correspond with Kevin Forcucci from PCB Piezotronics and Richard DeAlmeida from AstroNova regarding these issues. Without their help, we would have had a much harder time with this aspect of the project.

Although the test bench has been mostly completed, there are several aspects that were not able to be included. First of all, air consumption and pressure sensors were not specified. Many hours of research were performed on this subject until it was determined that the required equipment to collect this data would be much more expensive than expected. Most of this type of equipment is purpose built and cannot be purchased off-the-shelf like the rest of the sensors we have used.

Also, there is no inclusion of an unloaded testing area on the test bench. We wanted to focus on loaded testing, as results from this kind of testing are more in-line with real-world performance of these vibrators. To perform unloaded testing, the accelerometer would have to be affixed directly to the vibrating unit. We were not able to come up with a solution to this problem by the end of the semester.

According to feedback from VIBCO's engineering team, our test bench aligns closely with VIBCO's expectations when they originally presented the project in the fall. Our design has accomplished all of the most important requirements, including loaded testing and VPM and vibration force measurement. Team 4 believes the project was a great success and would like to thank Dr. Nassersharif for his excellent work in organizing and mentoring students in the URI MCE Capstone program.

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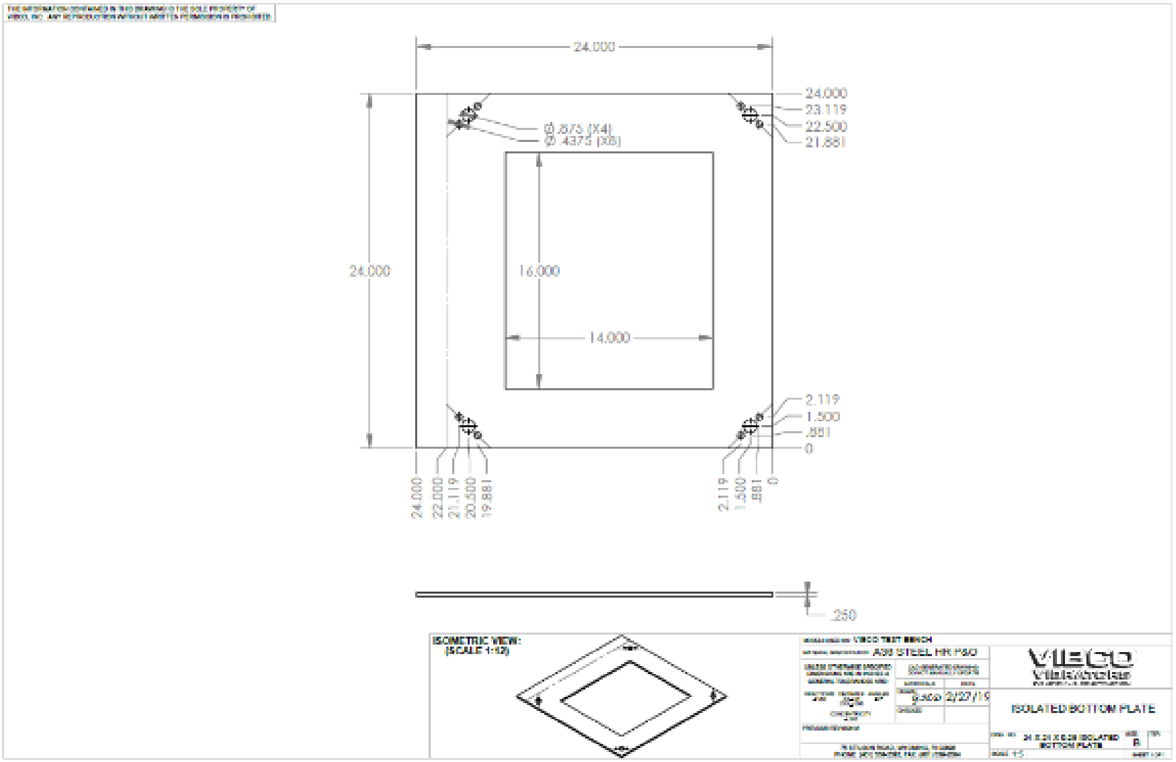
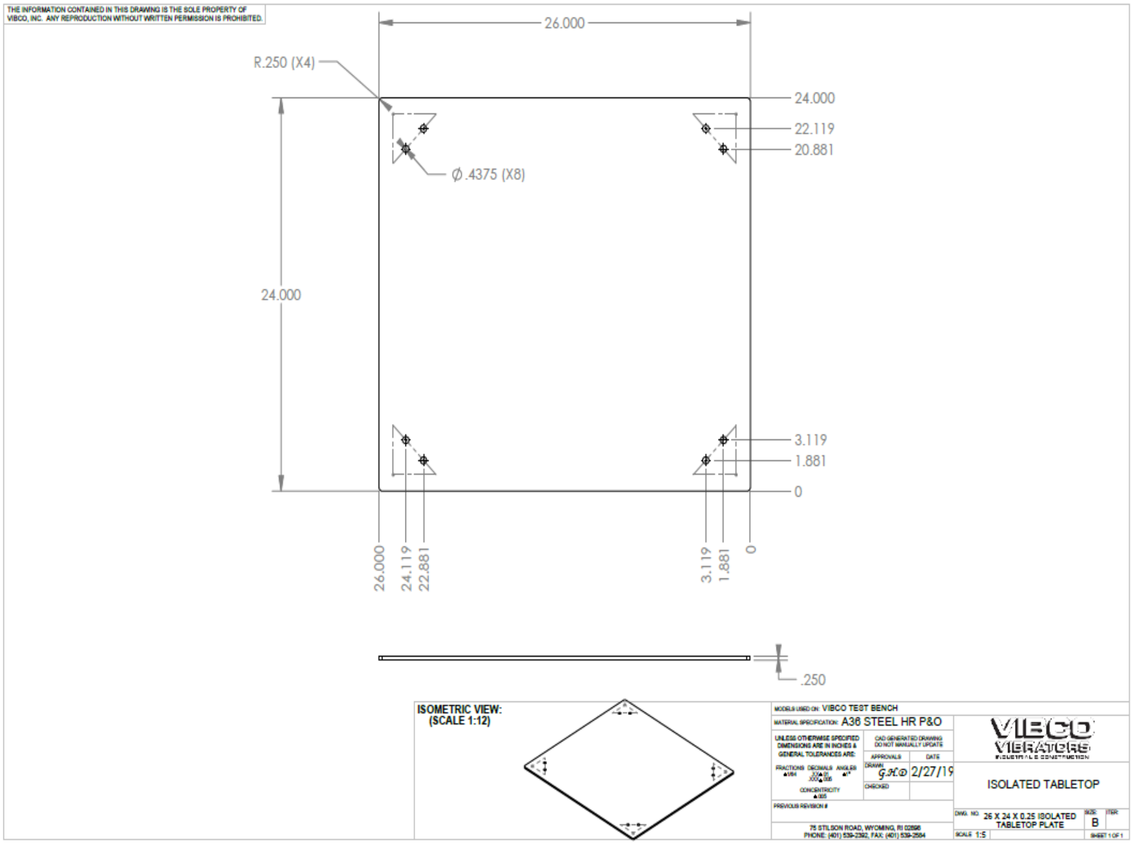
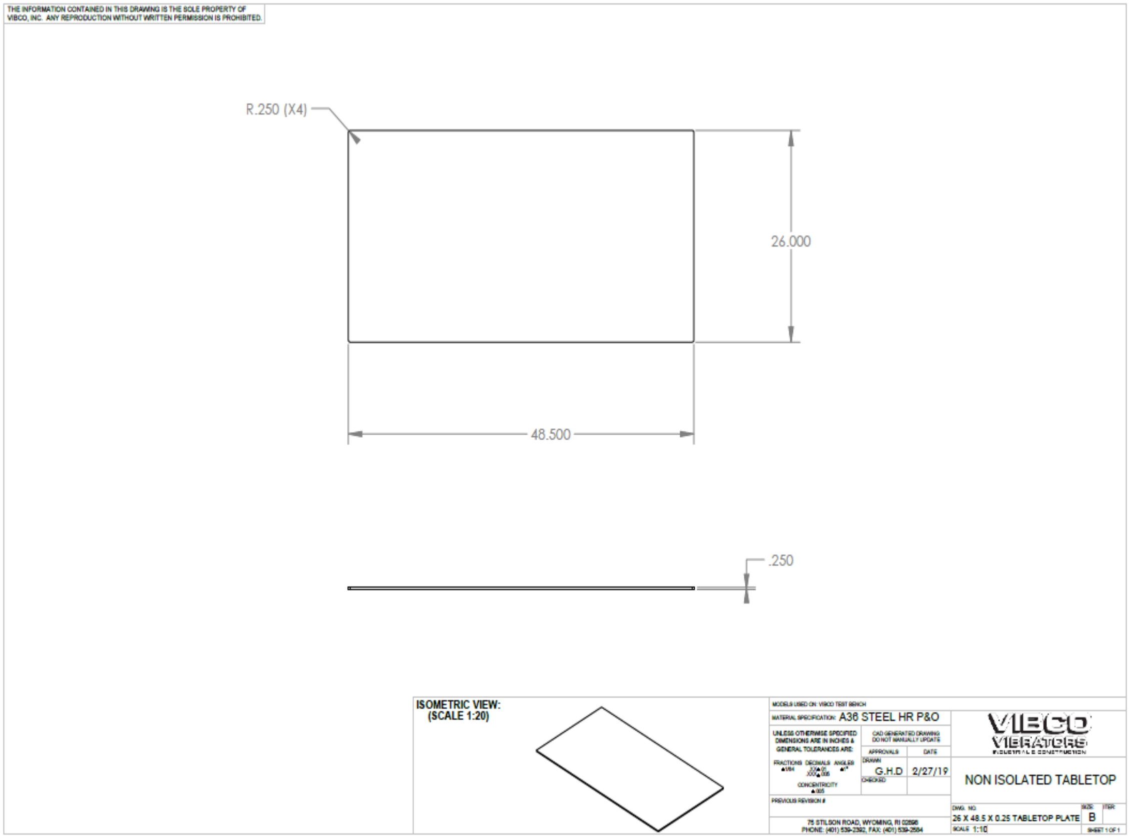
Appendices



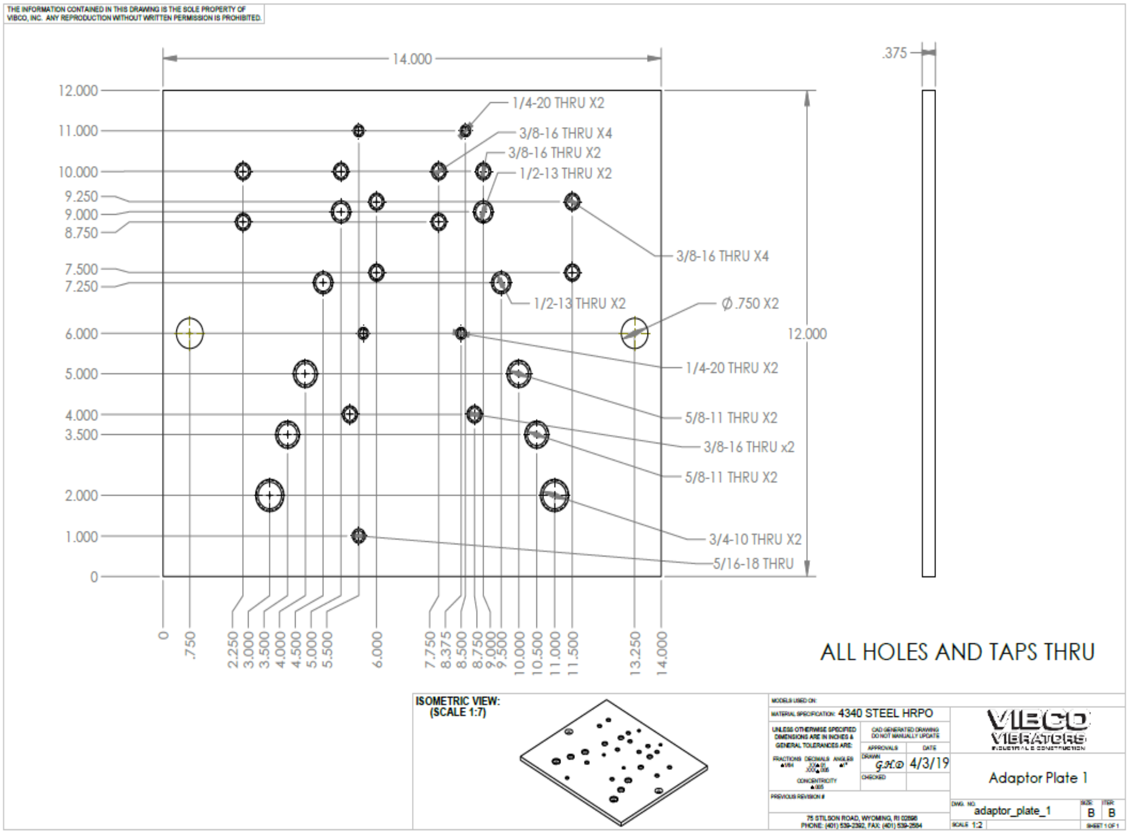
Appendix 1: Isolated Bottom Plate



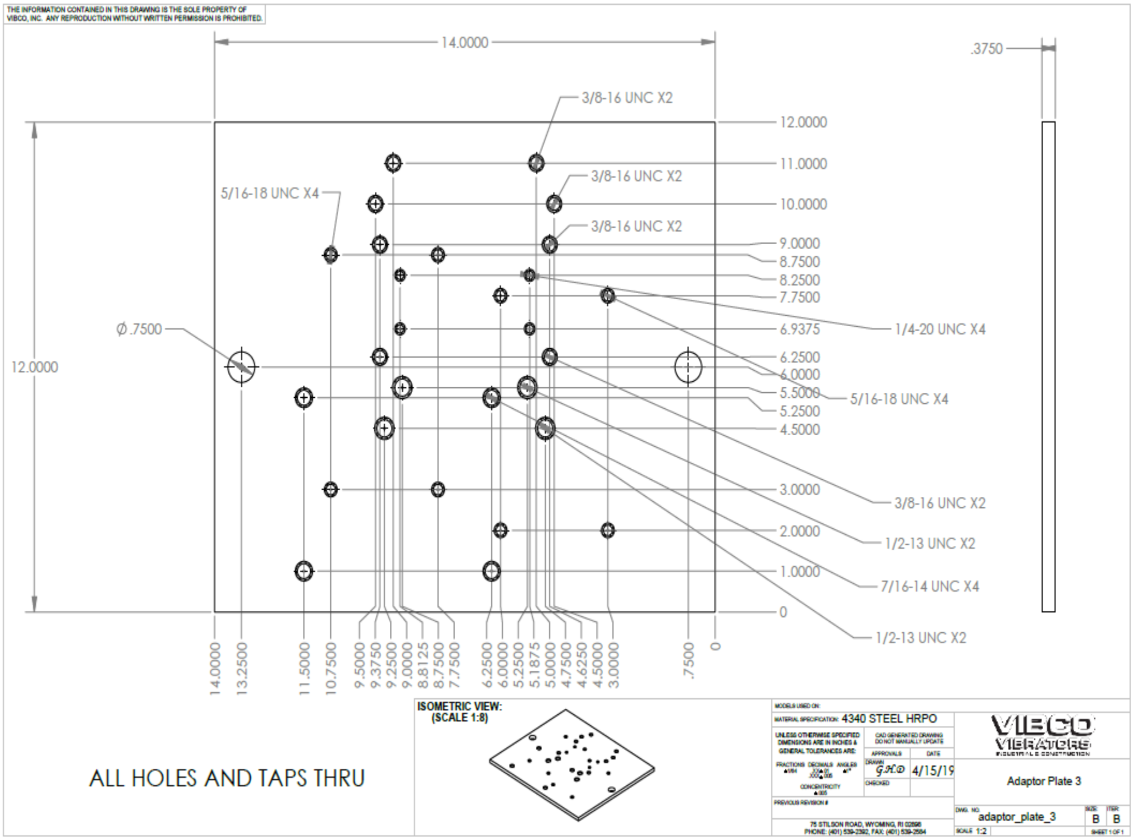
Appendix 2: Isolated Tabletop



Appendix 3: Non Isolated Tabletop



Appendix 4: Adaptor Plate 1



Appendix 5: Adaptor Plate 3