ME 450: Design and Manufacturing III
Professor Wineman
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Telerehabilitation Device

Final Paper

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EXECUTIVE SUMMARY

The main objectives of the project are to create one device that measures grasping force, another device to measure pinching force, and develop an accompanying computer program. Grasping was defined as holding an object with your entire hand and pinching was defined as holding an object with your thumb and a finger. This system will potentially be incorporated with the ULTrA (Upper Limb Training and Assessment) program previously designed by project sponsors, Dr. Susan Brown, professor at the University of Michigan, School of Kinesiology, and Dr. Jeanne Langan, research fellow, Physical Medicine and Rehabilitation, University of Michigan Medical School. Initial research has indicated that no program exists that is exactly like the one that will be created. Existing programs only incorporate arm movement and not grasping or pinching force, which are essential to the system and are requested by the project's sponsors.

There are many milestones that must be achieved during the completion of this project. These milestones have been created to ensure that the final prototype meets all required specifications and is completed on time. Design Review One concentrated on the project definition and the engineering specifications. Design Review Two focused on the alpha design and the process used to create it. Design Review Three expanded on the alpha design, providing the detailed final design, including the analysis for the devices and program and an execution plan for their creation. The final paper, this document, is a accumulation of all design reviews and also provides a validation and discussion of the final prototype.

The system will have three major components: one device to measure grasping force, one device to measure pinching force, and a computer program that assists patients to practice these manipulations. The program itself will provide a real time, visual feedback to show the patient how well they are completing the program. Detailed specifications of this project can be broken up into two categories: specifications of devices and specifications of the program. The specifications of the devices include ability to measure force applied, two different devices to measure pinching and grasping independently, affordability, portability, and resemblance to a common everyday object. The specifications of the program include real time visual feedback, user-friendly interface, variable difficulty, synchronized and unsynchronized applications, and production of force versus time plots. The specifications will be quantified with detailed engineering specifications.

The final alpha design was chosen with extensive deliberation. To begin concept development, a functional decomposition diagram was created. This created a way to map the flow of information through the system and give the team a better understanding of what concepts were important in the concept development. Brainstorming was completed individually and as a team to create a wide assortment of ideas. At this time it became apparent that two independent designs needed to be developed, one for grasping and one for pinching. After brainstorming, the top six designs for each device were chosen for further research during the concept selection process. The concept selection process was centered on the creation of Pugh charts. Pugh charts allowed for a weighted analysis to compare the concepts. The analysis of these designs resulted in the selection of the alpha designs.
The alpha design for the grasping device will be a bottle shape made out of plastic. The patient will squeeze the device with their entire hand to engage data delivery to the program. As the patient squeezes the bottle the volume of the bottle will change, and thus the pressure will change. The change in pressure is what will be analyzed. The alpha design for the pinching device will be shaped into a key. The key will have a small load transducer recessed into it, which the patient will squeeze. It has also been decided that both devices will transfer the data collected via a Data Acquisition Device (DAQ) to a LabVIEW program.

The final design is very similar to the alpha design, but provides much more detail for both of the devices, as well as, the program. The detail for the devices includes material selections, which are polyethylene terephalate (PET) for the grasping device and fiberglass for the pinching device. These materials were selected based upon the materials parameters determined by conducting analysis in dimensions and mathematical models. These parameters were then used with the Cambridge Engineering Selector (CES) software to determine the best possible material. In addition to material selection, research was conducted to determine the best sensors to be used in both devices. The sensors selected are the Kavlico P4055 Low Cost OEM Pressure Sensor and the Measurement Specialties FC23 Compression Load Cell for the grasping and pinching devices respectively. The final design also includes the manufacturing process, assembly description, and CAD drawings for both devices.

The final design for the program is also included in this report. First, a flow chart is provided that details how the signal will move through the system. Second, a description is provided that explains how the program will be developed and possible preexisting controls and indicators that have been identified to be incorporated into the program. Finally, a detailed description of each module, or task the patient will complete, is included and an instruction manual to assist in the execution of these modules.

Once the final devices and program had been completed it was tested among ourselves, our sponsors, and volunteer patients. This provided valuable information on how to improve the project. The most valuable recommendations were in regards to the program. More visual cues were needed to help the patient progress through the program. These changes were made before the project was handed over to the sponsors. On completion of the project a discussion was created that outlines the strengths and weakness of this design and also provides recommendations for future work.

The main purpose of this project is to create two devices that can measure the grasping and pinching forces applied by a patient, and then provide real time feedback to the patient, as well as provide extensive data for the doctors. These devices need to be inexpensive and very easy for the patient to use.

ABSTRACT

Stroke affects more than 700,000 individuals in the United States each year; this is approximately one person every 45 seconds (1). Stroke patients often suffer from loss of motor control in both their upper and lower limbs. Research has indicated that upper limb rehabilitation is much slower than the lower limb. This is due to the immediate need to walk following a stroke. Practicing moving and squeezing objects has shown to improve upper limb motor control and a device which helps patients do this could allow for quicker rehabilitation (2). Dr. Susan Brown, Motor Control Lab, School of Kinesiology and Dr. Jeanne Langan, research fellow, Physical Medicine and Rehabilitation, Medical School, are creating a telerehabilitation device to be used in a home environment, which allows patients to rehabilitate hand manipulation.

INTRODUCTION

Dr. Susan Brown, professor at the University of Michigan, School of Kinesiology, has created a telerehabilitation program. This program, named ULTrA (Upper Limb Training and Assessment) is an intensive motor training program aimed at the functional recovery of upper limbs. Her research has indicated that upper limb movement has a slower rate of recovery compared to lower limbs for cerebral palsy and stroke patients (2). This research has led to the creation of the ULTrA program. Specifically this program's objective is to incorporate arm reaching movements, hand manipulation, and tactile discrimination tasks. A unique feature of this program is that it is designed for home use with a feedback system to the doctor via an internet connection. No program like this presently exists.

Currently, Dr. Brown's program only addresses arm reaching movements. She, along with Dr. Jeanne Langan, Research Fellow at the University of Michigan, Physical Medicine and Rehabilitation, Medical School are now hoping to begin the creation of the hand manipulation portion of this program. Our project is to create the device and program that will eventually become a part of the ULTrA program. Dr. Langan and Dr. Brown would like the hand manipulation portion of this program to assist patients with their ability to grasp (hold things with their entire hand) and pinch (hold things with thumb and a finger). At the conclusion of three months we will have created a device and accompanying program that will allow patients to practice and test their ability to grasp and pinch in their homes. The program will provide visual, real time feedback to the patients and more detailed feedback to their doctor. The program must be versatile enough to incorporate patients of different hand size and strength, as well as patients at different stages of recovery. In addition the program needs to be adaptable enough to increase in difficulty as each patient regains his or her strength.

PROJECT REQUIREMENTS

The requirements of this project can be broken up into two categories: device and program requirements. The device requirements include the ability to measure force, two different independent devices for pinching and grasping, affordability, portability, and the resemblance to an everyday object. The major program requirements are real time visual feedback, user-friendly interface, variable difficulty, synchronized and unsynchronized applications, and production of a force versus time plot.

Device Requirements

There are five major device requirements specified by our sponsors. These are the ability to measure force applied, two different devices to measure pinching and grasping independently, affordable, portable, and resemblance of an everyday object.

The first, and most important, device requirement is the ability to measure the force applied by the patient. This will be done using a measurement tool placed directly on, or within, the device. This measurement tool needs to accurately measure the force and send this data to the associated program. We found the average strong male is able to exert grasping forces of approximately 700 N and pinching forces of approximately 150 N (3). This means that the measurement tool chosen needs to be able to measure forces accurately up to these maximum values. We predict that the patients will not be able to exert these high of forces, but something much less. The measurement tools need to be accurate throughout a range of forces up to the maximum. It is a possibility that different measurement tools will be used for the grasping and the pinching devices.

Another device requirement is the creation of two separate devices, one for measuring grasping force and one for pinching force. The grasping force can be defined as holding an object with the entire hand. An example would be holding a water bottle. The pinching force differs from the grasping force in that it is holding an object with only the thumb and finger. Picking up car keys is an example of exerting such a pinching force. The devices created will be different in length, width, height, weight, as well as, durability to accommodate these two different force needs. The device for measuring the grasping force will have larger dimensions to ensure that the patients can put their whole hand on the object. Specific attention will be paid to this dimension to make certain that the device is universal for all hand sizes. The device for grasping will also need to be stronger due to the larger force involved in grasping as compared to pinching. These two separate devices both need to work with the same computer program, but actual device appearance may be vastly different.

The affordability, portability, and resemblance to an everyday object are also very important device requirements to consider throughout the design development. The device will potentially be used in a patient's house for rehabilitation. If the device is not affordable then this will not be a possibility. Portability also affects whether patients will be able to use this system in their homes. The final system must be easy to transport from the hospital and assemble at the patient's home. The sponsors have also stressed the importance of the device resembling an everyday object. This will hopefully encourage the patients to practice because they can relate to the object. These customer requirements can be quantified using the engineering requirements of dimensions, strength, durability and the number of parts.

Program Requirements

There are also five major program requirements that need to be addressed. These include real time visual feedback, user-friendly interface, variable difficulty, synchronized and unsynchronized applications, and production of force versus time plot.

Real time visual feedback and user-friendly interface are the two most important aspects of the program. Real time visual feedback gives patients the ability to visually see the amount of force they are applying. Potentially the program will have a cursor on the computer screen that moves with the force applied. The cursor's speed will reflect the amount of force being applied (e.g. a rapid increase in the applied force will be represented by a sharp increase in the cursor speed). A user-friendly interface that incorporates this visual feedback is essential to the program. If patients cannot figure out how to use the program it is of no use to them. Many patients are not technologically savvy and this needs to be kept in consideration throughout the completion of this project. Real time visual feedback and user-friendly interface can both be quantified by task completion time, number of commands, and development time. The ultimate goal of the patient will be to complete the program in as little time as possible. Visual feedback will give the patients a way to improve their performance and thus lower completion time. The number of commands required in the program and the development time are directly correlated. The more detailed the visual feedback and interface, the more commands and longer the development time will be.

Another program requirement is variable difficulty. What is meant by this is that the program will accommodate patients at different stages of rehabilitation as well as grow in difficulty as the patient's progress. Each patient will have uniquely different abilities and the program will need to take this into account. It is also important that a patient never outgrows the program. As they regain their strength the program will need to become more difficult. One way of doing this is by incorporating the use of both hands, which is another program requirement (synchronized application). It will be required that the patient grasps or pinches with both hands with the same force in order to move the cursor. A step to further increase difficulty will be to grasp or pinch with one hand and then switch to the other (unsynchronized application). This can be a very difficult task for a patient who has lost motor control. The two program requirements of variable difficulty and synchronized and unsynchronized applications can be quantified with the engineering specifications of force, accuracy, and number of commands. The required force is an easy to way to vary the difficulty at different stages of this program. The accuracy of the patient will be an easy way for the doctor to assess a patient's performance and set the difficulty. The number of commands will also increase with the more detailed the program becomes. It will become more and more detailed as variable difficulty and synchronized and unsynchronized applications are incorporated.

The last program requirement is the production of a force versus time plot. The program should create this plot that will then be sent to the patient's doctor for assessment. The plot will visually show the doctor how much force was applied, how long the patient took to complete the task and the overshoot or undershoot of each target force. The engineering specifications that measure this requirement are force and accuracy. The force and accuracy are two data values that will be used to create the plot.

ENGINEERING SPECIFICATIONS

Engineering specifications were developed to quantify the customer requirements. These engineering specifications are compared in the Quality Function Diagram (QFD), which can be found in Appendix A1. A QFD specifically analyzes the importance of each customer requirement and engineering specification, as well as how they correlate to each other. A detailed explanation of how the QFD was developed can be found in Appendix A2.

The QFD shows that the most important specification is the force. Force is referring to the amount of force the patient will apply and thus the amount of force the device must be capable of reading. The second, third and fourth most important specifications were cost, development time, and number of parts, respectfully. If the project cannot be completed within the allowable budget and given period of time, the project will fail. Number of parts is important to consider when determining the amount of time necessary to put together the device. The next set of important engineering specifications is length, width, height, and weight. These refer to dimensions of the devices. These are important to consider because the device has be used by different hand sizes. They must be of the correct dimensions or the patient will not be able to use them. It is also important to note the difference in dimension parameters between the pinching and grasping device, this is due to the difference in their applications. Accuracy is another very important engineering specification. This specification refers to the devices' and program's ability to measure the actual forces applied. It is unreasonable to assume that the device will be perfect, but our sponsors have indicated that accurate within 5% is acceptable. Finally, the engineering specifications of task completion time and number of commands are important specifications to consider when completing the program. The task completion time refers to how long each task will take the patient, while number of commands refers to the number of commands in the written code to complete each task.

All engineering specifications have been given quantifiable target values. These values were determined using research and estimation with the sponsor. These values can be found in Table 1, below.

Engineering Specifications	Target Values	
	Pinching Device	*Grasping Device*
Force	< 200 N	< 700 N
Cost	< $200	< $200
Number of parts	10 - 15 parts	10 - 15 parts
Development Time	3 months	3 months
Length	0.04 - 0.08 m	0.15 - 0.25 m
Width	0.03 - 0.05 m	0.15 - 0.25 m
Height	0.02 - 0.04 m	0.08 - 0.15 m
Weight	2.2 - 8.9 N	4.4 - 22.3 N
Accuracy	0 - 5%	0 - 5%
Durability	5 years	5 years
Task completion time	10 - 15 min	10 - 15 min
Number of commands	Few as possible	Few as possible

Table 1: Engineering Requirements and Target Values

COMPETITIVE PRODUCTS

The QFD provided information on competitive products, but a more detailed analysis was performed to learn more about possible design concepts for this project. The systems compared were the web-based telerehabilitation for upper extremity after stroke, Autocite workstation, and the health management device.

A web-based telerehabilitation program for the upper extremities after stroke has been created at Northwestern University. This system can be seen in Figure 1, right. This system is based upon a computer joystick and arm support. The patient moves the cursor on the computer screen to a target location by moving the joystick. The joystick provides a resistive force to the patient's movement to increase the difficulty (4). A benefit of this system is that the feedback can be sent to the doctor, so patient can complete this program at home. The downfall of this system is that it is unable to measure and record the force applied and does not have two devices for pinching and grasping. This system is the most portable and affordable of the three but lacks versatility, the ability to pinch, and resemblance to a common everyday object.

Figure 1: Web-Based Telerehabilitation Program

The Autocite Workstation is an extremely elaborate system involving a variety of tasks geared towards enhancing motor control. This system can be seen in Figure 2, below. Some of the specific targeted areas for improvement are reaching, tapping, hand turning, and flipping various objects. This system is highly automated and requires minimal effort of the patient other than actually completing the tasks (5). Benefits include the system's ability to offer real time feedback and save force versus time data to a database, which can be accessed by the doctor. The main drawback to such a system is that it is much too elaborate. The goal of this project is to create a much simpler product, which is more intuitive for the patient to use. Also, while high in quality and automation, the Autocite system offers very poor portability, which would make it difficult to transfer from the hospital to various homes.

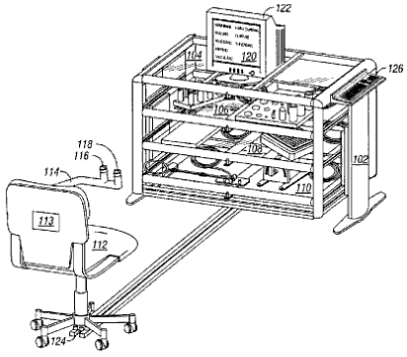

Figure 2: Autocite Workstation

The Health Management System targets the development of the upper extremity. The system is a three dimensional model that records the movements of the arm. Figure 3, at right indicates how only the position is recorded. It is essentially an exercise tool, which can report data regarding various positions of the upper extremity. The device has sensors, which report three dimensional data, which produces very accurate position feedback. This data is saved to a database upon the user following commands presented on the monitor (6). A major benefit is the doctor can access the data from a database and determine how well the patient was able to follow the sequence of tasks. A major drawback of this system is that there is no real time feedback, so the patient has no gauge as to how well they are executing a given task. Also, the system does not attempt to read any type of grasping or pinching force measurement.

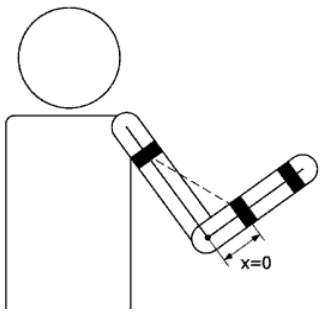

Figure 3: Health Management System

These three different systems all rate about the same to each other according to our QFD analysis and are not well suited for our customer requirements. Each of the systems has advantages, but none of them are capable of measuring the force applied. This means that the created system for this project will be brand new and does not have a product to benchmark against.

CONCEPT GENERATION

Concept generation is the first process used to develop a prototype. The first step in concept generation is mapping the flow of information through the system in a functional decomposition diagram. The second step in concept generation is brainstorming individually, in addition to, as a team. The concepts generated are then compared during the concept selection process.

Functional Decomposition Diagram

To better understand the system a function decomposition diagram was created, which can be found in Appendix B. The functional decomposition diagram is used to map how energy, materials, and signals flow through the system. The patient exerts a force on the device and then this force is converted to an electrical signal. The electrical signal is then displayed on the computer screen. It is probable to assume that the input signal will need amplification because it may be a very small voltage. It is also probable that a filter will need to be incorporated into the system to filter out any extraneous noise. These probable additions to the system will become obvious when testing occurs.

The system created for this project will be without material or signal inputs. This is due to the fact that the patient's force is the only parameter acting on the system. The only output of this system will be in the form of a signal displayed on the computer. The material of the system is the physical device which the patient will apply the force too; however, the specific material will not affect the output of the signal.

Brainstorming

Brainstorming was performed individually and then as a team. During brainstorming each member of the team developed different concepts and no idea was considered too extreme or unrealistic. Team members were encouraged to think out of the box because an unrealistic idea may spark a more realistic one. After individual brainstorming, team members gathered to openly discuss the concepts. Initially, all ideas were introduced without deliberation on them. After all ideas were explained, discussion began and more brainstorming followed. To prepare for the concept selection process, we voted on the concepts for grasping and pinching. The top six concepts, for grasping and pinching, are discussed in the following sections. Other significant, but not chosen concepts, can be found in Appendix C.

Grasping Device Concepts

The most encouraging design concepts for the grasping device are discussed in this section. They are the pressure device, the glove device, the adjustable hand device, the bike handle device, the mug handle device, and the finger tips device. The sketches included in the following subsections are sketches and not meant to include engineering detail. It became apparent that the most important characteristics of the grasping device are adjustability to patient hand size, ease of grasping, safe, and capable of measuring force accurately.

Pressure Device

The pressure device is a sealed plastic container that has a pressure gauge enclosed. The concept sketch can be seen in Figure 4, on page 8. The patient will squeeze the pressure device, which will cause a change in pressure within the device. This change in pressure will be read by the pressure gauge and an electronic signal will be sent to the data acquisition device (DAQ). Initial research indicates that the pressure device purchased will be made with a strain gauge and the transferred signal will be in the form

of voltage. Please see the Sensor Research and Selection section for more information on the pressure device measurement tool. The container will be made out of a durable and ductile plastic. The plastic will need to be capable of handling many cycles of compression. This container will potentially be purchased and need only slight modification. The main advantage to this device is that it is versatile to patient's size and ability. No matter where or how the patient grasps the device they will create a change in pressure. The major disadvantage to this device is that it may be unsafe. It is unclear at this point whether the device will need to be pressurized, but if it does it may create a safety concern.

Figure 4: Pressure Device

Glove Device

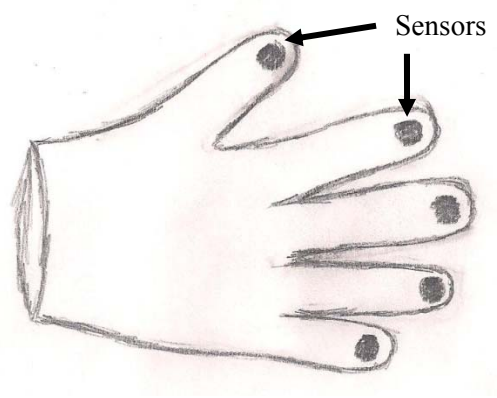

Figure 5: Glove Device

The glove device is a glove with small load transducers attached at each fingertip. The concept sketch can be seen in Figure 5, left. The patient will wear the glove and then grasp objects of their chose. As the patient grabs different objects a force will be applied on each of the load transducers. The load transducers will translate the force applied to a voltage signal that will be sent to the DAQ. The gloves would be made out of cotton (like winter gloves) or possibly a gardening glove (made out of rubber and plastic). It will be important that the glove is comfortable for the patient to wear. The load transducers will also be bought. The main advantage to this design is the large variety of objects the patients can grasp. It will make the rehabilitation process much more personal when they are able to practice grasping on their own objects. The major drawback to this system is that a set of equations will need to be generated to relate each sensor to each other. Each patient will squeeze differently and it may be difficult to generate equations that are a realistic model for all patients. Another major drawback to this system is that it may be difficult for patients to put these gloves on. Patients will have varying degrees of motor skills and it is uncertain if putting gloves on is plausible for all patients.

Adjustable Hand Device

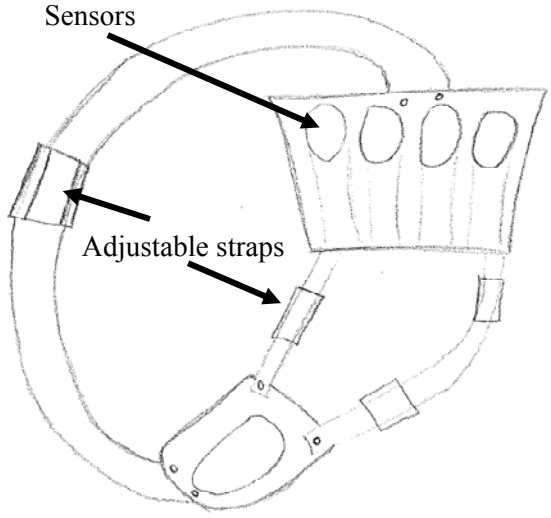

Figure 6: Adjustable Hand Device

The adjustable hand device is composed of five load transducers that will be connected together with straps. The straps will be adjustable to fit different patient hand size and different objects. Each patient can chose which object they would like to put the device on and then set it so their fingers line up with the load transducers. A sketch of this device can be seen in Figure 6, left. After the patient has successfully attached the device to an object the patient will squeeze the device with their fingers aligned with the load transducers. The straps can be purchased, along with different belts and buckles to make them adjustable. It will be necessary to find load transducers that can either be sewn or glued into these straps. Initial research indicates that this is possible. Similarly to the glove device, the load transducer will convert to the force applied to a voltage signal to be sent to the DAQ. The main advantages and disadvantages of

this device are the same as with the glove device as they both are adjustable and incorporate more than one load transducer. The only difference is that the adjustable hand device does not require the patient to put on a glove. The patient can have the doctor adjust the straps at their office before taking the device home if the patient is unable to do it for themselves due to their lack of motor control.

Bike Handle Device

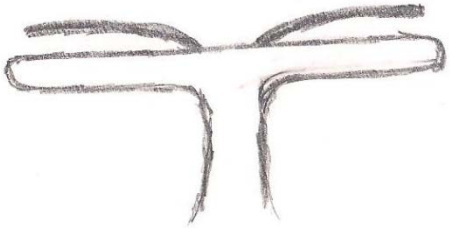

Figure 7: Bike Handle Device

As the name indicates the bike handle device is made of bike handles, including the brakes. A sketch of this design can be seen in Figure 7, right. The patient will squeeze the brakes on the bike handle which will pull the brake cable within the brakes. The brake cable will pull on a strain gauge, changing its resistance. A voltage signal will then be sent across the strain gauge and the change in voltage will be sent to the DAQ. In addition, the bike handle device will incorporate an adjustable spring that will create variable resistance to the brakes. This will make it versatile to different patients. The bike handle could potentially be bought, as is, from a local cycling store. In addition, a basic strain gauge could be purchased for this application. The main advantage to this design is it will easily incorporate synchronized rehabilitation programs. A customer requirement is that a patient can practice synchronizing their hands; all other devices will require the production of two devices for this application. A major drawback to this design is that it may have a safety concern. It creates a large pinch point for fingers.

Mug Handle Device

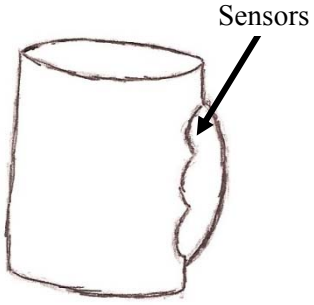

Figure 8: Mug Handle Device

The mug handle device is a mug, with load transducers recessed in them. It will also include a strap to help hold the patient's fingers in the correct location. A sketch of this design is included in Figure 8, right. The mug includes grooves which the patient will place their fingers within. Once the patients fingers have been correctly placed the strap can be tightened to hold their fingers in place. The patient will then squeeze on the mug to engage the load transducers. The load transducers will send a voltage signal to the DAQ. The plastic or wood mug could be potentially purchased and then altered to include the grooves and strap. Another option for the mug is to make it out of an epoxy using a wax mold. The strap could be purchased and attached. The main advantage to this design is that this design makes it easier for the patient to line their fingers up with the load transducers due to the grooves. The strap also makes it easier to keep their fingers in the correct location. A disadvantage to this design is that it still incorporates numerous load transducers that must be correlated together. In addition, the device is slightly awkward for a patient to use, since they will be strapped to it.

Finger Tips Device

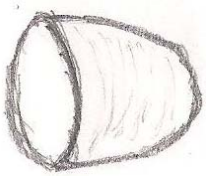

Figure 9: Finger Tips Device

The finger tips device is very similar to the glove device. Instead of the patient wearing an entire glove, the patient will just wear the tips of the gloves, similar to a thimble for all fingers. The tips of each finger will have a load transducer attached. A sketch of this concept can be seen in Figure 9, right. The finger tips portion of the device could be bought. Finger tips gloves exist or they could be fabricated by altering preexisting gloves. The advantages and disadvantages of the finger tips device are similar to the glove device except that it is less bulky. In addition, the finger tips could also prove to be harder to put on than the glove.

Pinching Device Concepts

The selected pinching device concepts to be considered in the concept selection process are included in this section. They are the pressure device, the bike handle device, the glove device, the finger tips device, the spring with sensor device, and the cantilever device. Many of the concepts are similar to those of the grasping devices, but on a smaller scale. The main considerations in the pinching device are a small size to accommodate the thumb and finger and a measurement tool that can measure smaller readings.

Pressure Device

The pressure device concept is the same for pinching as it was for grasping except in the size and shape. The size is much smaller and the shape is a rectangle. A sketch of this concept can be seen in Figure 10, below. The device also will work in the same manner as its grasping counterpart. One difference between the two devices is that the pinching device will have to be pressurized to ensure a range of pressure changes exists. If the patient can squeeze both walls all the way together, then an undesirable maximum will be reached. The pressure device will potentially be purchased, maybe in the form of a squeeze toy. Advantages of this concept include that the fingers do not need to be placed in a specific location to measure a force reading. Two major disadvantages exist. One, the device will be pressurized and this could lead to a safety concern. And, two, since the volume enclosed in the device is so small it is unclear whether the change in pressure will be large enough for a pressure sensor to read.

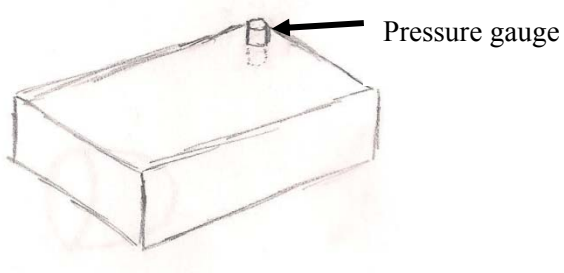

Figure 10: Pressure Device

Bike Handle Device

As with the pressure device, the bike handle device for pinching is the same grasping, but on a smaller scale. A sketch of this concept is the same as the grasping device, seen in Figure 7 on page 9. The pinching bike handle device will work exactly the same as the grasping device. The pinching bike handle could also be purchased, possibly using a child's set of handle bars. The advantages and disadvantages of this concept is the same as describe in the grasping bike handle device section.

Glove Device

The glove device for pinching would be the same as grasping. The sensors are already located in a position to accommodate measurement of the pinching force. The sketch of this concept was shown in Figure 5, on page 8. Advantages are the same as mentioned previously, with the addition of, only have to create one device that measures both grasping and pinching.

Finger Tips Device

Similarly to the glove device, the finger tips device for grasping would be the same for pinching. Potentially the patient could just wear the two finger tips, the thumb and forefinger. The sketch of this concept was shown in Figure 9, on page 10. The advantage of only having to create one device for both pinching and grasping exists for this device.

Spring with Sensor Device

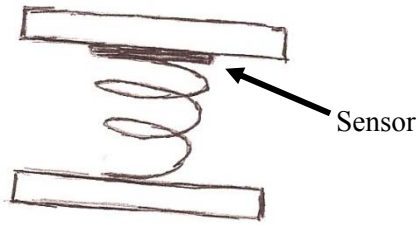

Figure 11: Spring with Sensor Device

The first entirely new concept for pinching is the spring with sensor device. It can be seen in Figure 11, right. This device consists of a spring enclosed between two plates. The patient would place this device between their fingers and then pinch. As they pinch the spring would compress and create a force on a load transducer attached to one of the plates. The load transducer would convert this mechanical signal to a voltage signal and send to the DAQ. The spring and load transducer could be purchased, while the two plates could either be purchased or manufactured. Careful consideration needs to go into the spring, to make sure that the spring purchased is appropriate for weaker and stronger patients. This could prove to be very difficult. The plates need to be very stiff and durable. If they bend then not all of the force applied is transferred to the load transducer. In addition, it needs to be durable to accommodate cyclic loading. The main advantage to this device is the patient would not need to have exact finger alignment on a force transducer and since there is only one force transducer, there is no need to correlate load transducers. One of the disadvantages to this design is a more complicated conversion from voltage to actual load applied will be involved due to the spring.

Cantilever Device

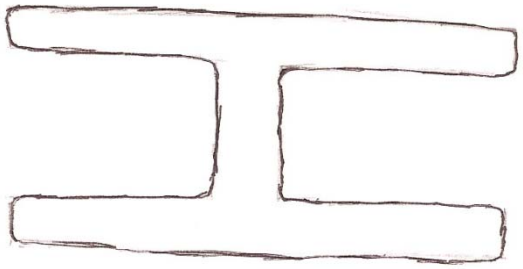

Figure 12: Cantilever Device

The final pinching device concept is the cantilever device. The cantilever device is composed of two cantilever beams originating from the center of the device. The patient could chose to pinch one or both of the cantilevers depending on what portion of the rehabilitation program they are completing. The sketch for the cantilever device can be seen in Figure 12, left. The patient will pinch the cantilever beam, causing it to deflect. A strain gauge would be mounted on the cantilever to measure the deflection of the beam. A voltage would be applied across the strain gauge, which would change with changing deflection, due to changing resistance. This would be sent to the DAQ and sent into the LabVIEW program. This device would need to be entirely fabricated. A material would need to be selected that accommodate large and continuous deflections without failure. The sensor could be purchased, but needs to be appropriate for the amount of bending that the beam would incur. An advantage to this system is that its design allows for the portion of the rehabilitation program where the patient needs to synchronize their pinching, similarly to the bike handle device. The main disadvantage to this device is the careful material selection that would need to be incorporated. Without knowing the specific forces applied, this could prove to be a very difficult task.

CONCEPT SELECTION PROCESS

After selecting the top six designs, for each grasping and pinching, these designs were compared to pick the alpha design. These six concepts were compared in Pugh charts. The Pugh charts provided a way to analyze and compare each concept.

Pugh Charts

Pugh charts are a means to compare different design concepts to one another. They are analyzed on criteria selected specifically for each application. The Pugh chart was the first step in the concept selection process and can be seen in Appendix D. Two different Pugh charts were created, one for grasping and one for pinching.

The first step in the creation of the Pugh charts was to determine what criteria were important to analyze each design. These specific criteria were different for both the pinching and grasping devices. Examples include safe, intuitive, and portable. These criteria were determined based upon the customer requirements and other considerations that became apparent during the brainstorming process. Once specific criteria had been chosen, the criteria were weighted for importance. Each criterion would later be scored for each concept. A zero meant average, a positive one meant better than the reference concept, and a negative one meant worse than the reference concept. The next step was to choose the reference concept for the designs. The reference concept chosen was the handle bar design for both pinching and grasping. It was chosen because it was thought to be an average design, not perfect nor terrible compared to the others. This concept received zeros for all criteria. All concepts were then scored by comparison to the reference concept, using the positive one, zero, and negative one method explained above.
On completion of the Pugh charts, it was determined that the best concepts for grasping and pinching forces were the pressure device and the key device, respectively.

ALPHA DESIGN

The alpha design consists of three main components: the grasping device, the pinching device, and the accompanying program. The concepts chosen for these are the pressure concept, the key concept, and LabVIEW as the program, respectively.

Grasping device

As described previously in the Concept Generation Section the pressure device transmits an applied force through a change in pressure to an electric signal. The patient will squeeze the device, which will change the pressure within the device. This change in pressure will be read by an electronic measurement tool and displayed on the computer screen. The signal will pass from the device, through a cable, into the DAQ, which will be connected via a USB port to the computer. A CAD model of the grasping device can be seen in Figure 13, on page 13.

Material

The pressure device will be made out of a plastic bottle. This material will be similar to that of which plastic water and beverage bottles are made of. Important considerations when choosing a bottle is durability, flexibility, ability to hold a gas without leaking, appropriate diameter to allow for grasping, and a resemblance to an everyday object. The bottle needs to withstand repetitive squeezing without breaking. The bottle also needs to be flexible enough to create changes in volume, and thus changes in pressure which the DAQ will be able to register. Also, the bottle needs to have a good seal because if the contained gas leaks out then the entire mechanical applied force will not be converted into a pressure change and energy will be lost. Finally, the bottle needs to resemble a common object. This is to encourage patients to use the rehabilitation device.

Sensor

Important considerations when purchasing a sensor will be accuracy, measure over correct range of pressures, small enough to fit in bottle, and generate a signal compatible with LabVIEW. To provide the doctors with accurate data regarding the patient's rehabilitation performance, the sensor used to measure the change in pressure must also be accurate. It has been indicated in the engineering specifications that accuracy within 5% is required. The engineering specifications also indicate that the forces applied will be approximately 700 N. Additional tests will need to be completed to find a more accurate range of the applied forces. The sensor must also fit easily within the bottle for this concept to work correctly. Finally, the sensor outputs must be compatible with the chosen DAQ and LabVIEW, a voltage output would be ideal because team members have used this type of output before.

At the completion of this project, two of these devices need to be created. This will allow the patients to complete the portion of the rehabilitation program that involves synchronizing their hand movements and forces.

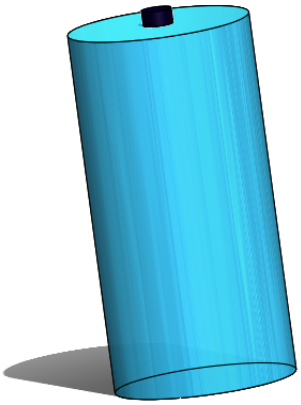

Figure 13: Alpha Grasping Device

Pinching device

The pinching device will also transmit an applied force to an electrical signal, but it will not involve the change in pressure. The patient will apply a load to the imbedded load transducer. The load transducer will convert the mechanical signal to an electrical signal that will be relayed to the LabVIEW program, via a DAQ. A CAD model of the pinching device can be seen in Figure 14, below.

Material

The main portion of the pinching device will be either made out of wood or plastic. It has yet to be determined which will be used. Important considerations when choosing the material include: durability, safety, and ease of manufacturing. The material needs to be durable enough to withstand continuous pinching as well as accidentally drops. The material also needs to be safe. This means that rough edges on the material need to be able to be rounded to avoid potential sharp corners. Finally, the ease of manufacturing needs to be considered. Some materials will be easier to cut into a key shaped then others, and this will need to be considered.

Sensor

The important considerations when purchasing the load transducer is the same as purchasing the pressure sensor: accuracy, measure over correct range of pressure, small enough to fit on key, and generate a signal compatible with LabVIEW. The load transducer needs to be able to read forces less than 200 N. Similarly to the grasping device, two of devices will need to be created.

Figure 14: Alpha Pinching Device

Data acquisition and LabVIEW program

The third and most challenging component of the alpha design is the computer program. The current ULTrA program uses LabVIEW software. It would be highly advantageous to use this same program, for congruent incorporation into this program. It would also be advantageous to use this program because team members are most familiar with this program as compared to other data acquisition programs. In addition, the DAQ needed could potentially be the same as that currently used in ULTrA program. This will depend on the type of sensor used with the system. A more detailed outline of the computer program will be provided in the final design.

FINAL DESIGN: DEVICES

This section provides a detailed description of the final design, and sequential sections present the design analysis, material selection, sensor selection, DAQ selection, fabrication, and assembly of this final design. The final design is very similar to the alpha design, with the exception of the shape of the pinching device. The pinching device is now a rectangular object, designed to resemble a garage door opener remote. An illustration of this design, as well as, the grasping device design can be seen in Figure 15, below.

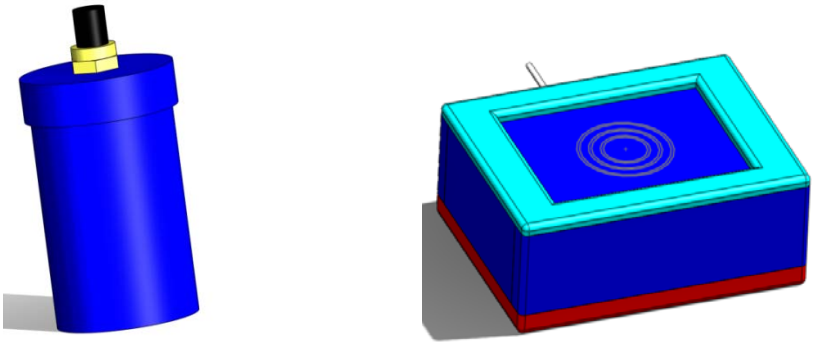

Figure 15: Final Design (Grasping Left, Pinching Right)

Grasping Device

The final design of the grasping device is the same as the alpha design and can be seen in Figure 15, above. The final design resembles a water bottle, a common everyday object, which is a customer requirement. The main advantage to using this design is its ability to measure the applied force regardless of where the patient applies force. The patient's applied force will cause a change in pressure in the bottle, which will be sensed by the pressure sensor. In addition, the shape of a water bottle is perfect for grasping. Water bottles are designed for all consumers to be able to grasp. Finally, this design also only includes one sensor, which will save money and ease in the manufacturing and assembling process.

The grasping device has three main parts: the bottle, the manufactured fiberglass piece, and the pressure sensor. The bottle is used as the main container for the grasping device. As previously mentioned, the shape of the bottle is ideal for grasping and most patients will be able to fit their hand around it. The manufactured fiberglass piece is a circular piece, which will reinforce the top of the water bottle. This piece will provide extra strength to the top of the bottle and prevent possible rupture. Finally, the pressure sensor is used to measure the pressure difference caused by the applied grasping force exerted by the patient. The pressure sensor is the cylindrical shape located at the top of the bottle in Figure 15, above.

During the rehabilitation program the patient will grasp the device, applying a force to the walls of the bottle. The force applied will cause a change in volume of the bottle and thus a change in pressure. The pressure sensor will be provided a voltage from the computer when the patient starts the required task. The applied force will cause a change in resistance in the in the pressure sensor, which will alter the

voltage. The changed voltage is sent through a wire to the SAQ then through another wire to the computer's Universal Serial Bus (USB) port. The LabVIEW program reads the voltage measurement and converts it into a force which is shown on the computer screen. The LabVIEW programming will be discussed in further detail in the LabVIEW section.

Pinching Device

The final design of the pinching device is a rectangular box designed to resemble a garage door opener remote, this can be seen in Figure 15, on page 14. The reason for changing the final design to a garage door opener from a key was to make the device easier to use. The key required the patient to press in the middle of the device, the garage door opener remote is designed to allow the patient to push anywhere on the device. In addition, there was a small safety concern regarding the rough edges on the shaft of the key. This has now been eliminated.

The garage door opener is a common object that patient's can relate too; a customer requirement specified by the project's sponsors. The device is also an ideal size for pinching, as commercially available garage door opener remotes are designed for that purpose. Another major benefit to this design is that it only requires the use of one sensor; this will save cost and ease in the manufacturing and assembling process.

There are 10 different fiberglass pieces that compose the pinching device. Detailed drawings of these pieces can be seen in Appendix E and an exploded assembly view can be seen in Figure 23, on page 25. There are four outer wall pieces that are the pinching device's housing. These will enclose and hide all other components of the device. The button panel piece is where the patient will apply the pinching force and the button panel will transfer this force to the force sensor. In order to hold the force sensor in place, two sensor holder pieces will be used. These pieces are also used to provide extra support for the outer walls and provide a place to insert the bolts. The small circular pieces from the holes cut out in the force sensor holder piece will also be used to ensure the force sensor does not move inside the devices. Two of these pieces will be used inside the device. There will be one square top lip piece created out of 1/8" thick fiberglass that will be placed on top of the outer walls. This piece ensures that the button panel stays inside the pinching device. The last pieces required to complete the pinching device are the two bottom pieces. The bottom requires two pieces because that is where the most force will be applied and it needs to hold the device together. To transfer the applied force from the button panel to the force sensor a rubber plug is used. The only non-fabricated component of the pinching device is the force sensor and this will be located on top of the two bottom pieces and between the sensor holder pieces.

During the rehabilitation program the patient will pinch the device, compressing the top button panel downward. The force applied will be transferred from the button panel, through the circular button extension pieces to the force sensor. The force sensor will be provided a voltage from the computer when the patient starts the required task. The applied force will cause a change in resistance in the force senor, which will alter the voltage. This changed voltage is sent through a wire to the DAQ then through another wire to the computer's Universal Serial Bus (USB) port. The LabVIEW program reads the voltage measurement and converts it into a force which is shown on the computer screen. The LabVIEW programming will be discussed in further detail in LabVIEW section.

ENGINEERING DESIGN ANALYSIS

This section is intended to show how the device design and sensor requirements were obtained. This was done through completing parameter research on water bottles and garage door opener remotes. These were studied because they are dimensionally similar to the required devices. In addition, theoretical mathematical models of the devices were developed. This section will begin by explaining the research conducted and will provide a detailed explanation of the mathematical models developed for the devices.

The parameters and calculations provided in this section are necessary in the material selection process, which will be discussed in the Material section below on page18.

Parameter Research

The details of the final designs were previously discussed and this section will provide the research on device dimensions. It is important to note that the water bottle will be purchased to serve as the housing of the grasping device. To help aid in material selection and dimensional consideration, measurements of height (*h*), circumference (*C*), and thickness (*t*) were taken of commercially available water bottles. The average of ten water bottles were taken and it was determined that *h* is approximately 21.59 cm (8.5 in), *C* is approximately 22.86 cm (9 in), and *t* is approximately 0.159 cm (0.0625 in) shown in Figure 16, below. The dimensions of the ten water bottles can be seen in Appendix F.

Similarly to the water bottle, dimensions of commercially available garage door opener remotes were recorded and averaged. In this case, dimensions of length (*l*), width (*w*), and height (*h*) of five garage door opener remotes were recorded. Only five garage door opener remotes were recorded due to the smaller available selection. The averaged dimensions were determined to be *l* is approximately 8.89 cm (3.5 in), *w* is approximately 6.35 cm (2.5 in), and *h* is approximately 3.81 cm (1.5 in), shown in Figure 17, below. The dimensions of the five garage door opener remotes can be seen in Appendix F.

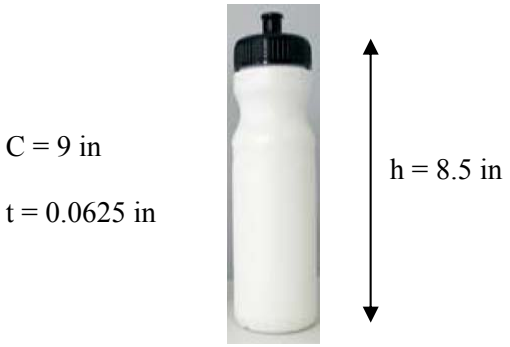

Figure 17: Water Bottle Average Dimensions

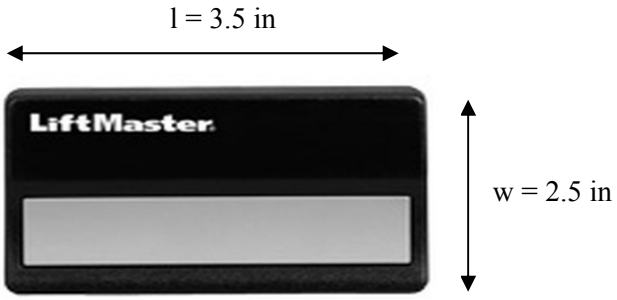

Figure 16: Garage Door Opener Remote Average Dimensions

Grasping Mathematical Model

A mathematical model was developed for the grasping device by assuming it to be a thin wall pressure vessel. This assumption is possible because the ratio of the bottle radius to the thickness is much greater than ten (7). Calculations were executed to determine an estimate for the maximum pressure that could be achieved. This was done for two different cases; case A and B. Case A assumes a rigid bottle, such that all the force is acting on the cap. Case B assumes a rigid cap, such that all the force is acting on the sides and bottom only. These are shown in Figure 18, on page 17. Throughout all calculations in this section, the dimensions determined from the Parameter Research section were used.

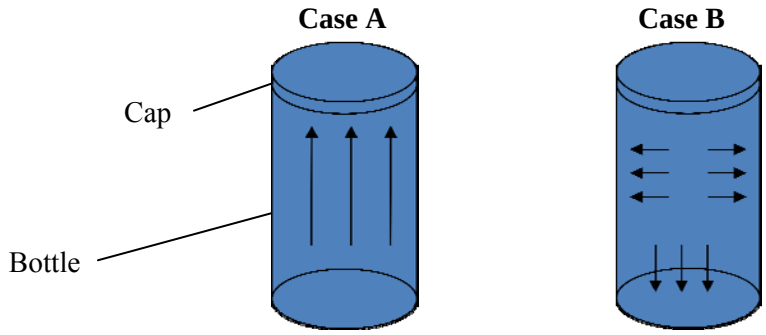

Figure 18: Force Diagrams
(Case A Right, Case B Left)

As mentioned above, Case A assumes a rigid bottle, such that all forces are acting on the cap. The purpose of this calculation is to ensure that the threads in the cap can withstand the maximum pressure applied to the bottle. Previous research has shown that the average maximum grasping force for a strong male is 700 N (3). The maximum pressure was calculated using a force equal to 800 N to provide a safety factor of 1.14. Equation 1 was used along with the assumptions that the fluid was massless and incompressible, where *A* is the surface area of the cap and *F* the grasping force for a strong male. The maximum pressure on the cap was determined to be 1.56e5 Pa (22.6 psi).

$$P = \frac{F}{A} \qquad \text{(Equation 1)}$$

In Case B, the cap is assumed to be rigid, such that all the forces are acting on the bottle. The bottle is defined as the sidewalls and the bottom of the bottle. Forces acting on the cap have been disregarded, but this allows a more conservative pressure estimate. The purpose of this calculation is to ensure that the bottle does not fail due to plastic deformation. The maximum pressure was determined using Equation 1, where the force value, *F*, was the same maximum value of 800 N as described above and *A* is the surface area of the sidewalls and bottom of the bottle. This value was determined to be 1.31e4 Pa (1.9 psi). The hoop stress was then calculated using Equation 2 and the longitudinal stress calculated using Equation 3, where *r* is the radius of the bottle and *t* is the thickness of the walls. The value of hoop stress was determined to be 2.97e5 Pa (43.1 psi) and longitudinal stress was determined to be 1.49e5 Pa (21.6 psi).

$$\sigma_{hoop} = \frac{Pr}{t} \qquad \text{(Equation 2)}$$

$$\sigma_{long} = \frac{Pr}{2t} \qquad \text{(Equation 3)}$$

Pinching Mathematical Model

A mathematical model was developed for the pinching device. A cross section of the pinching device is shown in Figure 19, below.

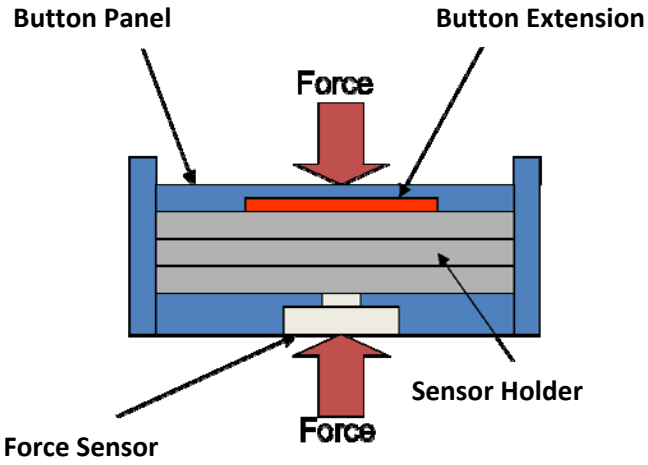

Figure 19: Cross Section of Pinching Device

The pinching device is assumed to be in static equilibrium with no deflection, since it is supported throughout and the force is applied directly in the middle of the device. The average maximum pinching force of a strong male (approximately 150 N) was used in calculating a yield stress (7). Assuming a uniformly distributed load at the fingertips (about 1.6e-4 m^2 (.25 in^2) each finger pad), and using Equation 4 below, where *F* is the maximum pinching force of a strong male and *A* is the area of the finger tip. The maximum stress was determined to be approximately 2.97e5 Pa (43.1 psi).

$$\sigma = \frac{F}{A} \qquad \text{(Equation 4)}$$

There is a possible cantilever beam situation that may occur if the patient applies a force off center. This problematic situation has been designed against by creating the space between the button panel and the spacers to be only a few millimeters. To ensure that this will not introduce error, the maximum possible deflection at the button panel edges has been determined. This was done using Equation 5, below, where *F* is the applied force, *L* is the distance from the center, *E* is the modulus of elasticity and *I* is the second area moment. This calculation determined that the maximum deflection is less than the two millimeter space provided.

$$v = \frac{FL^3}{3EI} \qquad \text{(Equation 5)}$$

MATERIALS SELECTION

The above mathematical modeling subsections were completed in order to determine the greatest possible forces, pressures, and stresses acting on the devices. The characteristics required in order to select an appropriate material were determined based on both mathematical modeling and parameter research results. A table of these critical material characteristics can be seen in Appendix G.1. This section discusses the way in which this data was used in order to select the materials for the grasping and pinching devices.

The density was determined using weight measurements and dimensions gathered during the parameter research. In addition, research was conducted on similar products, such as soda bottles for the grasping device and garage door opener remotes for the pinching device using Cambridge Engineering Selector (CES) software. CES software was used in order to compile a list of possible materials based on the determined material characteristics. The CES software also generated a graph of yield strength against price to aid in the selection of a material that could satisfy the required characteristics at the lowest possible cost (USD/kg). This relationship is shown in Appendix G.2 for both the grasping and pinching devices.

The graph shows that the possible materials for the grasping device are polymethyl methacrlate (Acrylic, PMMA), Polyvinylchloride (tpPVC), and polyethylene terephalate (PET). Polyethylene terephalate (PET) was the selected material for the grasping device. This was selected based on it satisfying all material requirements, as well as passing subjective testing. Subjective testing was conducted by grasping soda bottles (which use the same material) as hard as possible. This was done in order to test the strength of both the pressure seal as well as the structural integrity of the bottle. The result of this test was that the pressure seal never broke, and the material never experienced plastic yield under the loads that were applied. Another consideration that was taken into account was the relatively low cost of PET in comparison to Acrylic, PMMA according to the CES plot. It is important to note at this point that the grasping device bottle will be purchased from a supplier because it is more economical than if the part were to be blow molded by the designers. Due to this constraint, the actual crystalline structure of the purchased bottle may not be purely PET, however, every effort will be made to purchase a high composition PET bottle.

The CES software was also used to determine the material for the pinching device. These materials include low alloy steel, cast magnesium alloys, and GFRP epoxy matrix (fiberglass). After gathering pricing information, not only from CES but also from actual suppliers, it was found that a local supplier, Jack's Hardware (Ann Arbor, MI), could offer fiberglass material at a discounted rate. For this reason, and because it met all of the material and strength requirements, fiberglass was selected to be used to construct the pinching device.

SENSOR REQUIREMENTS & SELECTION

A wide variety of sensors were researched in order to determine the best fit for the devices. First the requirements for the devices were determined. Next, sensors that met the requirements were researched. It is important to note that any of the sensors discussed below are capable of reporting the data that is needed, however not all can report it within the physical and electrical constraints that the system design requires.

Sensor Requirements

The main requirements necessary in selecting each sensor are shown below in Table 1.

	Pressure Sensor	**Force Sensor**
Range	0-30 psi	0-100 lb
Voltage	5 V DC max	5 V DC max

Table 2: Sensor Requirements

The most important characteristic of the sensors is the range and these were previously determined in the Analysis section. If the sensor's range is not large enough, clipping of the data could occur. However, if the range limit is too large, resolution can be sacrificed. This is because as the range of a sensor increases, the resolution decreases.

The computer is able to provide up to approximately 5 V DC and 5 mA to the sensors. If a sensor was selected which required a voltage greater than this, a separate power supply would be necessary. For this reason, it is important that the computer can provide the power requirements for the selected sensors.

In addition to the above specifications, the dimensions of the sensors were also considered in the selection process. The sensors need to fit within the devices and the dimensions of the devices will be discussed in the Fabrication section on page 23. Also, the project sponsors did not want the pressure sensor to contain a physical display that would show the pressure reading directly on the device. This could skew patient progress, as they would be able to view the pressure reading without following the computer program.

Pressure Sensor

The pressure sensors that were considered are shown in Table 3, below, along with their respective specifications. This table will be followed by a brief explanation of each pressure sensor. In addition, detailed specification sheets for all considered pressure sensors can be found in Appendix H.

Product	*Image*	*Cost*	*Range*	*Power Required*	*Notes*
Futek Industrial Pressure Sensor		$520	0-29psi	10V DC	High cost, power requirement too high
Honeywell Low-Cost pressure transducer		$245	0-30psi	10V DC	Power requirement too hight
Grainger Pressure Transmitter		$389	0-100psi	6-14V DC	High cost, pressure range too large
Transducers Direct TDG Series Pressure Transducer		$320	0-30psi	5V DC	High cost
Kavlico P4055 Low Cost OEM Pressure Sensor		$140	0-30psi	5V DC	Satisfies all required specifications

Table 3: Pressure Sensors Considered

The Futek Industrial Pressure Sensor (Appendix H.1) and the Honeywell Low-Cost Pressure Transducer (Appendix H.2) both have a pressure range that is within the sensor requirements for the device, however they both required a supply voltage of 10 V DC. A 10 V DC supply voltage require the purchase of an external power supply. In addition, the Futek Industrial Pressure Sensor is very expensive. Therefore, both of these sensors are inadequate for this application.

The Grainger Pressure Transmitter (Appendix H.3) is also not a good option for this application because the pressure range is too large. As explained above, this would lead to an output signal with a lower resolution. Also, this is the second most expensive option and would require a separate power supply.

Both the TGD Series Pressure Transducer from Transducers Direct (Appendix H.4) and the Kavlico P4055 Low Cost OEM Pressure Sensor (Appendix H.5) satisfy all required specifications. The Kavlico pressure sensor was selected over the Transducers Direct model solely due to cost.

Force Sensor

The force sensors that were considered are shown below in Table 4 below, along with their respective specifications. This table will be followed by a brief explanation of each force sensor. In addition, detailed specification sheets for all considered pressure sensors can be found in Appendix I.

Product	*Image*	*Cost*	*Range*	*Power Required*	*Notes*
Futek Miniature Load Button		$450	0-100lb	5V DC	High cost
Omega Miniature Compression Load Cell		$375	0-250lb	5V DC	High cost, too large of a range
Honeywell Load Cell		$839	0-100lb	10V DC	High durability, extremely high cost, power requirement is too high
NexGen Tekscan FlexiForce A201 Variable Resistance Sensors		$75 /4pack	0-150lb	5V DC	Requires additional circuitry and $199 LabVIEW driver
Measurement Specialties FC23 Compression Load Cell		$100	0-100lb	5V DC	Satisfies all required specifications

Table 4: Force Sensors Considered

The Futek Miniature Load Button (Appendix I.1) satisfies most required specifications. It has an adequate pressure range and it is within the power limitation. It also fits dimensionally in the device. However, this force sensor was not selected because of its very high cost. The Omega Miniature Compression Load Cell (Appendix I.2) also satisfies most required specifications. However, the force range for this sensor is much too high. As explained above, this would introduce an unnecessary resolution error. The Honeywell Load Cell (Appendix I.3) is also not a good option for our application. While it is a very high quality force sensor, it is extremely expensive, and would require an external power supply.

At first glance, the NexGen Tekscan (Appendix I.4) seems to be a great product for the devices. However after looking more closely, a few important issues were noted. One issue is that it will not fit within the physical requirements. This sensor is flat, and requires direct contact with the finger. The pinching design does not allow the patient's hand to make direct physical contact with the force sensor. Another flaw in this senor is that it requires additional circuitry to be added to the sensor (Appendix I.4). Also, the NexGen force sensor requires a LabVIEW driver to be installed to allow LabVIEW to recognize the signal, which costs $199.

The Measurement Specialties FC23 Compression Load Cell (Appendix I.5) is able to satisfy all required specifications, as well as offer the lowest cost. For these reasons, this sensor was selected.

DAQ REQUIREMENTS & SELECTION

The purpose of this section is to show the physical connectivity of the system, as well as provide the data acquisition (DAQ) requirements. Also, the selected DAQ will be presented. This DAQ was selected based on the determined requirements.

DAQ REQUIREMENTS

This section presents and explains exactly how the pressure and force sensors' signals are transferred from the sensors to the computer. Shown below, in Figure 20, is a schematic of the connections of the system.

Figure 20: Physical Connectivity of System

The pressure sensors and force sensors are wired directly to a DAQ. Each sensor has two leads coming out, which are wired into available analog input pins located in the DAQ. The DAQ has a digital signal processor (DSP) chip, which receives the analog signal, converts the signal into a form that can be read by

the computer and then sends it to the computer through the computer's Universal Serial Bus (USB) port. Also, a supply voltage signal (5 V DC) will be sent from the computer to the sensors to supply power to the sensors.

DAQ Selection

In considering which DAQ to use in the system, a few requirements had to be met. The DAQ selected needs to have at least eight analog inputs to accommodate the four sensors, each with two leads. The DAQ also requires at least two analog outputs to supply power to the sensors. Another important requirement of the DAQ is that it is inexpensive. Taking these things into account, the NI-USB-6008 DAQ from National Instruments was selected. This DAQ satisfied all requirements and was able to be used with LabVIEW without purchasing additional extra drivers. The specification sheet for this DAQ can be found in Appendix J.

BILL OF MATERIALS

The necessary materials to complete the manufacturing and assembly of the grasping and pinching devices are discussed in this section. The materials required to complete the grasping devices are two pressure sensors, two bottles, Teflon tape, two 7/16" o-rings, and two 7/16" nuts. The pressure sensors will be purchased from Measurement Specialties, Inc. The specific pressure sensor to be used is the MSP-300-030-P-2-N-1 Pressure Sensor. The pressure sensor will be used to measure the change in pressure within the device. This change in pressure is caused by the changing volume of the device caused by the applied force by the hand. The bottle will be purchased from Meijer, in Ann Arbor, MI, and is used as the main container of the grasping device. The Teflon tape will be purchased from ACE Hardware and will be used to create an airtight seal with the pressure sensor's threads. The 7/16" nut and 7/16" o-ring will be purchased from Jack's Hardware, in Ann Arbor, MI and will be used to securely fasten the pressure sensor to the top of the bottle.

The materials required for the pinching devices are two force sensors, 1/4" thick fiberglass, 1/8" thick fiberglass, J-B Weld Mini Clear Epoxy, six screws, four bolts, four nuts, and 1/4" rubber plug. The force sensors will be purchased from Measurement Specialties, Inc. The specific force sensor is the FX1901-0001-0050-L Compression Load Cell. This force sensor will be used in the pinching device to measure the patient's applied force. The fiberglass will be provided by the University of Michigan machine shop. The fiberglass will be used to create components of the pinching device, which are discussed in the Manufacturing of the Pinching Device subsection. The J-B Weld Mini Clear Epoxy, screws, bolts, and nuts will be purchased from Meijer, in Ann Arbor, MI. The rubber plug will be purchased from Jack's Hardware in Ann Arbor, MI. These will be used in assembly of the device. A tabular representation of the Bill of Materials can be seen in Appendix K.

FABRICATION

This section will discuss the necessary steps involved in fabricating the grasping and pinching devices. The fabrication of the devices will take place in the machine shop, X50 lab, and the assembly room at the University of Michigan. The fabrication of the devices will consist of manufacturing and assembly.

Manufacturing

This section discusses the manufacturing considerations for both the grasping and pinching devices. The manufacturing of the components will take place primarily in the machine shop at the University of Michigan.

Manufacturing of the Grasping Device

The grasping device will be manufactured by modifying a purchased bottle in the machine shop at the University of Michigan. The mouthpiece on the top of the bottle will be cut off and the pressure sensor will be inserted into the created hole. The mouthpiece will be cut off by fastening the bottle with a vice and using a hacksaw to remove the mouthpiece. After the mouthpiece has been cut off, the hole will have to be widened; this will be done using coarse grip sandpaper. This is necessary to fit the pressure sensor's threaded shaft through the hole.

Manufacturing of the Pinching Device

The pinching device will be manufactured out of 1/4" thick fiberglass. The fiberglass will be cut using the laser cutter in the machine shop at the University of Michigan. The tolerances required for this device need to be small and the laser cutter will provide high accuracy as well as fast production. The components that will be manufactured are the four outside walls, the two bottom plates, the button panel, and the two sensor holders. These components, designed in SolidWorks, can be seen in detail in Appendix E. Before manufacturing could begin all parts were combined into one SolidWorks drawing. This drawing must be no larger than 18" x 24" and have pieces separated by at least 0.025". This ensured that the laser cutter could fit the work piece and be able to cut each individual part without interfering with the next. The completed drawing can be seen in Appendix P.1 and it was saved as a .DXF file to be opened in the BobCAD software. BobCAD is the software used with the laser cutter and allows for a print out of the screen to be sent to the laser cutter to perform the necessary cuts.

In the BobCAD program, the lines that are cut have to be changed to red and the lines that are engraved have to be changed to blue. The circles on the button panel were engraved with the laser cutter. This provides the patients with a visual and tactile sense of where to press the device. To ensure the accuracy of the parts, the holes in the part were cut out first. The reason for cutting the holes out first is because the cutting path of the laser cutter cannot be controlled and once a part is cut it moves a small amount downward to the laser cutters work area. If the holes were not cute first, then the slight distance the part would fall would change where the laser would cut the outline of the part, thus affecting the accuracy. Once all the holes are cut out, the outside of all the parts are then cut. The top lip part, which is used to hold the button panel inside the device, is manufactured out of the 1/8" thick fiberglass. The 1/8" thick fiberglass is used because the top lip parts needs to be thin so it does not obstruct the patient from pressing the button panel. The top lip part is manufactured the same way as the 1/4" thick fiberglass and the SolidWorks drawing of the pieces can be seen in Appendix P.2.

ASSEMBLY

This section will discuss the necessary steps to assemble the grasping and pinching devices after manufacturing. The assembly of the devices will take place primarily in the machine shop, X50 lab, and the assembly room at the University of Michigan.

Assembly of the Grasping Device

The grasping device will be assembled using the modified bottle, the 7/16" nut, the 7/16" o-ring and the pressure sensor. A complete exploded view of the assembly can be seen in Figure 21, right.

Figure 21: Grasping Device Assembly

The following steps will be used to complete the assembly of the grasping device. The first step will be to assemble the bottle cap. First, the pressure sensor's shaft will be inserted into the hole created during manufacturing. This shaft is threaded and will be secured to the bottle by securing a 7/16" o-ring and 7/16" nut on the shaft from the inside of the bottle cap. The o-ring will create a seal and the nut will ensure the pressure sensor is securely attached. Once the bottle cap assembly has been completed

the bottle cap will need to be screwed onto the bottle. The completed grasping device assembly can be seen below in Figure 15, on page 14.

Assembly of the Pinching Device

The pinching device will be assembled out of the manufactured 1/4” thick fiberglass components, the screws, a 1/4” rubber plug, 1/8” thick fiberglass, the 1/4" x 1” bolts, the 1/4" nuts, and the force sensor. A complete exploded view of the assembly can be seen in Figure 22, below. The device will be assembled using the previously manufactured fiberglass pieces. These pieces will be laminated together using J-B Weld Mini Clear Epoxy. The epoxy will be applied to the desired sides of the pieces and then the pieces will be clamped together. The pieces will remain clamped until the pieces are fully dried and bonded together.

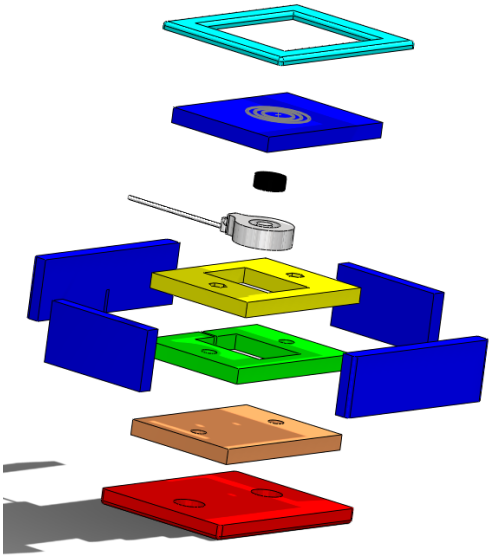

Figure 22: Pinching Device Assembly

The following steps will be used to complete the assembly of the pinching device. The first step will be to laminate the two sensor holder pieces as shown in Figure 23, below. Once the two pieces are fully dry, the 1/4" nuts will be inserted into the sensor holder piece with the hexagon holes, shown on top in Figure 23, below. Epoxy will be applied to the outer edges of the nut and inserted into the hexagon holes. The nuts need to be permanently attached to eliminate vertical displacement. If the nuts were allowed to shift up and down within the device, it would be very difficult to screw the bolts into the nut and create a snug fit.

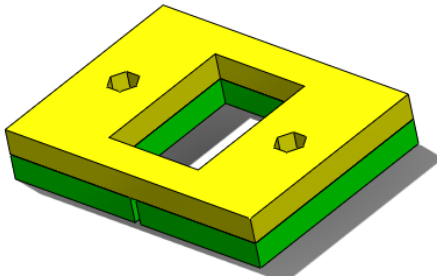

Figure 23: Laminating Component of Pinching Device

Next, the outer walls of the pinching device will be attached to the previously laminated sensor holder pieces. All outer walls will then be attached to the laminated sensor holder pieces. Walls will be attached individually, one at a time. A piece of fiberglass will be placed, but not attached, to the bottom of the

sensor holder pieces. This will provide the height at which walls need to be attached to the sensor holder pieces. This piece of fiberglass represents the bottom of the device that will be attached during future assembly steps. Each piece will be allowed to fully dry before the next piece is attached. A view of the pieces after the walls have been attached can be seen in Figure 24, below.

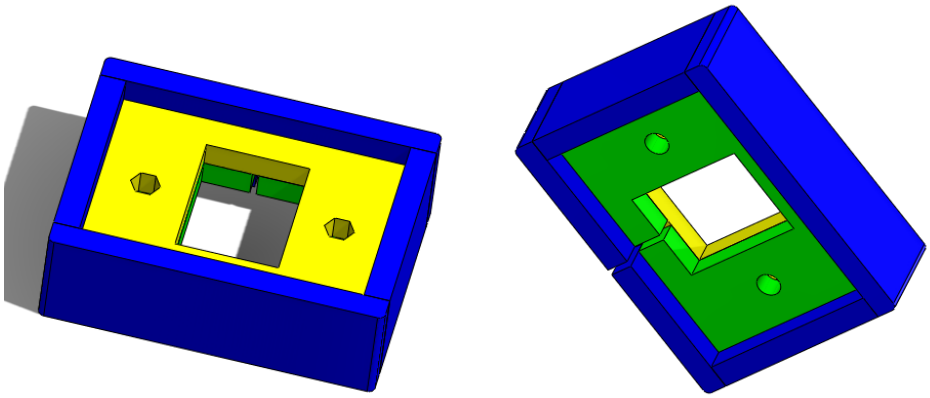

Figure 24: Outer Walls and Sensor Holder Assembly of Pinching Device

The next step will be to create the bottom panel. As seen in Figure 25, below. The bottom panel consists of two pieces. The top piece will be inserted into the hole created by not aligning the walls with the bottom of the sensor holder pieces. To ensure that the top piece is aligned correctly the previously assembled pieces, the walls and sensor holder piece, will be used for spacing. Once the spacing has been verified to the two bottom panel pieces will be laminated together. Again, they will be allowed to fully dry before moving on to the next assembly step.

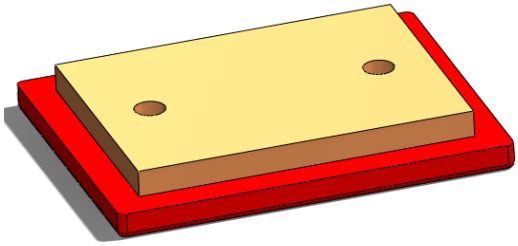

Figure 25: Bottom Panel Assembly

During the manufacturing of the bottom panel assembly piece, cylindrical pieces of fiberglass were left over. These pieces were attached to the bottom panel to ensure that the load sensor will not move or shift once it has been inserted into the device. This location is illustrated in Figure 26, below.

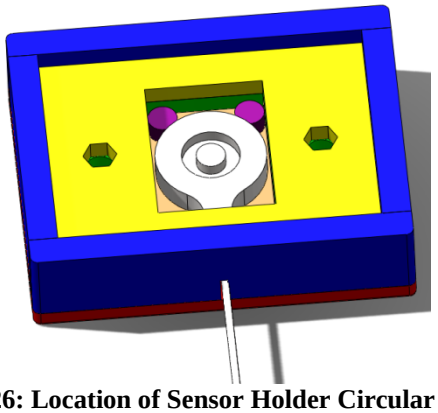

Figure 26: Location of Sensor Holder Circular Pieces

Next, the square top lip will be attached to the housing, as seen in Figure 27, below. The top lip is made out of 1/8” thick fiberglass. The top lip piece will be allowed to fully dry. Next a 1/2" rubber plug will be inserted in the device’s housing. The rubber plug is used between the button panel and the force sensor to allow for movement in the button panel when it is pressed. The rubber plug will also help reduce the frictional forces on the outer walls of the device and improve the life time of the device. The rubber plug will have a 1/4" screw threaded into the center of it. The screw is necessary in the rubber plug to press on the correct location of the force sensor.

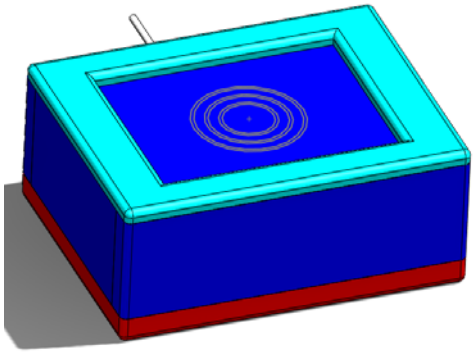

Figure 27: Final Pinching Device Assembly

ELECTRICAL CIRCUIT

During validation, which is discussed in detail in the Validation section, it was determined that an electrical circuit would need to be created. This electrical circuit would consist of operational amplifiers. These are needed to amplify the voltage signal being supplied from the sensors to the DAQ. The electrical circuit was first created on a bread board to ensure proper results before a soldering board was used. A picture of the bread board can be seen in Figure 28, below. The illustration is only intended to provide a general visual of the circuit, a more detailed illustration of how the circuit should be created will be provided on the following page.

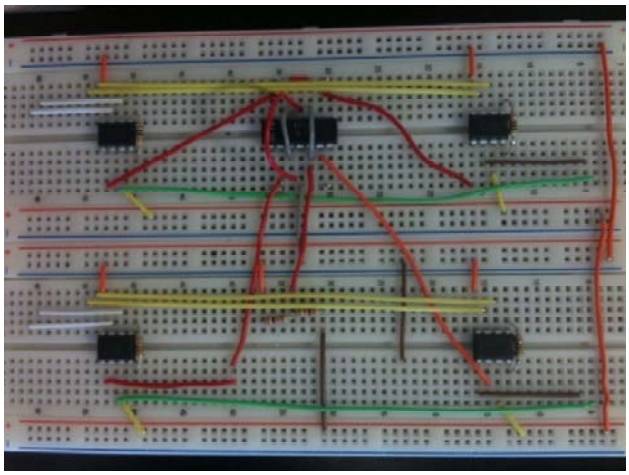

Figure 28: Electrical Circuit on Bread Board

In the circuit above, the black parts are the operational amplifiers. The four smaller operational amplifiers in the four corners are AD620 amplifiers and the one in the middle is an LM324. The LM324 is a type of operational amplifier that actually contains four smaller operational amplifiers. Each device, the two grasping and two pinching, uses one AD620 and a portion of the LM324. A detailed connectivity of the operational amplifier is provided in Figure 29, below and the data sheets for both amplifiers can be found in Appendix Q.

Figure 29: Connectivity of the Operational Amplifier

SAFETY

To ensure the grasping and pinching device's final designs are safe, Failure Mode and Effects Analysis (FMEA) and Designsafe were completed. FMEA was performed on all of the purchased components to determine the potential failure modes and Designsafe was performed on all of the manufactured components to analyze the possible hazards.

Failure Mode and Effects Analysis Results

Failure Mode and Effects Analysis (FMEA) was used on each of the purchased components to determine the potential failure modes, the effects of the failure, the cause of the failure, and the ways to reduce the failure. The FMEA results will help to reduce the risk of failure of components. From the results that are shown in Appendix L it was determined that the pressure sensor, force sensor, and the seals are the components most likely to fail. The failure of the pressure sensor would result in complete system failure which is extremely severe. The failure of the pressure sensor could be from excessive applied force, improper wiring, or improper voltage applied. To avoid these failures, research will be performed on what is the maximum pressure that will be applied to select an appropriate pressure sensor. Visual inspection of the wiring will also be done to ensure it is wired properly and the computer program will be error checked

to ensure the proper voltage is supplied. The force sensor was found to have the same failure modes and solutions as previously stated for the pressure sensor. The grasping device container has the potential failure of seal breaking. This would result in an inaccurate pressure reading by the pressure sensor and means the data observed by the patient and doctor would not be accurate. To avoid this failure, the use of Teflon tape on the pressure sensor's threads and using an o-ring will greatly reduce the risk of a seal leaking. To test for possible leaks, an inspecting of listening for leaks while pressure is applied will be performed.

Designsafe Results

The use of Designsafe is to analyze the risks and hazards which are associated with each of the manufactured components. Designsafe provides the possible failure mode, the risk level of the failure mode, the risk reduction methods, and the risk level after the reduction methods. From the complete analysis, which can be seen in Appendix M, it was found that the pinching device walls, the pinching device button panel, and the grasping device container were the most important components. The pinching device walls had failure modes of a possible pinching point, fatigue, and breaking under excess force. The possible pinching point is between the walls and the moving button panel. To reduce this risk, the gap between the walls and the button panel will only be a few millimeters. Fatigue is another possible failure mode because of the repeated use by patients. To reduce the effect of fatigue, the selected material must have a high yield strength. Another possible failure would be the patient applying excessive force and the component breaking under operation. This would be reduced again by selecting a material with a high yield strength. The next component is the pinching device button panel and the possible failure modes are a possible pinching point, fatigue, and breaking under operation. These failure modes are the same as the pinching device walls, as previously discussed, resulting in the same methods to reduce the risks.

The last component is the grasping device container. This is the modified bottle top with the pressure sensor in it. The potential failure modes of this are excessive force, fatigue, and high pressure. Excessive force will result if the patient squeezes the device to hard and causes the seals to break. To avoid this failure, the use of a reinforcement fiberglass piece on the top of the bottle is used along with an o-ring, Teflon tape, and a nut to securely attach the pressure sensor. Fatigue is another possible failure mode because of the repeated use of the device. Fatigue can result in a seal breaking or the material breaking. To avoid this, a material must be selected with a high yield strength. The last failure mode is high pressure resulting it a broken seal or rupture of the device. The high pressure is because the container is sealed and the large forces that can be applied to it. This can be avoided by selecting a high yield strength material and the use of Teflon tape, o-rings, and a nut to securely fasten the pressure sensor.

FINAL DESIGN: LABVIEW PROGRAM

To accompany the grasping and pinching devices a computer program must be developed. LabVIEW has been chosen because of its real time feedback, and user friendly set up. The development of the accompany program will be discussed in the following section.

Flow Chart

To better understand how the signal produced by the sensors will flow through the system a flow chart was created. The flow chart can be seen below in Figure 30, on page 29. The sensor will be supplied a voltage either by LabVIEW or an external power supply; further investigation will determine which option is the best. The sensor will create a change in voltage which is dependent on the type of sensor used. This output voltage is then returned to the LabVIEW program through a Data Acquisition Device (DAQ). LabVIEW then uses this output voltage to provide feedback to the patient and doctor. It was first believed that the voltage that the LabVIEW program would receive would need to be amplified or filtered throughout the program; however, upon research and discussion with Dr. Bress it is believed that this is

not necessary. The output voltage of the sensor is the input voltage to the LabVIEW and can be converted into force through the developed program. As a requirement of the project the patient will need a real time visual feedback; a detailed description of the real time graphs can be found in the Modules section. The doctor will receive an exported file which contains these voltages and times for further analysis. This output may be in the form of an Excel or text file.

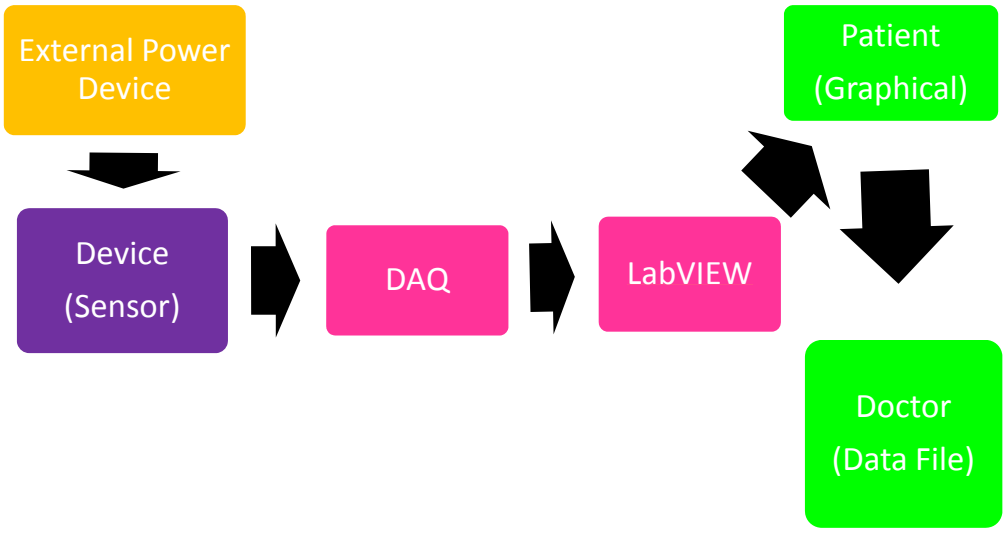

Figure 30: Flow Chart of Signal in System

Developing the Telerehabilitation Program

As mentioned previously, creating the LabVIEW program will be the most challenging part of this project. This is due to the extensive programming knowledge required to make such a detailed program. It has been recommended to our team to contact Dr. Thomas Bress as source for LabVIEW assistance. Preliminary meetings have been completed with him at this time. The first meeting was used to discuss the plausibility of the actual program as well as starting points. After showing and explaining to Dr. Bress the proposed modules he indicated that the ideas seemed entirely plausible, but will not be easy. He also showed the team a few preexisting controls in LabVIEW that he thought would be useful. These controls include the system tab control and the horizontal sliding bar, which will be explained in detail in the LabVIEW Control section. He also explained that one of the major benefits to this project is that the device and the program can be completed independent of each other. A dial can be put into the program before the devices are completed, which will provide a signal similar to that of the device. This dial can be manual altered by the programmer to make sure the program works at each step throughout the program writing process. When the device is finished, the dial can be removed, and will be replaced with the signal from the device. The device signal will come from the device and be acquired through the (DAQ), as explained in the previous Flow Chart section. He suggested proceeding one module at a time and consulting with him when any major problems arose. Further meetings with Dr. Bress are anticipated as the program progresses.

The actual programming will be completed module by module. We will begin with module one and work through all four modules. The first step to completing a module is to create the front panel. The front panel is the user interface. All of the graphics that will be displayed to the user will need to be added. Next, the back panel will be created. The back panel is not visible to the user and is used to connect the front panel items together with programming code. LabVIEW is a graphics based computer programming code, so all front panel items will be graphically written together. Programming will proceed from this point via trial and error. As mentioned previously, a dial will be used to simulate the device's signal and

this will be manipulated to see how the program responds. When the program responds correctly, the module will be complete, and programming will begin on the next module. Programming with this method will provide a systemic and organized execution.

LabVIEW Controls & Indicators

The LabVIEW program has many preexisting controls and indicators that can be incorporated into the telerehabilitation program. A control is a front panel object for entering data and an indicator is a front panel object for displaying information to the user. These preexisting controls and indicators are beneficial to use because they have already been developed, debugged, and made aesthetically pleasing. The use of these preexisting controls and indicators will aid in completing the program on time. At this time a few controls and indicators have already been identified that could possibly be incorporated into the telerehabilitation program and will be described in the following section.

System Tab Control

The system tab control is container control; meaning it consists of different user interfaces which hold other controls. The system tab control can be thought of as file folders, where each folder contains a different user interface. In this proposed application, each folder, or user interface, would contain a different module. To navigate through each user interface the user would click on a tab in the system tab control. When a tab has been selected the corresponding user interface is shown and the others hidden. A welcome page is also being considered with instructions on how to complete the telerehabilitation program. An illustration of the possible system tab control can be seen in Figure 31, below.

Figure 31: System Tab Control

The major benefit to using the system tab control is that it will easily allow patients to move through the different modules. The patient will be presented with easily identifiable buttons to click on which will take them to the desired module. If the system tab control was not used, other code would have to be written that takes patients through the different modules. This would be very extensive and difficult to complete with the team's current knowledge of LabVIEW. The only foreseeable disadvantage to using the system tab control is patients will be given the option to complete the modules in any order. Since module one determines the maximum force capabilities of the patient it must be completed first. Specific instructions will be provided in an attempt to avoid this through the welcome page, instruction manual, and doctor's verbal instructions.

Dial Control

The dial control is a type of numeric control; meaning manipulation of this control will operate a numeric number. An illustration of the dial can be seen in Figure 32, right. As the programmer, via mouse control, rotates the dial a numeric number is altered and can be sent as a signal. The correlation between the dial and the numeric number is linear. As explained previously, the application of the dial control is just during the programming testing processes. It will represent the signal from the device. The only foreseeable challenge with using the dial control will come when it is removed and the device is used instead. The dial is an accurate representation of the device, but not exact. It is hard to predict the differences that will be present when the signal is from the device as opposed to the dial.

Figure 32: Dial Control

Horizontal Sliding Bar Indicator

The horizontal sliding bar is a type of numeric indicator, meaning the sliding bar represents a numeric number. As the numerical value of the signal being read changes the horizontal bar adjusts to indicate that value. The far right is the maximum value and the far left is the minimum value. An illustration of the horizontal sliding bar can be seen below in Figure 33, below. The potential application of the horizontal sliding bar is it could be used in each module to indicate the force the patient is applying to the device. In this application, it will be necessary to set the minimum to zero, for no applied force, and the maximum to the patient's maximum force capabilities. Markers could be added to indicate to the patient the force at which they should be applying to the device during that portion of the rehabilitation program. It is also important to note that many types of horizontal sliding bars exist. They operate in the exact same fashion, but have different visual appearances. Examples of these have been included in Appendix N.

Figure 33: Horizontal Sliding Indicator

The major benefit to using the horizontal sliding bar is that it is already created within the LabVIEW program. The slider will move as the patient changes the applied force and will provide real time visual feedback to the patient. Other controls do not provide the continuous feedback that the horizontal slider provides. The horizontal slider is also very easy to read and patients will not struggle to know if they are performing the rehabilitation program correctly. There are three major challenges present with using the horizontal slider. The first is going to be in calibration. The horizontal sliding bar's maximum value will have to change with patients and as the patient progresses to correlate to the patient's maximum force applying capabilities. Module one will measure the maximum applied force and set the horizontal slider. The second challenge will be creating the gates, or goal areas, the patient will be aiming for. During the rehabilitation program the patient will need to apply a certain force for a certain amount of time, for example between 27 and 33% of their maximum strength for three seconds. An indicator must be put on the horizontal slider so that the patient not only knows where to shoot for, but also if they are within the zone or to the right or left of it. This can easily be done by placing clip art on the slider, but it would be beneficial to write these images into the program so they can be changed if the doctor wants to change the gate areas. The final challenge is that the patient will need to keep the horizontal slider within the gates for a certain amount of time and the program must indicate when that time has been reached. In addition it will need to indicate this when both hands are being used and make sure both hands exert the correct

amount of force for the correct amount of time. This will probably be the largest challenge of the three because it incorporates the most computer programming.

Round Light Indicator

The round light is a type of Boolean indicator, meaning it only responds to a signal of true and false. The round light will illuminate if a signal of true is sent to it and remain unlit if a signal of false is sent to it. The potential application of this indicator is it could be used as an indicator to for the patient. For example, it could light up when the patient reaches the desired force and a second one could indicate when the patient has held that force for the required amount of time. An illustration of the round light can be seen below in Figure 34, right.

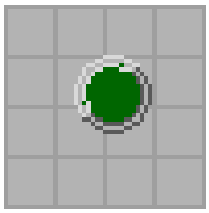

Figure 34: Round Light Indicator

The major benefit to using this indicator is it provides an easily recognizable real time, visual feedback, which is required by the sponsor. A round light up is a common way to indicate a signal to people, for example stop lights. In addition, the signal will be provided in real time so the patient knows exactly when they have completed a task. There are two major challenges for using the round light up for this application. The first is determining how to make the round light illuminate if the patient reaches a certain force range. It is predicted that this can be done using simple and, or, if, and then statements (programming code on the back panel). The second challenge is how to make the round light illuminate if the patient maintains the appropriate force for the specific amount of time. It is predicted that similar and, or, if, and then statements will be used along with some timer function. A preexisting time function has not been found at this time that does exactly what is needed for the rehabilitation program, but it is probable that one may be altered to achieve this goal. This will be the hardest challenge when using the round light and in the entire program.

Numeric Indicator

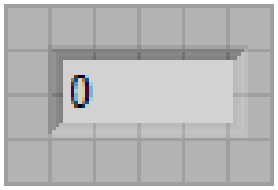

Figure 35: Numeric Indicator

The numeric indicator is a display of a numerical value. It has not been determined if this control will necessarily be used in the telerehabilitation program, but is possible. It may be used in Module one to let the patient know the maximum force they could exert. This type of control is very easy to use and can be added almost anywhere in the program to indicate a number on the user interface. An illustration of this control can be seen below in Figure 35, left. There are no major foreseeable challenges with this indicator.

System Button Control

Figure 36: System Button Control

The system button control is another type of Boolean control. Similar to the round light it only works with signals corresponding to true and false. The main different between the round light and the system button is that the round light indicates something to the user, while the system button indicates something to the program. At this time it has not been determined if this control will be used, but may be incorporated, possibly at the end of each module to tell the program that the patient has finished this module and is ready to move on to the next. The text on the button can easily be changed to text such as STOP, GO, COMPLETE, ect. An illustration of the system button can be seen below in Figure 36, left. There are no major foreseeable challenges with this control.

Description of Modules

The patient will use the same LabVIEW Program for the grasping and pinching tests. This program will consist of four different modules which the patient will complete by the end of the therapy session. Modules are different rehabilitation tasks that the patient will perform.

Module One

The first module will measure the maximum force that the patient can exert on the device. This force will be used as the maximum value of the remaining modules.

Patient: A possible user interface of the first module can be seen below in Figure 37, below. In this module the patient will simply grasp or pinch the device as hard as they possibility can. LabVIEW will then analyze the data to determine the maximum force that the patient can exert on the device. The patient will only see a light for a predetermined amount of time and then the patient will move on. The maximum force exerted on the device during this module will be determined using a preexisting LabVIEW function and will be used for calibration of the remaining modules.

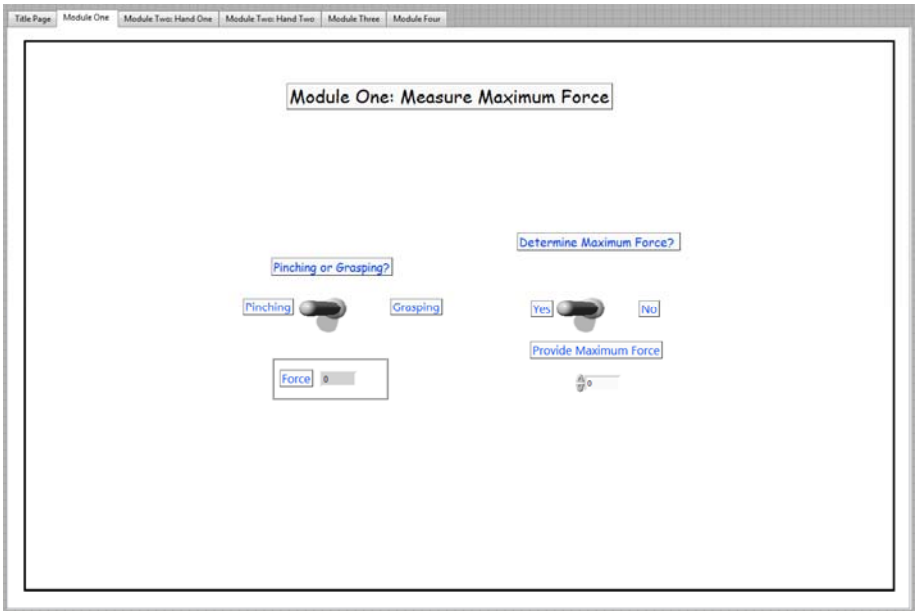

Figure 37: Module 1 User Interface

Doctor: The doctor will receive an Excel file which contains all the data of force against time. The doctor can use this data to further investigate the patient's progress at a later date as well as use another program; such as, Excel to plot force against time.

Module Two

In module two the patient must exert varying amounts of force on the device using only one hand at a time. They will complete the module for each hand to improve hand manipulation of each hand independently of the other hand.

Patient: A possible user interface for the second module can be seen below in Figure 38, on page 35. This module contains a sliding bar that visually shows the force applied to the device. At zero force, the sliding bar is all the way to the left and all the way to the right is the patient's maximum, which was determined in module one. There are three gates which represent different percentage ranges of the patient's maximum force. These gates will be located at 10, 30, and 50 percent with the range extending two percent on each side. The patient will proceed through the program by moving the sliding bar into

each gate, by applying the appropriate amount of force, and maintaining that position for the specified amount of time. The patient will know when they have applied the correct force, when they enter the gate, because the first green light will illuminate. After the patient has maintained this force for the desired specified amount of time, the second light will illuminate. Once both lights have been illuminated, the patient will need to return to zero force and proceed to the next gate. It is important to note that the patient will not perform these tasks in ascending numeric order. Instead, the patient will go to the 30 percent gate, the 10 percent gate, and then finally the 50 percent gate.

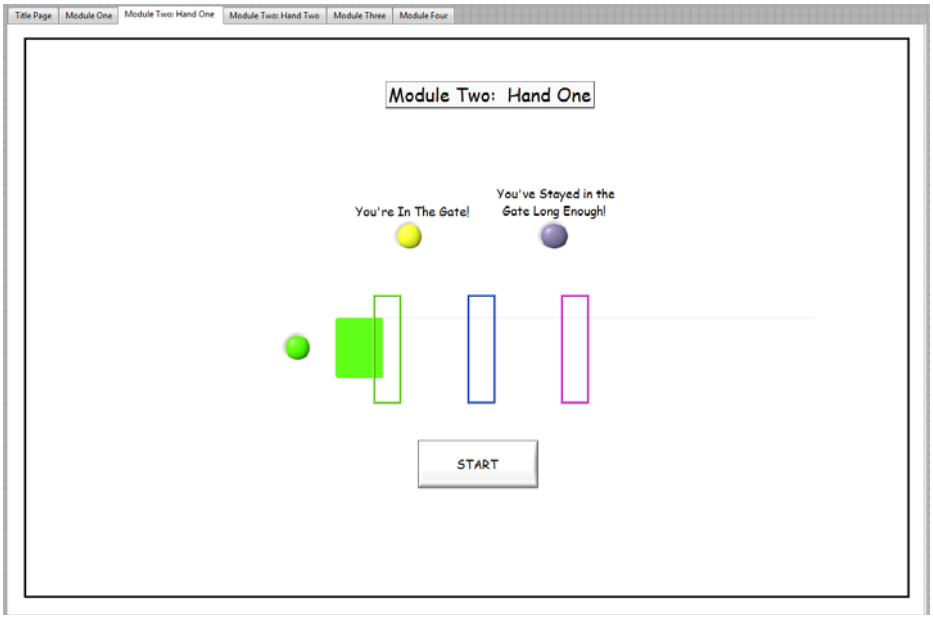

Figure 38: Module 2 Screen Shot

Doctor: In this module the doctor will receive a data file containing the data of force against time to tell how well the patient performed. Specifically, the doctor will be able to tell how long it took the patient to get to the gates, and if they overshot or undershot the boxes. The data will be exported in a data file which the doctor can use to perform their analysis.

Module Three

In module three the patient must grasp or pinch two devices simultaneously and at the same varying percentages as in module two.

Patient: A possible user interface for the third module can be seen below in Figure 39, on page 36. This module contains two sliding bars that visually show the force applied to the two devices. At zero force, the sliding bar is all the way to the left and all the way to the right is the patient's maximum, which was determined in module one. There are three gates which represent different percentage ranges of the patient's maximum force. These gates will be located at 10, 30, and 50 percent with the range extending two percent on each side. The patient will proceed through the program by moving the sliding bar into each gate, by applying the appropriate amount of force, and maintaining that position for the specified amount of time. In this module this must be done by both hands simultaneously. The patient will know when they have applied the correct force to both hands, when they entered the gates, because the first green light will illuminate. After the patient has maintained this force for the desired specified amount to time, the second light will illuminate. Once both lights have been illuminated, the patient will need to return to zero force and proceed to the next gate. It is important to note that the patient will not perform these tasks in ascending numeric order. Instead, the patient will go to the 30 percent gate, the 10 percent gate, and then finally the 50 percent gate.

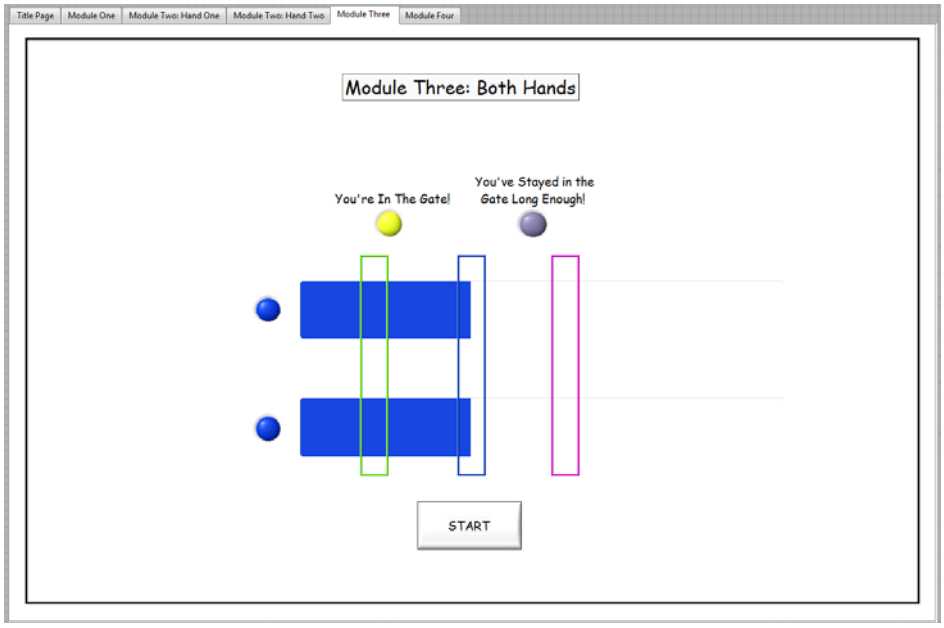

Figure 39: Module 3 User Interface

Doctor: In this module the doctor will receive a data file containing the data of force against time to tell how well the patient performed. Specifically, the doctor will be able to tell how long it took the patient to get to the gates, and if they overshot or undershot the boxes. They will also be able to compare the force applied by each hand. The data will be exported in a data file which the doctor can use to perform their analysis.

Module Four

The final module of the rehabilitation exercises requires the patients to either grasp or pinch the devices in a non-simultaneous pattern.

Patient: A possible user interface for the fourth module can be seen in Figure 40, on page 37. This module contains two sliding bars that visually show the force applied to the two devices. At zero force, the sliding bar is all the way to the left and all the way to the right is the patient's maximum, which was determined in module one. There are three gates which represent different percentage ranges of the patient's maximum force. These gates will be located at 10, 30, and 50 percent with the range extending two percent on each side. The patient will proceed through the program by moving the sliding bar into each gate, by applying the appropriate amount of force, and maintaining that position for the specified amount of time. In this module this must be done one hand at a time. The patient will know when they have applied the correct force, when they entered the gates, because the first green light will illuminate. After the patient has maintained this force for the desired specified amount to time, the second light will illuminate. Once both lights have been illuminated, the patient will need to return to zero force and then do the same for the other hand. It is important to note that the patient must use one hand at a time or the bar will not move, also the patient will not perform these tasks in ascending numeric order. Instead, the patient will go to the 30 percent gate, the 10 percent gate, and then finally the 50 percent gate.

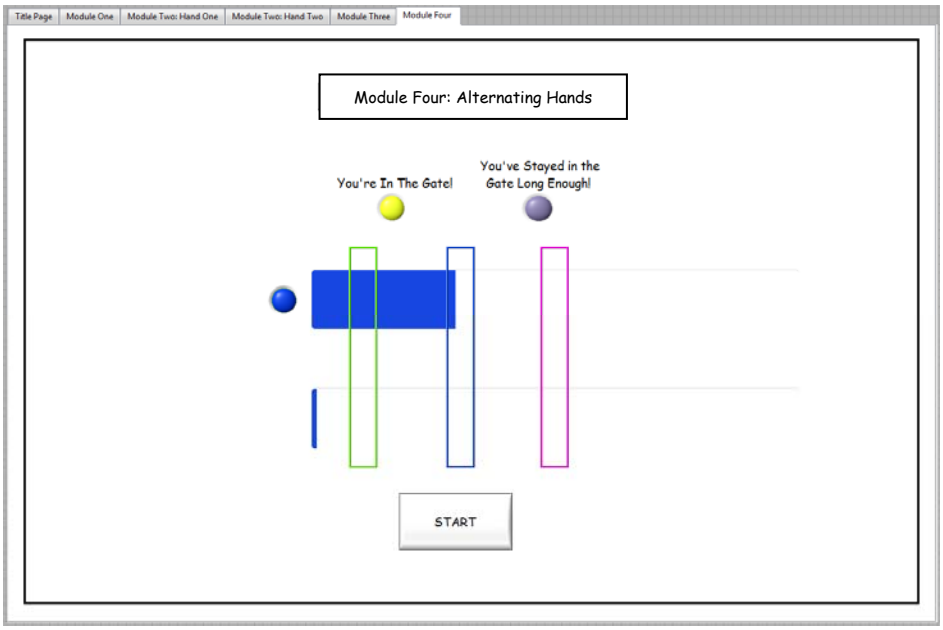

Figure 40: Module 4 User Interface

Doctor: In this module the doctor will receive a data file containing the data of force against time to tell how well the patient performed. Specifically, the doctor will be able to tell how long it took the patient to get to the gates, and if they overshot or undershot the boxes. They will also be able to compare the force applied by each hand. The data will be exported in a data file which the doctor can use to perform their analysis.

Patient Instruction Manual

A patient instruction manual will be provided with the project to assist both the patient and the doctor in the usage of our final product. The creation of this manual at this stage of development is beneficial because it ensures that everyone on the team and the sponsors are on the same page. The instruction manual was presented to the sponsors prior to the start of writing the program. The sponsor was then able to read through the manual and make sure that program met their requirements and was not too difficult for the patients to complete. It is anticipated that the instruction manual will evolve as the program is written (including the addition of graphics), but the preliminary instruction manual provided excellent feedback. This preliminary instruction manual is provided in Appendix O.

VALIDATION

In order to prove that the design works as expected, various tests for verification will be implemented. These tests will be implemented throughout the design and manufacturing of the devices and program. Validation was completed for both the devices, as well as, the program.

Device Validation

To validate the devices, tests were completed to ensure both devices performed correctly and accurately. The devices were somewhat difficult to validate with objective data, so a number of subjective tests were conducted as well. This section also includes countermeasures that were taken to avoid potential problems.

Grasping Device

The first step to validate the grasping device was to ensure the sensor worked with the DAQ and the LabVIEW program. After connecting the sensors, it was determined that the voltage output from the sensors was much too small to be recognized by the DAQ. To fix this, an amplifier circuit had to be constructed in order for the appropriate voltage to be provided to the DAQ. The circuit was created using a trial an error method. Different operational amplifiers were attached in different configurations until the appropriate voltage was obtained. One of the major problems in finding a configuration that worked was in regards to the voltage gain. An optimal gain existed. This optimal gain would ensure that the voltage signal was not clipped at minimum and maximum levels of force applied to the sensor. The gain must also ensure that the voltage spanned as large a range as possible; this was done to ensure accuracy. This means that the voltage difference between the minimum applied force and maximum applied force was a large a value of possible. It is important to recognize the help provided by John Baker, University of Michigan, in providing circuit knowledge.

While the circuit was being created, testing was performed on the grasping device. It became apparent that there needed to be an extremely tight seal on the device. Before any actual testing of the device, preliminary testing was completed to make sure the devices could maintain a tight seal. To do this two strong males squeezed the device for 30 seconds and listened for air to be released. The devices were also inserted into a bucket of water and visually inspected to make sure no air bubbles reached the surface during compression of the device. It was determined initially that the seal was not adequate. Two countermeasures were proposed to improve the seal. The first was to add an o-ring between the female bushing and the bottle cap. This would effectively create a stronger seal between the bottle cap and the threads. The second proposed countermeasure was to add a hose clamp around the top of the cap. This would improve the seal in the area between the cap and the male thread on the pressure transducer. After implementation of the first countermeasure, it was determined through repeating the initial testing that the devices were properly sealed. These tests showed that the device was properly sealed even after repeated and lengthy grasps. Therefore, the hose clamp countermeasure was not implemented. This testing method was explained and displayed for the sponsors, and they agreed that the devices were strong enough and the seal was adequate for patient use.

Once the circuit had been completed and the seal on the device verified, physical testing was done to ensure the grasping device worked properly. This was first done by the team. The team would use the rehabilitation program and ensure that the grasping device responded as expected. This testing went extremely well, it appeared the grasping device worked well. The next physical testing was completed by the sponsors and a volunteer patient. This testing went well, but brought up a few important issues. The first issue was in regards to the deformation of the bottle. As the patient squeezed the bottle the sensor worked correctly, however, when the patient released their grasp on the bottle, the bottle did not return quickly to the undeformed shaped. In addition, sometimes it wouldn't return to the original shape at all. This is a problem because there are many portions of the rehabilitation program where the patient is required to apply zero force to the bottle. To fix this problem, water was put in the bottle. This created a more rigid structure and seemed to eliminate the problem. Another issue that arose during sponsor and patient testing was with all of the wires. There are four wires that lead from the device to the circuit board. This was a little overwhelming for the patient. To eliminate this problem all four wires were concealed within one tube.

Pinching Device

Similarly to the grasping device, the pinching device voltage output was not large enough. Therefore the pinching devices also needed to be amplified. The same process was completed to create an operational amplifier circuit that would satisfactorily amplify the signal. The circuit used for the grasping device proved to be adequate for the pinching device as well.

Aside from this issue, the pinching device did not have any mechanical issues that would prevent it from providing the information required by the program. However, a couple things that could help the actual patient were overlooked in the design and manufacturing process.

The first was that there was no physical feedback for the patient. When they squeezed the device, there was no physical indication that they had done anything. As a countermeasure for this issue, a rubber plug was installed between the button panel and the load cell. This gave a small amount of spring or compression in the button panel motion. A small gap needed to be installed in the device as well in order to allow for extra motion of the button panel. This aided the user in their understanding of how the device operated as well as their ability to function the device.

Another thing which was overlooked was the sharpness of the corners. During manufacturing, special attention should have been paid to how sharp the corners would turn out. As a countermeasure to this issue, all corners were sanded so that no sharp edges remained. After these two countermeasures were implemented, the device operated adequately and successfully.

A series of tests were performed to verify that the pinching devices were strong enough to withstand large pinching forces. These tests consisted of two strong males pinching the devices for 30 seconds at a time. After repeated pinching was completed on the devices, it was determined that the devices were strong enough for any force the patients could apply. This testing method was explained and displayed for the sponsors, and they agreed that the devices were strong enough for patient use.

Finally, after the circuit and initial testing were complete, the pinching device underwent the same team, sponsor, and volunteer patient testing that the grasping device underwent. The testing on the pinching device went extremely well. The only issue that arose was that of the wires and containing all wires within a tube, like the grasping device, was the most obvious solution.

Program Validation

As with the devices, the program also needed to be validated to ensure the program worked correctly and accurately. Validation was performed throughout the program development progress, as well as at the program's completion. As mentioned previously, a dial was used during the programming process to represent the signal from the sensors. As each module was completed, the sensor signal was modeled to ensure each module worked correctly. After the program had been completed the program was tested. This was explained previously in the Device Validation section. During the sponsor and patient testing a few valuable suggestions were made. First, more visual cues would be helpful to guide the patient through the rehabilitation program. Second, the sponsor would like the patient to take their max force three times and then have the program use an average of this value. Third, allowing the patient to do each module multiple times would be beneficial. And finally, creating a start/stop button for each module would help the patient know they are doing the program correctly. Both the sponsor and the volunteer patient were very happy with the program and provided confirmation that all customer requirements were met.

DISCUSSION

This section discusses the project after its completion. Specifically, this section provides an analysis of the strengths and weaknesses. In addition, it provides a discussion of where improvements should be made to the system. This discussion is provided for both the devices and the program.

Device Discussion

Each device was discussed separately due to the large difference in the designs. Both designs have different strengths and weakness and thus require different suggestions for improvement.

Grasping Device

The grasping device was initially using air as a media inside the bottle. As testing progressed, it was working adequately as a means to translate the pressure change information to the pressure sensor. However when the device was tested on an actual patient, the patient had to struggle to register the appropriate pressure. As a countermeasure, the bottle was filled with water. When the same patient tried the grasping device, now with the water, it was much easier for them to register the appropriate pressure. The sensor was more responsive, and the patient had less trouble completing the tasks required by the program.

When the initial analysis was completed to verify that the grasping device would function properly, it was assumed that the fluid inside the bottle was incompressible. One thing that should have been noted from the start was that air is not actually incompressible. In retrospect, water should have been selected from the beginning, because it is safe to assume that water is incompressible. This would have improved our system from the start. The pressure sensor was selected based upon the cost as well as its ability to be used with multiple fluids. This shows that this issue was at least considered from the beginning, and it would have been possible to incorporate an incompressible fluid from the start. The strengths of the grasping device are that it has flexibility to use different fluids, it can be grasped with virtually any hand position and still register and accurate pressure reading, and it is entirely unique: even after an extensive patent search, no other device exists which operates like this one.

Currently there is no way to fill the inside of the device completely with water without any air. There is always a small amount of air in the system. This gives a small amount of 'lag,' or compressibility of the device prior to the change in pressure registering. While this is good in that it offers the patient physical feedback, it makes it slightly more difficult for the patient to complete the tasks. In the future, it would be beneficial to the user if the device would be able to be filled completely with water and without any air. This would decrease and virtually eliminate the 'lag' in the device. Also, a slightly more rigid material for the device may help in this effort as well.

The biggest strength of the grasping device is that it is able to be grasped in virtually any hand position and it still is capable of reporting an accurate voltage output. There are a couple weaknesses to the grasping device. First, it has a bit of a lag when it is initially squeezed. This is because it currently is not filled entirely with water. There is a small amount of air present, which can be compressed and cause a lag in the device.

Pinching Device

The pinching device was able to register an appropriate force reading quite adequately considering how inexpensive the embedded force sensors were. While the force sensors were limited to a 3/8" diameter area of actual force sensing area, the device attempted to expand this by using the button panel. The button panel gave the patient a larger area where they could pinch and register a force reading. If the budget for this project could be expanded in the future, it would be beneficial to purchase a more expensive force sensor which has a larger force sensing area. This would increase both the accuracy of the device, as well as the patients' usability. This would increase the diameter of the area which could be pinched to yield an accurate pinching force.

The initial final design technically worked how it was supposed to. However while the technical aspect of this device was studied, analyzed, and implemented successfully, not enough care was taken into account for the actual user. This is a common mistake for engineers. In the case of this device, a couple things stand out as good examples of this point. First, the edges of the fiberglass were too sharp. While laser cutting the components of the device, it should have been taken into account how sharp the corners of the pieces would turn out. These corners could have been filleted using the laser cutter. Since this was not

done, all corners had to be sanded before the patient could use the device. Special consideration should be taken into account for sharp corners in the future.

Another aspect that was overlooked was the sizing of the device. From a manufacturing and assembly standpoint, it was easier to implement a larger device. However upon having actual patient and doctor feedback, they desired to have a smaller device, so that it would be easier to hold and more intuitive to use for the patient.

One feature that was thought to be great from a serviceability standpoint was designing a device which could be serviced both from the bottom and the top. Therefore, the initial design had access to the force sensor from the bottom, by removing two bolts, and from the top, by rotating the pieces that were securing the button panel. However after reviewing with the doctors, they determined that it was not necessary to access it from the top. They thought that the patient would play with the pieces that were free to rotate. This was another area which was designed adequately from a technical perspective, however not enough consideration was given to the actual patient who would be using the device.

The biggest strength of the pinching device is that it is intuitive to use. The sensing area is marked not only visually, but physically, as there is an engraved target in the area. This makes it incredibly easy for the patient to know where to pinch. The biggest weakness in the pinching device is that the output seems to be slightly non-linear. As you press, it seems to become harder and harder to register the appropriate force. Also, the device is not covered in any type of material which would protect it when being dropped. In practice, it is inevitable that the device will be dropped and tossed about. A good suggestion for the future would to be to cover the device in a protective material.

Program Discussion

The current program features many strengths which include a user friendly interface and real-time feedback. The program is not to complex and is easy for the patient and sponsor to navigate throughout. Also, the block diagram of the LabVIEW file includes a preferences section where the doctor may change different settings of the program like the different gate locations, the time the patient must remain within the gates, and the size of the gates. This allows the doctor to accommodate the test for each patient on an individual basis.

There are a few things that still need to be completed to make the program even better. The first addition to the program would be to allow the patient to complete one module multiple times in one session. This would allow the doctors to look at the patient's progress throughout a given module without having to complete all the modules to do so. Completing the entire program multiple times can get very tiring for a patient rather quickly. The second addition to the program would be to develop a way to calibrate the system to determine a relationship between the voltage applied and the force that is exerted on the device. This could be done by placing different known weights on the pinching device and obtaining the voltage using LabVIEW to develop this relationship between the force applied, in this case the weight, to the voltage. To develop a relationship between voltage and force applied to the grasping device a known force must be exerted around the device to simulate a hand grasping the device; a clamp could be tightened at varying forces around the device and then a similar relationship could be developed for the grasping device. The force exerted by the clamp could be determined by applying the same force to a force transducer. The results for these tests could then be used to determine an accurate relationship between the output voltage and the applied force. This relationship could then be used within the LabVIEW program to make an easy conversion from voltage to applied force for the doctor to see.

RECOMMENDATIONS

The completed system is a very good first draft for the grasping and pinching portion of the ULTrA program. The devices provide accurate and reliable data and the program guides patients through a rehabilitation program. All customer requirements have been met. That being said, there are still many recommendations for the sponsor's of this project before mass producing this design. They have been outlined in this section and will hopefully prove to be a valuable tool as future drafts for the grasping and pinching portion of the ULTrA program are created.

Device Recommendation

All customer requirements for the devices were met, but on the completion of the project a few recommendations would like to be made. These are provided for both the grasping device and the pinching device.

Grasping Device

As discussed previously, the main flaw in the grasping device is in the rigidity of the bottle. Putting water into the bottle solved this problem, but also created another. Adding water to the system makes it harder for the patient to take the system home and has the potential to leak over time. It is recommended that a different bottle type is used for future devices. A plastic bottle with thicker walls is recommended. The bottle would need to flex, but not to the extent that the current one does. If this is not an option, finding another way to secure the top of the bottle to main portion would also work.

Pinching Device

The pinching device works extremely well. Two recommendations for its improvement do exist. The recommendation is to experiment with different rubber plugs. The rubber plug is the small piece of rubber located below the button panel. The softer the rubber plugs the more feedback the patient gets, but this also creates more inaccuracy in the readings. It is also hypothesized that the rubber plug may deform over time and thus provide inaccuracy; a harder plug would eliminate this problem. The other recommendation for improvement would be to create a design that can change shape for each patient. The size the device is currently will fit most patients' hands, but a design that allows the addition of height or width might make the device more comfortable for some patients. A snap fit of small pieces of fiberglass to the bottom and sides of the device was previously discussed and would be a good solution to this problem.

Program Recommendation

As mentioned previously, the program meets all initial customer requirements. However, the program is not perfect. There are a few recommendations that would be made at this point to provide a more robust design for the patient and provide more valuable laboratory data for the doctors. The first recommendation would be to purchase a better DAQ. The DAQ currently being used works well, but a higher quality DAQ would provide better visual feedback for the patient. Occasionally the current DAQ does not collect data at a rate fast enough to provide smooth feedback to the patient. Specifically, the slider bar jumps around just a little during some portions of the program. The second recommendation is to create a better user interface for the patient. The current ULTrA program is very well designed and does not allow patients to accidently reach the back panel of the LabVIEW program. This type of program is beyond the knowledge of the team members, but would be beneficial before sending the program home with patients. Finally, during the creation of the program the sponsor indicated it would be beneficial to be able to choose of the maximum force used throughout the program as either the max force applied by the stronger hand or the weaker hand. This information was provided to the team at a time too late to implement into the program, so it is recommended for future work.

CONCLUSION

Stroke patients suffer from loss of motor control in their limbs. The ULTrA program has been created by Dr. Brown to help patients rehabilitate their upper limbs from home. The projected she, along with Dr. Langan, has presented is to create a telerehibilitation device and program to help patients rehabilitate hand manipulation as part of the ULTrA program. Hand manipulation includes the ability to grasp (hold things with entire hand) and pinch (hold things with thumb and a finger). With the specific requirements requested, the final designs for the grasping and pinching devices were created. Through researching the average dimensions of commercially available water bottles and garage door opener remotes the final dimensions of the grasping and pinching devices were selected. In order to select the correct material, mathematical models of the grasping and pinching devices were developed and determined the maximum forces on the devices. With these maximum forces, CES software was used to select the proper material. After the materials were selected, the manufacturing and assembly steps were determined for both the devices. This report also provided the initial research of the requested LaBVIEW program. The LaBVIEW program will include four modules (or tasks) which will use the horizontal sliding bar and the round light indicator. The main goals of this project are to create two devices that will measure the grasping and pinching forces applied by the patient, provide real time feedback for the patient, provide data that is sent to the doctors, and create cheap, easy to use devices.

ACKNOWLEDGEMENTS

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APPENDIX

A. Quality Function Deployment (QFD)

A.1 QFD Diagram

System QFD

	Project:	Telerehabilitation Device for Stroke Patients
	Date:	January 27, 2010
		Input areas are in yellow

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www.robuststrategy.com
kevin_n_otto@yahoo.com
http://www.kevinotto.com/RSS/templates/QFD Template.xls
Modified from a template from Design4X Inc.

#		Force	Cost	Developement Time	Length	Width	Height	Weight	Accuracy	Strength	Durability	Toughness	Hardness	Number of Parts	Temperature	Task CompletionTime
1	Force															
2	Cost	9														
3	Developement Time	9	0													
4	Length	1	3	3												
5	Width	1	3	3	0											
6	Height	1	3	3	0	0										
7	Weight	1	3	3	3	3	3									
8	Accuracy	9	9	9	3	3	3	1								
9	Strength	1	3	3	3	3	3	3	3							
10	Durability	3	3	9	3	3	3	3	3	9						
11	Toughness	3	3	3	3	3	3	3	3	9	9					
12	Hardness	1	3	3	3	3	3	3	3	9	9	9				
13	Number of Parts	3	3	3	0	0	0	1	3	1	3	1	1			
14	Temperature	3	0	1	0	0	0	0	0	0	0	0	0	1		
15	Task CompletionTime	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
16	Number of Comands	0	0	9	0	0	0	0	0	0	0	0	0	0	0	9
17																
18																
19																

Survey Legend	
A	Web-based telerehabilition for the upper extremity after stroke
B	Autocite workstation
C	Health management system

Technical Requirements / **Customer Opinion Survey**

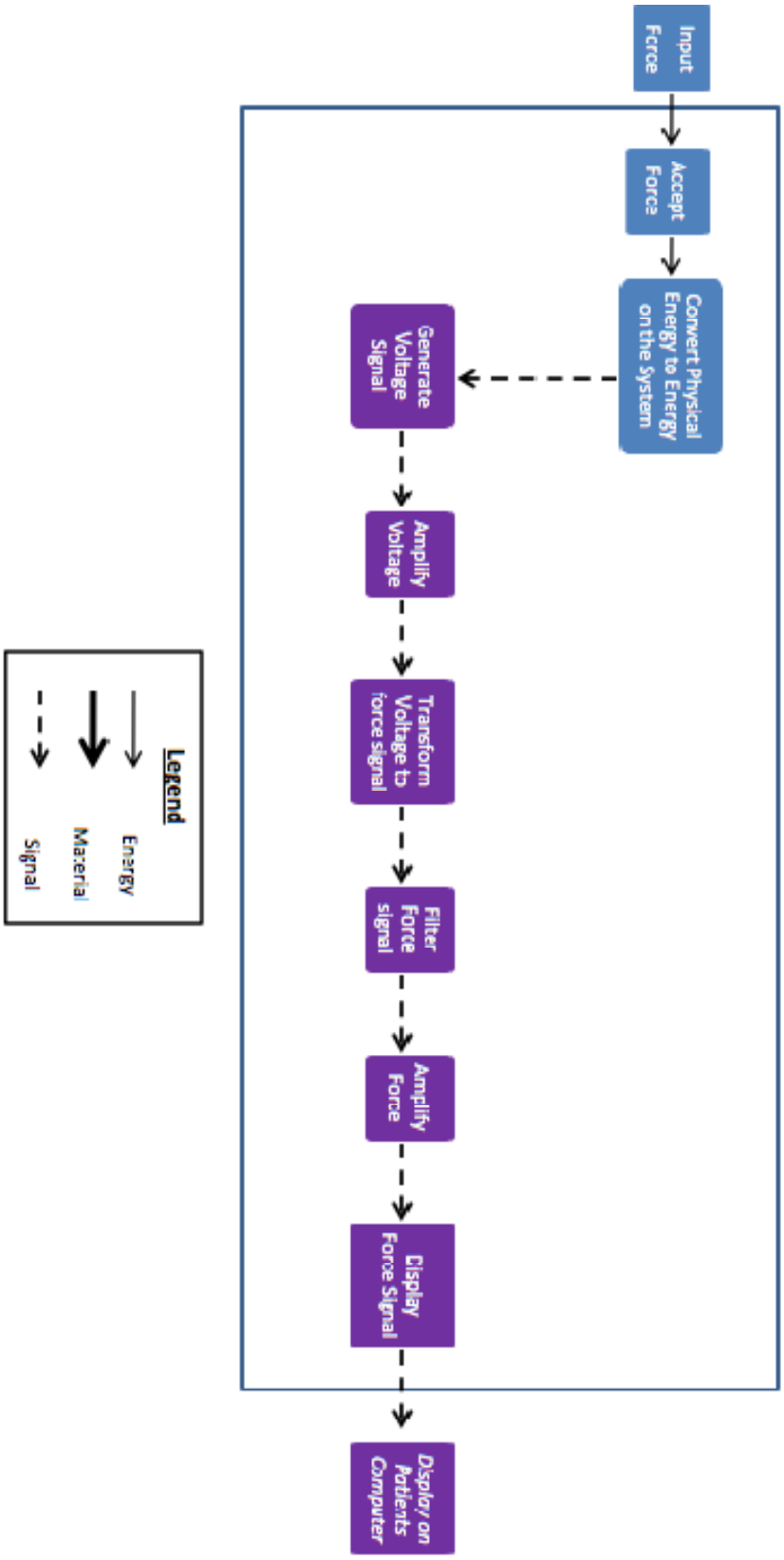
#	Customer Needs	Customer Weights	Kano Type	Force	Cost	Developement Time	Length	Width	Height	Weight	Accuracy	Strength	Durability	Toughness	Hardness	Number of Parts	Temperature	Task CompletionTime	Number of Comands	1 Poor	2	3 Acceptable	4	5 Excellent
1	Ability to grasp	12		9	1	3	9	9	9	3	3	9	9	9	9	1	1	3	0				ABC	
2	Ability to pinch	12		9	1	3	9	9	9	9	3	9	9	9	9	1	3	3	0	A			BC	
3	User friendly program	7		0	9	9	0	0	0	0	9	0	0	0	0	0	0	9	9		C	AB		
4	Affordable	2		9	9	3	1	1	1	0	9	9	9	9	9	3	1	0	0	BC		A		
5	Measurement of Force	13		9	9	9	1	1	1	1	9	3	9	3	3	3	3	0	0	ABC				
6	Common everyday objects	1		0	3	3	1	1	1	3	0	3	1	1	1	1	0	0	0	A	BC			
7	Variable difficulty	6		9	9	9	1	1	1	0	9	0	0	0	0	3	0	9	9			A	BC	
8	Versatile	8		9	9	9	3	3	3	1	9	0	0	0	0	0	0	1	0		A	B	C	
9	Real time visual feedback	10		9	9	9	0	0	0	0	9	0	0	0	0	1	0	9	9				ABC	
10	Force Versus Time Plot	5		9	1	1	0	0	0	0	9	1	1	1	1	0	0	0	3					
11	Overshoot Error/ Movement Time	4		9	1	1	0	0	0	0	9	1	1	1	1	0	0	0	3					
12	Synchronized/unsynchronized applications	3		9	9	9	0	0	0	0	9	0	0	0	0	3	0	9	9					
13	Portability	9		9	9	3	9	9	9	9	3	9	9	9	9	9	1	0	0	BC			A	
14																								
15																								

		Force	Cost	Developement Time	Length	Width	Height	Weight	Accuracy	Strength	Durability	Toughness	Hardness	Number of Parts	Temperature	Task CompletionTime	Number of Comands
	Raw score	756	558	540	343	343	343	249	621	366	442	364	364	188	98	314	261
	Scaled	1	0.74	0.71	0.45	0.45	0.45	0.33	0.82	0.48	0.58	0.48	0.48	0.25	0.13	0.42	0.35
	Relative Weight	12%	9%	9%	6%	6%	6%	4%	10%	6%	7%	6%	6%	3%	2%	5%	4%
	Rank	1	3	4	9	9	9	14	2	6	5	7	7	15	16	12	13
Requirement Benchmarking	Best in Class	N/A	A	A	C	C	C	C	N/A	N/A	N/A	N/A	N/A	A	N/A	N/A	N/A
	AVE	N/A	C	B	A	A	A	A	N/A	N/A	N/A	N/A	N/A	C	N/A	N/A	N/A
	Worst in Class	N/A	B	C	B	B	B	B	N/A	N/A	N/A	N/A	N/A	B	N/A	N/A	N/A
	Kano	L	L	L	B	B	B	B	L	B	L	B	B	L	B	L	L
	Direction	T	↓	↓	↓	↓	↓	↓	↑	↑	↑	↑	↑	↓	↓	↓	↓
Technical Requirement Units		N	USD	months	m	m	m	N	%	MPa	Years	Pa(m^0.5)	HRC	#	Deg. Celsuis	minutes	#
Technical Requriement Targets	Pinching Devic	700	< 200	3	0.04-0.08	0.03-0.05	0.02-0.04	2.2-8.9	0-5	30-50	5	70-90	20-40	10 to 15	0	10 to 15	few as possible
	Grasping Devic	200	< 200	3	0.15-0.25	0.15-.025	0.08-0.15	4.4-22.3	0-5	50-70	5	80-100	50-70	10 to 15	0	10 to 15	

A.2 QFD Development

To determine the importance for the customer's requirements we used the method of creating a table with 13 rows (the number of customer requirements) and 78 columns (determined by $n(n-1)/2$ where n is the number of rows). Each column was a different combination of the customer requirements (e.g. requirement one versus requirement two is column one). With this table, we were able to compare the different combinations of customer requirements and determine which was more important giving it a number one and the other a zero. After this was done for all the combinations, we summed up the rows to determine the level of importance of each customer requirement. The level of importance is based on a scale of 13 being the most important and one being the least important. The level of importance for each requirement is shown in the QFD, appendix A.2.

B. Functional Decomposition Diagram



C. Other Significant Design Concepts

This section presents other significant design concepts. Though they were not chosen for the design selection process, many of them encouraged development of better designs.

C.1 Grasping Device Concepts

Liquid Pressure Device

The liquid pressure device concept uses a container with liquid inside that the patient will squeeze which will displace the liquid. The liquid would move up a tube attached to the container that can give the patient visual feedback of the force they are applying. We would be able to measure the displacement of the liquid and convert that into a force measurement. This concept would be used for measuring the patients grasping force.

Grooved Cup Device

The cup device concept uses a basic cup that has grooves where the force sensors are placed. The grooves will also help guide the patient's fingers into the correct spot to measure their applied force. A sample of this design can be seen in Figure 41, below. The cup device concept was designed to be used as a grasping device.

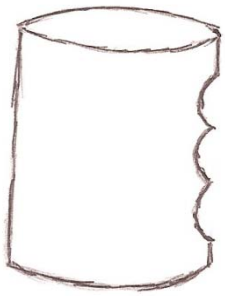


Figure 41: Grooved Cup Device

Large Spring Device

The larger spring with sensor device was thought of after the original spring with sensor device was discussed. This concept is a more complicated form of the spring with sensor device and is a cylinder type container. There would be a few springs that would extend from the center of the cylinder to the walls, as seen in Figure 42 to the right that shows a top view. The patient would squeeze the cylinder cause the springs to compress and the force would be measured by a sensor attached to the springs. This concept was designed to be used for the grasping device.

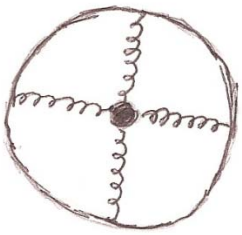


Figure 42: Large Spring Device

C.2 Pinching Device Concepts

Cover device

The cover device concept is a cover that can be slipped onto different objects like a sleeve. On the cover we would put the force sensors. The cover device concept was thought of because of its versatility of being used on various objects.

D. Pugh Charts

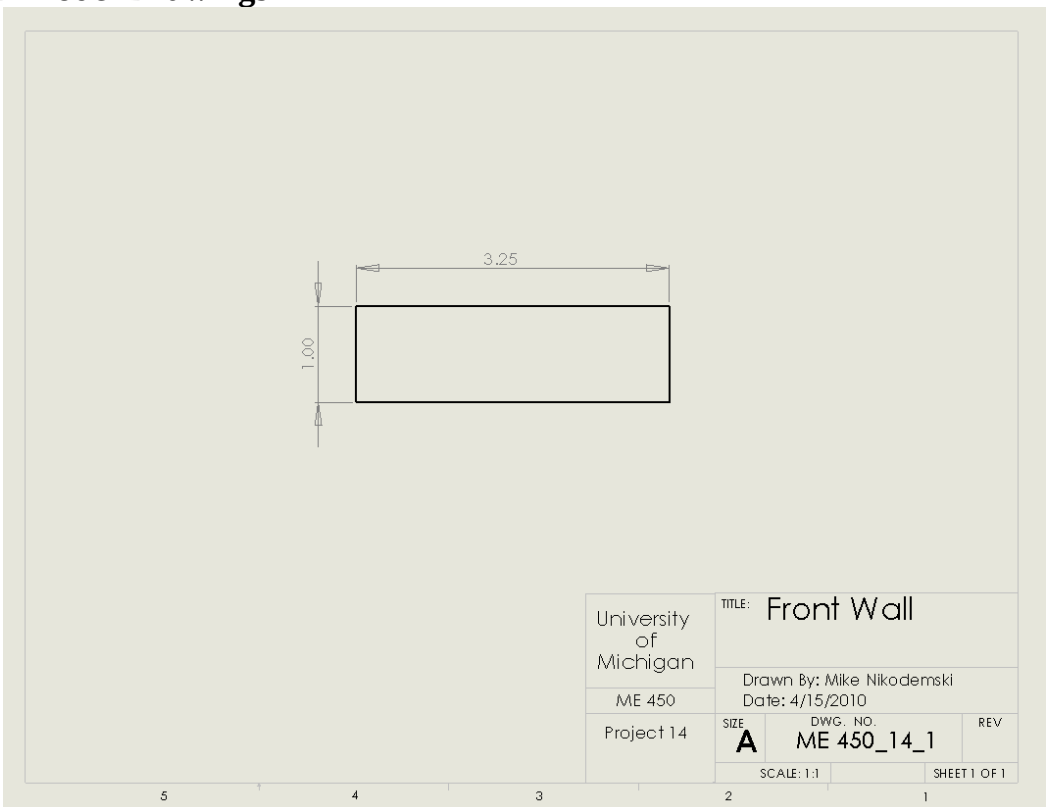
GRASPING CONCEPT DESIGNS

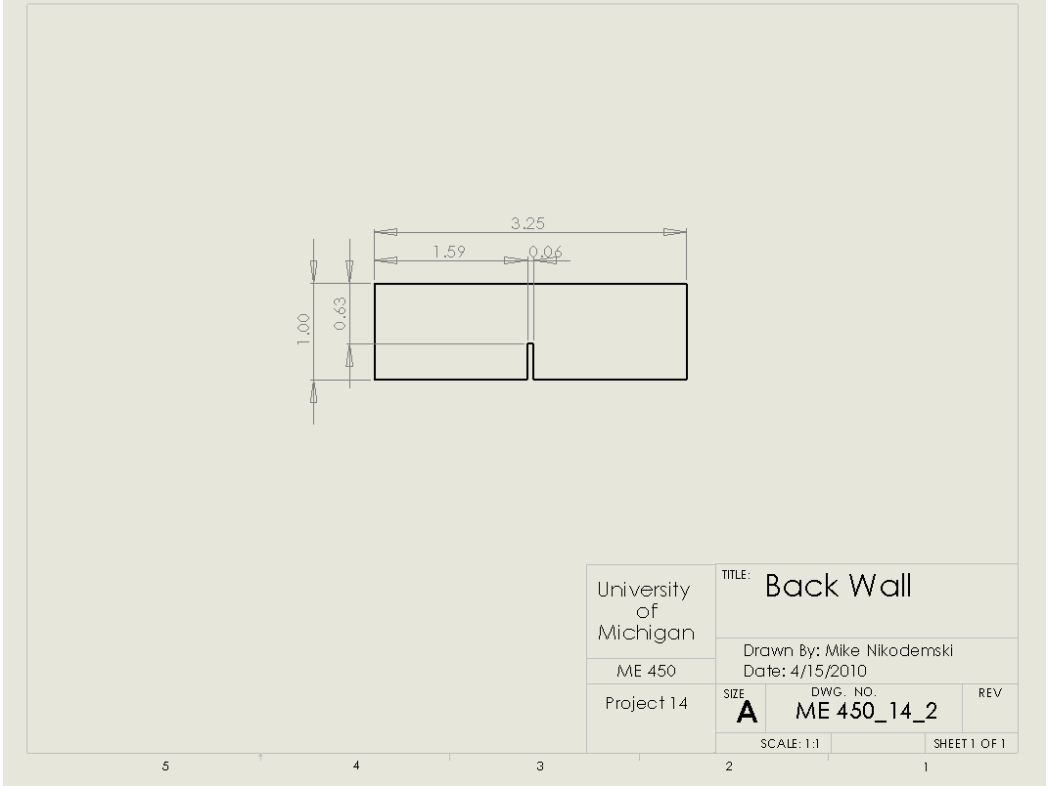
Selection Criteria	10= Most Important 1= Least Important Weight	A Pressure Circles	B Adjustable Circles	C (Reference) Bike Handles	D Wire Handle	E Glove	F Finger Tips
Finger alignment	8	1	-1	0	-1	1	1
Safe	10	1	1	0	1	1	1
Intuitive	8	1	-1	0	0	1	0
Common object	9	1	1	0	1	1	1
Portable	9	1	0	0	1	1	-1
Versatile to patient handsize	7	0	1	0	-1	-1	-1
Versatile to patient strength	9	1	0	0	0	0	0
Ease of syncing	1	-1	-1	0	-1	-1	-1
Durability	4	0	0	0	0	-1	-1
Development Difficulty	6	1	-1	0	-1	-1	-1
		9	-1	0	-5	-3	-3
RANK		1	2	4	5	3	3

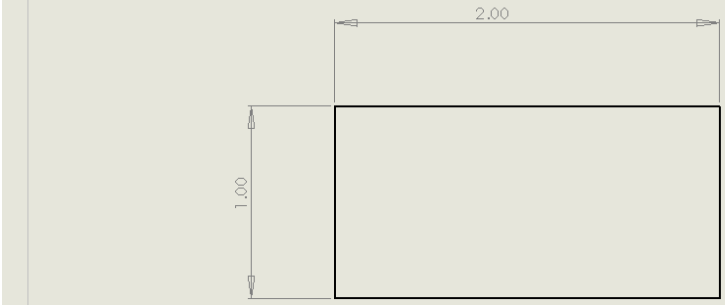
PINCHING CONCEPT DESIGNS

Selection Criteria	10= Most Important 1= Least Important Weight	A Pressure Circles	B (Reference) Bike Handles	C Spring with Sensor	D Glove	E Finger Tips	F Cantilever	G Key
Finger alignment	8	1	0	0	1	1	0	0
Safe	10	0	0	1	1	1	0	1
Intuitive	8	0	0	0	0	0	0	1
Common object	9	1	0	0	1	1	-1	1
Portable	9	1	0	1	1	0	1	1
Versatile to patient handsize	7	0	0	0	0	0	0	0
Versatile to patient strength	9	-1	0	-1	1	1	-1	0
Ease of syncing	1	-1	0	-1	-1	-1	0	0
Durability	4	0	0	0	-1	-1	-1	1
Development Difficulty	6	1	0	1	-1	-1	-1	1
		3	0	0	-3	-3	-5	3
RANK		4	6	5	3	3	7	1

E. CAD Model Drawings







University of Michigan	TITLE: Side Wall	
ME 450	Drawn By: Mike Nikodemski Date: 4/15/2010	
Project 14	SIZE A DWG. NO. ME 450_14_3	REV
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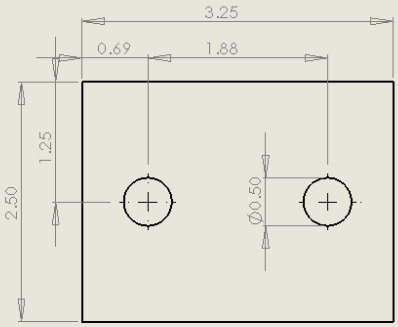
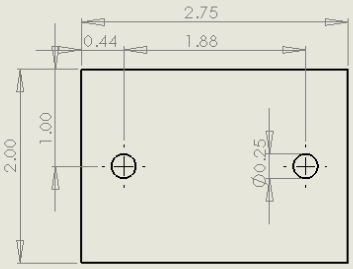
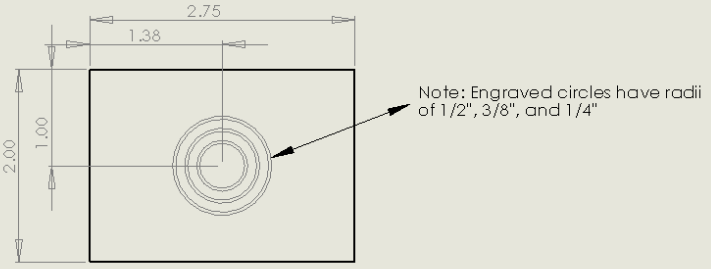


University of Michigan	TITLE: Bottom	
ME 450	Drawn By: Mike Nikodemski Date: 4/15/2010	
Project 14	SIZE A DWG. NO. ME 450_14_4	REV
	SCALE: 1:1	SHEET 1 OF 1



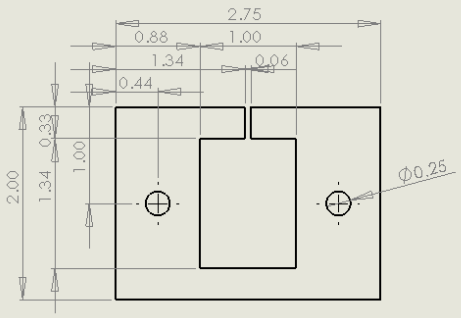
University of Michigan	TITLE: Top of the Bottom Laminate	
	Drawn By: Mike Nikodemski	
ME 450	Date: 4/15/2010	
Project 14	SIZE A / DWG. NO. ME 450_14_5	REV
	SCALE: 2:1	SHEET 1 OF 1

5 4 3 2 1



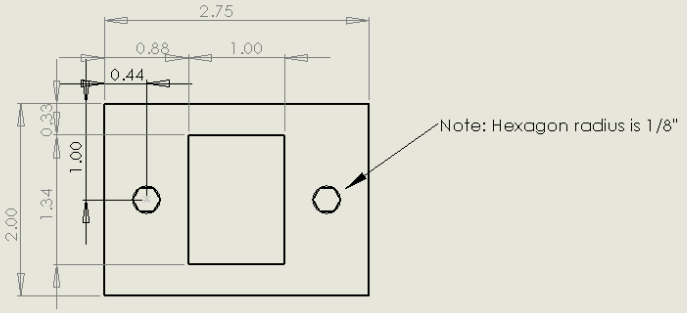
University of Michigan	TITLE: Button Panel	
	Drawn By: Mike Nikodemski	
ME 450	Date: 4/15/2010	
Project 14	SIZE A / DWG. NO. ME 450_14_6	REV
	SCALE: 2:1	SHEET 1 OF 1

5 4 3 2 1



University of Michigan	TITLE: Force Sensor Bottom Section Holder	
	Drawn By: Mike Nikodemski	
ME 450	Date: 4/15/2010	
Project 14	SIZE A / DWG. NO. ME 450_14_7	REV
	SCALE: 2:1	SHEET 1 OF 1

5 4 3 2 1



University of Michigan	TITLE: Force Sensor Top Section Holder	
	Drawn By: Mike Nikodemski	
ME 450	Date: 4/15/2010	
Project 14	SIZE A / DWG. NO. ME 450_14_8	REV
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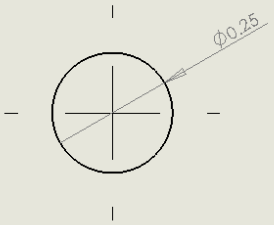
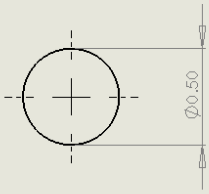
5 4 3 2 1



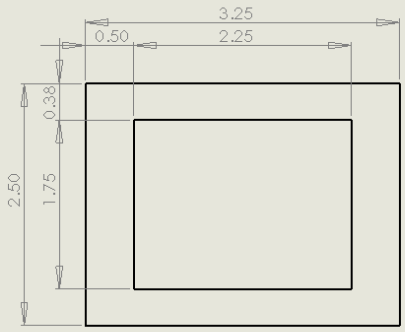
University of Michigan	TITLE: Force Sensor Circle Holder Piece	
ME 450	Drawn By: Mike Nikodemski Date: 4/15/2010	
Project 14	SIZE A	DWG. NO. ME 450_14_9 REV
	SCALE: 5:1	SHEET 1 OF 1

5 4 3 2 1



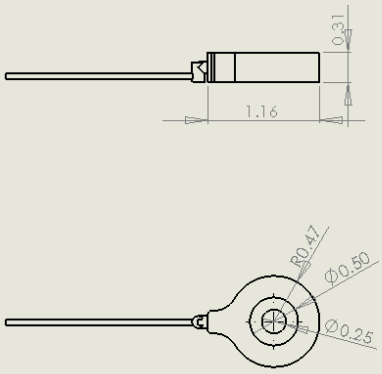
University of Michigan	TITLE: Rubber Plug	
ME 450	Drawn By: Mike Nikodemski Date: 4/15/2010	
Project 14	SIZE A	DWG. NO. ME 450_14_10 REV
	SCALE: 5:1	SHEET 1 OF 1

5 4 3 2 1



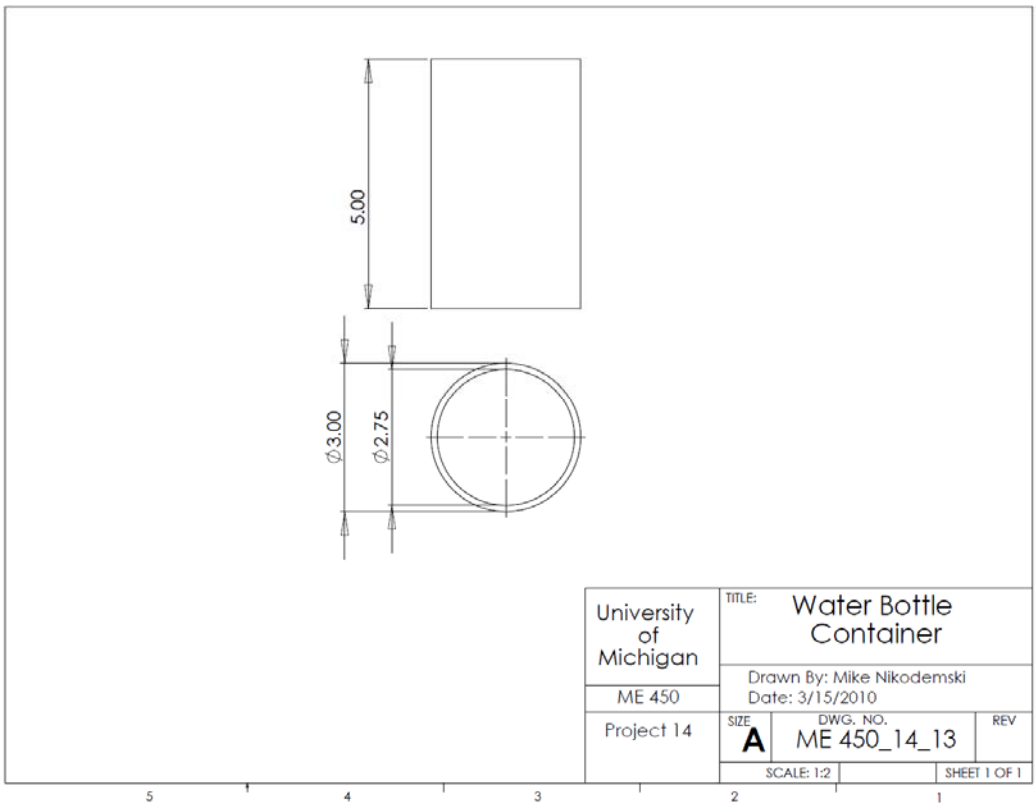
University of Michigan	TITLE: Top Lip Piece	
	Drawn By: Mike Nikodemski Date: 4/15/2010	
ME 450		
Project 14	SIZE A	DWG. NO. ME 450_14_11 REV
	SCALE: 1:1	SHEET 1 OF 1

5 4 3 2 1



University of Michigan	TITLE: Force Sensor	
	Drawn By: Mike Nikodemski Date: 4/15/2010	
ME 450		
Project 14	SIZE A	DWG. NO. ME 450_14_12 REV
	SCALE: 1:1	SHEET 1 OF 1

5 4 3 2 1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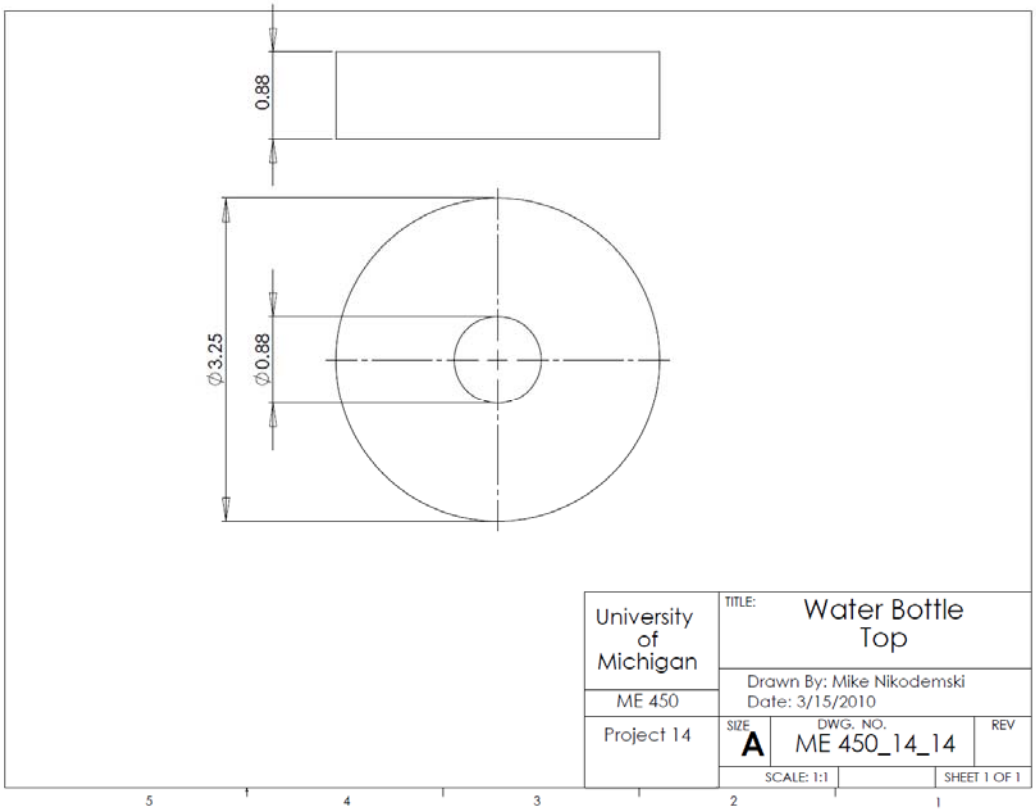
Ø3.00
Ø2.75
University of Michigan
ME 450
Project 14
TITLE: Water Bottle Container
Drawn By: Mike Nikodemski
Date: 3/15/2010
SIZE A
DWG. NO. ME 450_14_13
REV
SCALE: 1:2
SHEET 1 OF 1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Date: 3/15/2010
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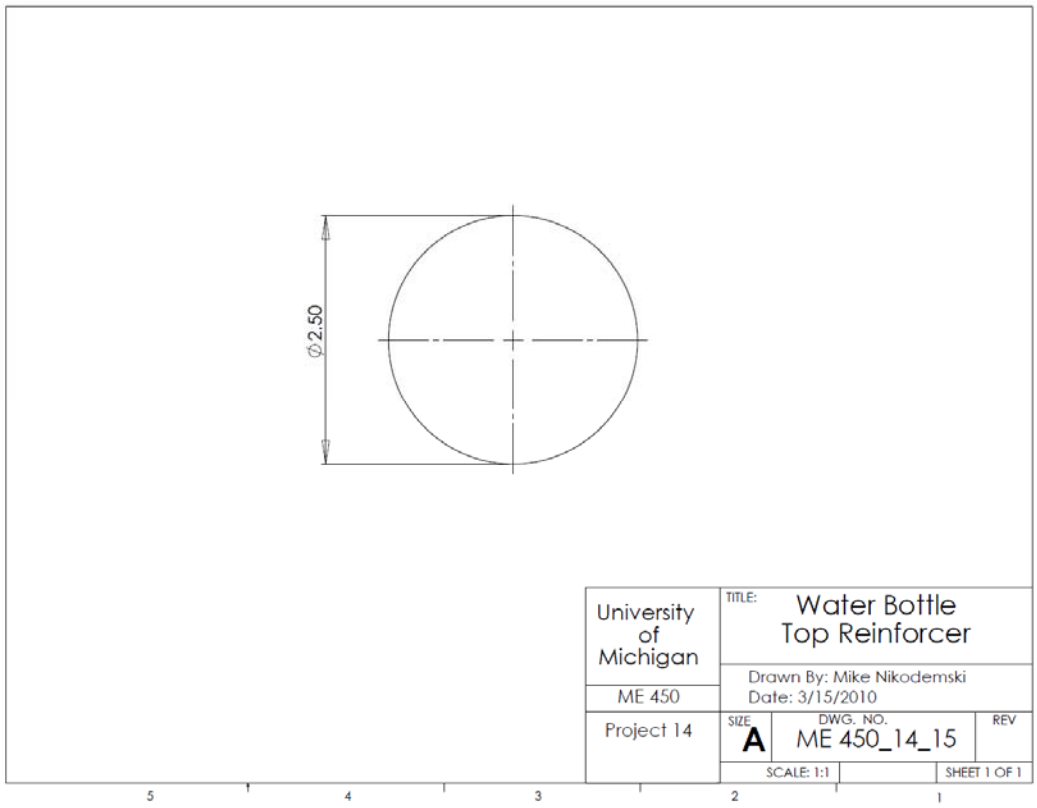
SHEET 1 OF 1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University of Michigan
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Project 14
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Water Bottle Top Reinforcer
Drawn By: Mike Nikodemski
Date: 3/15/2010
SIZE
A
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ME 450_14_15
REV
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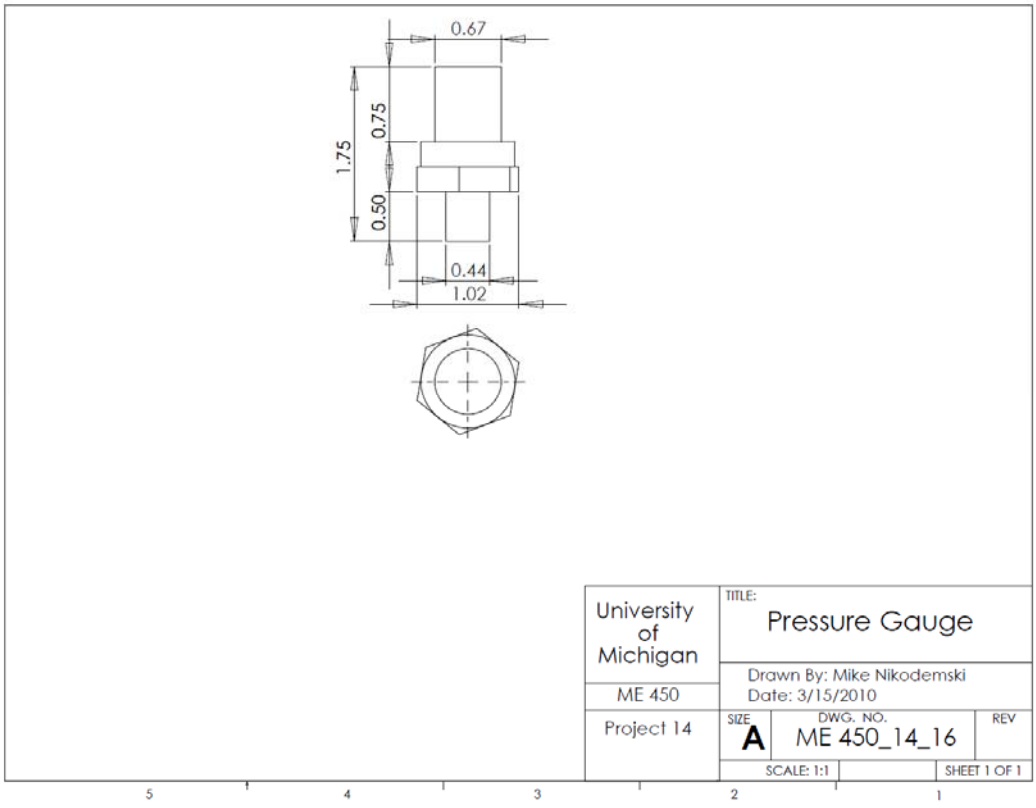
SHEET 1 OF 1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1.75
0.50
0.44
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University of Michigan
ME 450
Project 14
TITLE:
Pressure Gauge
Drawn By: Mike Nikodemski
Date: 3/15/2010
SIZE
A
DWG. NO.
ME 450_14_16
REV
SCALE: 1:1
SHEET 1 OF 1

F. Parameter Research

Water Bottle Dimensions (in)

Bottle	1	2	3	4	5	6	7	8	9	10	AVERAGE
Circumference	10	10	9.5	8.7	9.3	10.5	10.5	10.3	10.5	10	**9.93**
Thickness	0.0625	0.0627	0.0600	0.0625	0.0720	0.0615	0.0625	0.0625	0.0615	0.0570	**0.06247**
Height	6.00	7.50	6.50	9.00	9.00	10.00	9.00	9.00	9.00	9.50	**8.45**

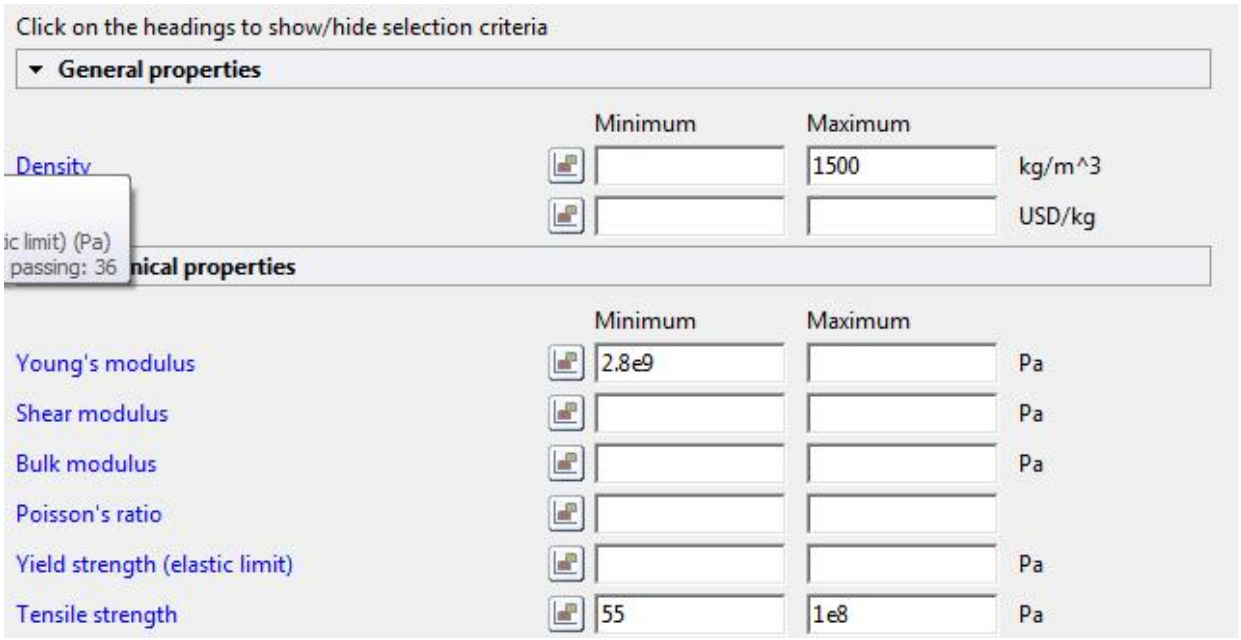
Garage Door Opener Dimensions (in)

Opener	1	2	3	4	5	AVERAGE
Length	2.00	3.50	3.75	4.00	4.00	**3.45**
Width	1.00	2.50	2.50	3.00	3.50	**2.50**
Height	0.50	1.50	1.00	2.50	2.00	**1.50**

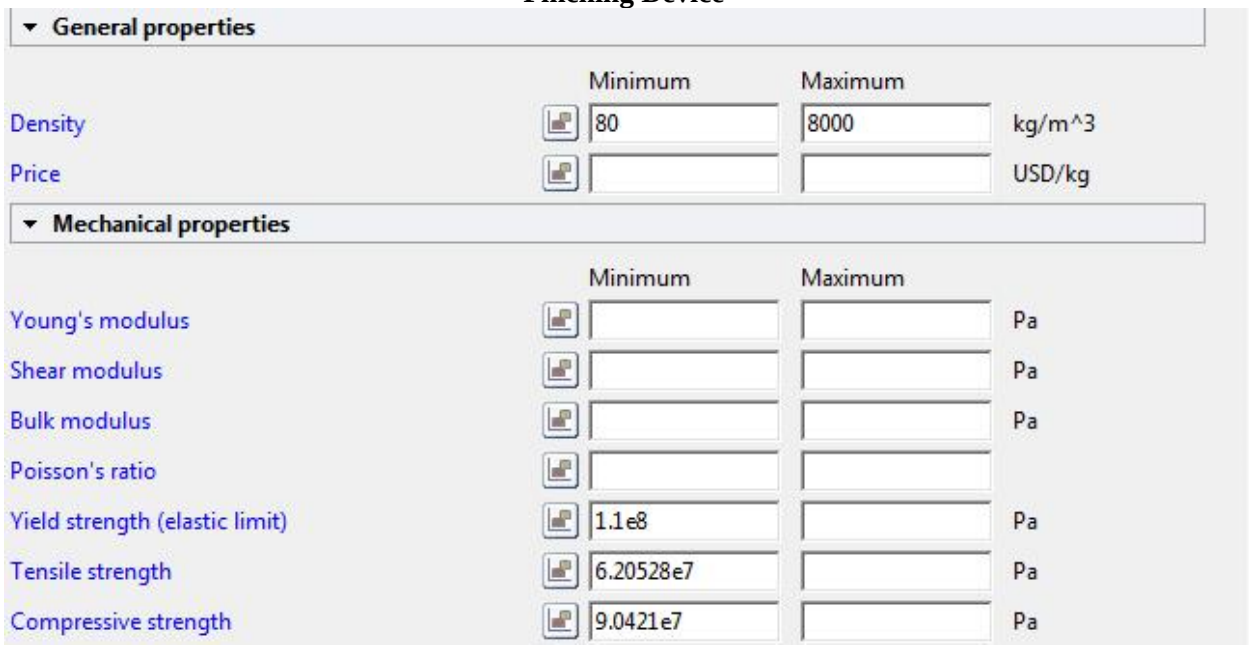
G. CES

G.1 Parameters

Grasping Device

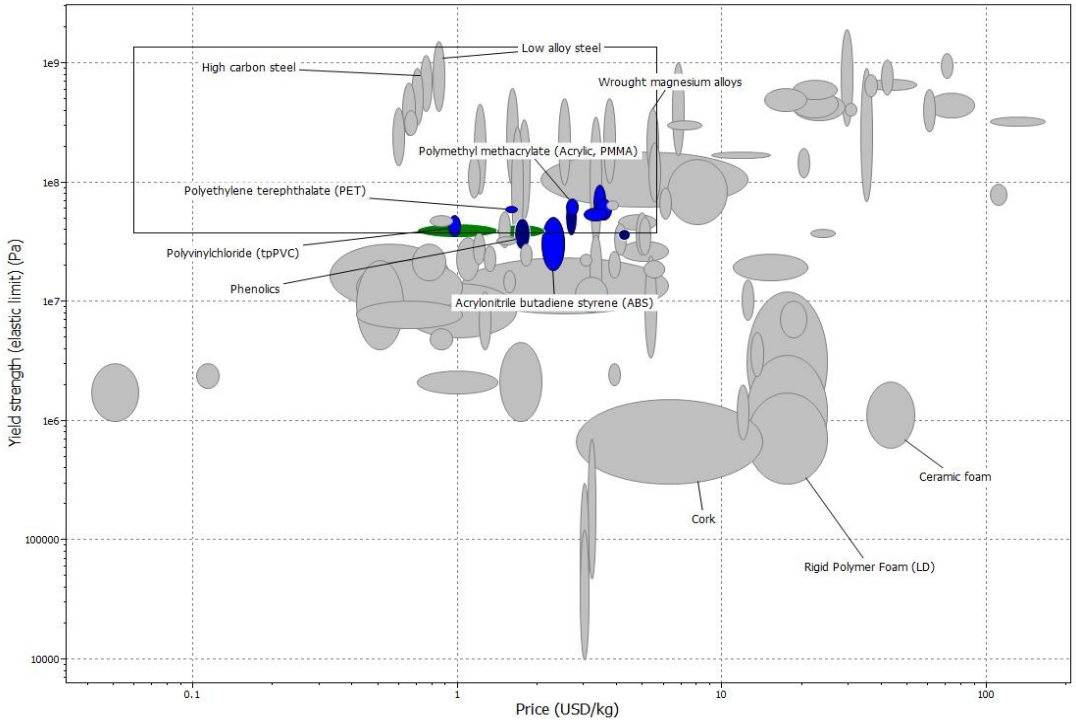


Pinching Device

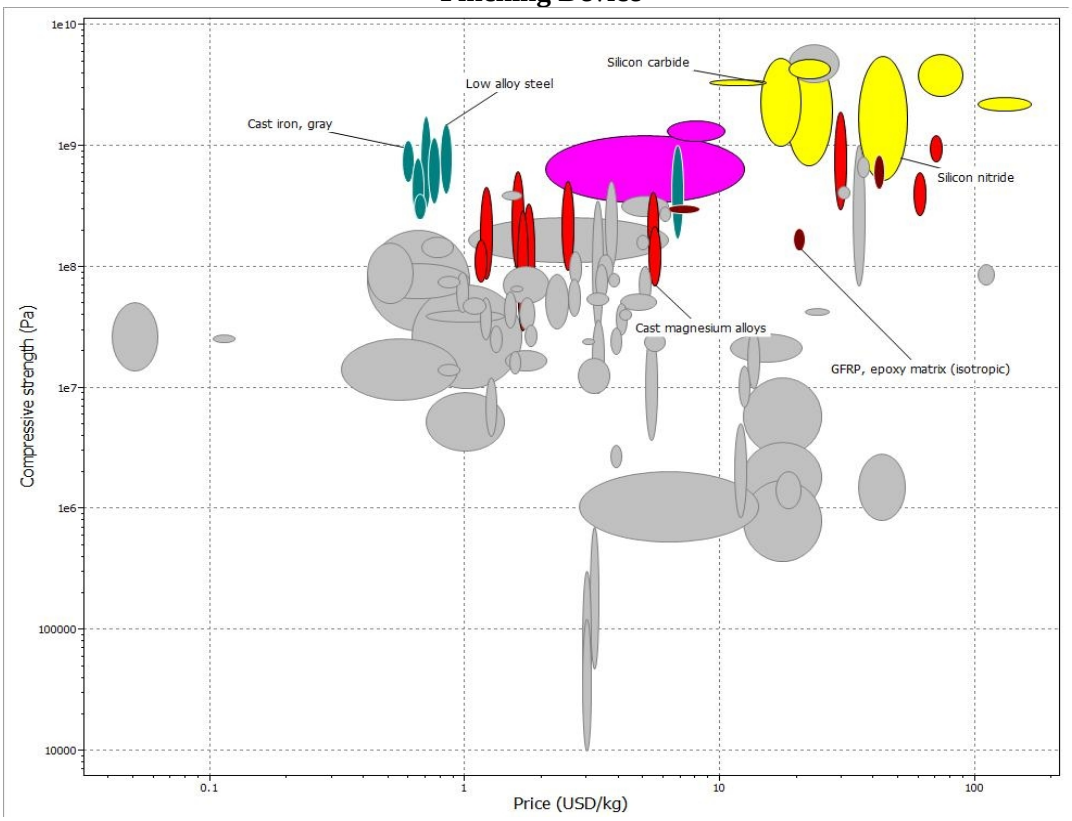


G.2 CES Graphs

Grasping Device

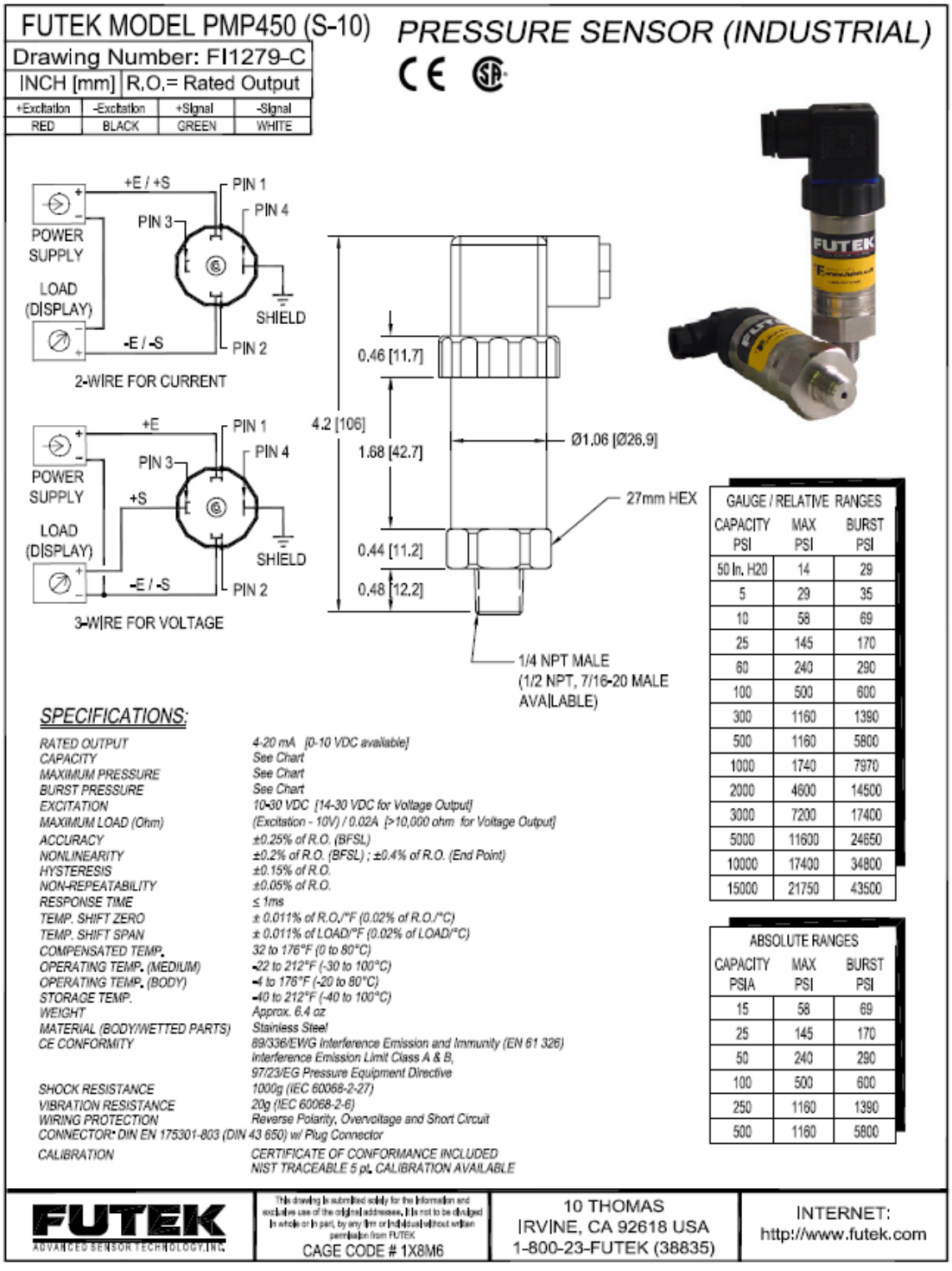


Pinching Device



H. Pressure Sensor Specifications

H.1 Futek Industrial Pressure Sensor



Source: http://www.futek.com/files/pdf/Product%20Drawings/pmp450.pdf

H.2 Honeywell Low-Cost Pressure Transducer

Model LM

Gage Pressure Transducer

PERFORMANCE SPECIFICATIONS

Characteristic	Measure
Accuracy[1]	±0.5 % full scale

ENVIRONMENTAL SPECIFICATIONS

Characteristic	Measure
Temperature, operating	-54 °C to 121 °C [-65 °F to 250 °F]
Temperature, compensated	16 °C to 71 °C [60 °F to 160 °F]
Temperature effect, zero	0.01 % full scale/°F
Temperature effect, span	0.02 % reading/°F

ELECTRICAL SPECIFICATIONS

Characteristic	Measure
Excitation (calibration)	10 Vdc
Excitation (acceptable)	10 Vdc
Insulation resistance	5000 mOhm @ 50 Vdc
Electrical termination (std)	Cable 0.91 m [3 ft]

MECHANICAL SPECIFICATIONS

Characteristic	Measure
Media	All gases/liquids compatible with wetted parts
Overload, safe	50 % over capacity
Pressure port	1/4-18 NPT female
Wetted parts	Stainless steel
Weight	170 g [6 oz]
Case material	Stainless steel

OPTION CODES

Range Code	Many range/option combinations are available in our quick-ship and fast-track manufacture programs. Please see http://sensing.honeywell.com/TMsensorship for updated listings.
Pressure ranges	1, 2.5, 5, 15, 25, 50, 75, 100, 150, 200, 300, 500, 750, 1000, 1500, 2000, 3000, 5000, 7500, 10000 psig
Temperature compensation	1a. 60 °F to 160 °F
Internal amplifiers	2u. Unamplified, mV/V output
Pressure ports	5a. 1/4-18 NPT female
Electrical termination	Cable 0.91 m [3 ft]
Special calibration	9a. 10 point (5 up/5 down) @ 20 % increments 9b. 20 point (10 up/10 down) @ 10 % increments

WIRING CODES

Cable	Unamplified
Red	(+) Excitation
Black	(-) Excitation
Green	(-) Output
White	(+) Output

RANGE CODES

Pressure range (psig)	1	2.5	5	15	30	50	75	100	150	200	300	500	750	1000	1500	2000	3000	5000	7500	10000
RANGE CODE	AP	AS	AT	BJ	BM	BN	BP	BR	CJ	CL	CP	CR	CT	CV	DJ	DL	DN	DR	DT	DV
L mm [in]	57,4 [2.26]			56,6 [2.23]					51 [2.00]					45 [1.78]						
Hex mm [in] psia	25,4 [1.0]			25,4 [1.0]					22,2 [0.875]					19 [0.75]						
Over pressure (test) (psi)	4	10	20	50	100	150	150	150	150 % full scale											
Over pressure (burst) (psi)	Consult factory								600	800	1.2 K	2 K	2 K	4 K	6 K	8 K	12 K	15 K	20 K	20 K
Natural frequency (Hz)	Consult factory								9.8 K	11 K	14 K	18 K	22 K	30 K	48 K	54 K	66 K	85 K	>100 K	
Port volume mm³ [in³]	2,5 [0.15]								2,8 [0.17]					3,1 [0.12]						
Output (mV/V)	5			10					2											
Wetted parts	316 stainless steel								17-4 PH stainless steel											
Bridge resistance	5000 ohm								350 ohm											
Strain gage type	Silicon								Foil											

Source: http://content.honeywell.com/sensing/sensotec/pdf_catalog08/008702-1-EN_Model_LM.pdf

H.3 Grainger Pressure Transmitter

Transmitter, Pressure

Pressure Transmitter, Pressure Range 0 to 100 PSI, Fixed Range, 4-20 MilliAmps Output

Grainger Item #	1X817
Price (ea.)	**$389.00**
Brand	U.S. GAUGE
Mfr. Model #	831TG0100BLS
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	1.35
Usually Ships	Today
Catalog Page No.	686

Price shown may not reflect your price. Log in or register.

Additional Info

There is currently no additional information for this item.

Tech Specs

Item: Pressure Transducer
Range: 0 to 100 psi
Accuracy: +/-0.3%
Output: 4-20 mA DC, Limited at 38 mA DC
Power Required: 6 to 14 VDC
Process Connection: 1/2" NPT Female
Electrical Connections: 3/4" NPT Female Conduit
Lead Length (In.): 24
Wetted Materials: Stainless Steel
Housing: All Welded 316 Stainless Steel
Operating Temp.: -40 to 140 F
Safety Rating: Class 1, Div. 1, Groups B, C, and D
Max. Pressure (PSI): 300
Compatible With: Any Process Compatible with 316Stainless Steel
Includes: Instructions
Manufacturers Warranty Length: 1 Year

Notes & Restrictions

There are currently no notes or restrictions for this item.

Optional Accessories

Sealant, Thread

Photo Not Available

Item #: 4X222
Brand: ANTI-SEIZE
Usually Ships: Today
Price (ea): $9.16

Sealant Tape, 1/2 x 260 In

Photo Not Available

Item #: 4X227
Brand: ANTI-SEIZE
Usually Ships: Today
Price (ea): $1.53

Alternate Products

Transmitter, Pressure

Item #: 1X819
Brand: U.S. GAUGE
Usually Ships: Today
Price (ea): $389.00

Source: http://www.grainger.com/Grainger/items/1X817?Pid=search

H.4 Transducers Direct TGD Series Pressure Transducer

FEATURES

- Gauge, Absolute, Vacuum and Compund Pressure Models Available
- Submersible, General Purpose and Wash Down Enclosures
- High Stability Achieved by CVD Sensoring Element
- Voltage and Current Output Models
- Custom pressure ranges available
- ASIC Technology. No Zero/Span Potentiometers

DESCRIPTION

The TDG series features stability and accuracy in a variety of enclosure options. The TDG series extends the packaging options via an all welded stainless steel back end for demanding submersible and industrial applications.

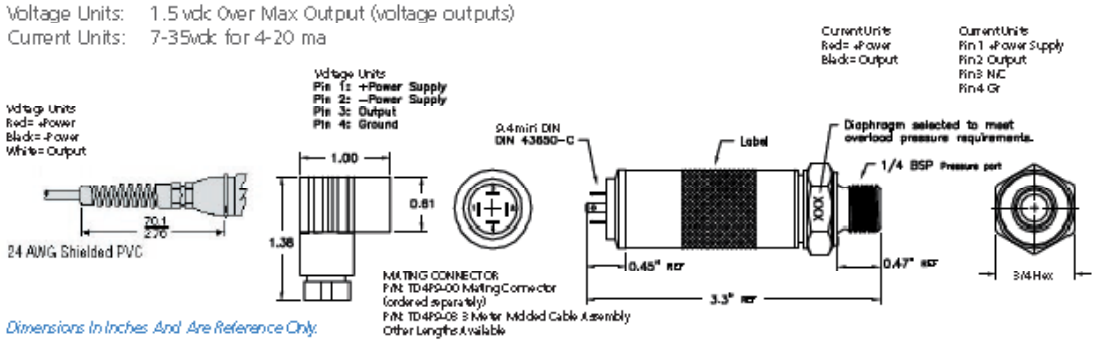
The TDG series feature proven CVD sensing technology, an ASIC (amplified units), and modular packaging to provide a sensor line that can easily accommodate specials while not sacrificing high performance.

ELECTRICAL CONNECTIONS

Power Supply Requirements

Voltage Units: 1.5 vdc Over Max Output (voltage outputs)

Current Units: 7-35vdc for 4-20 ma



Dimensions In Inches And Are Reference Only

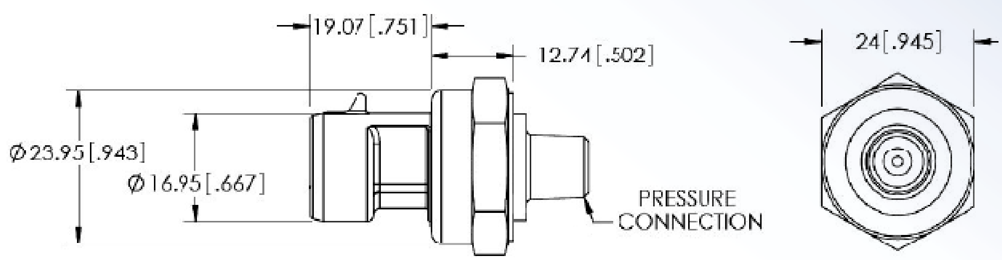
SPECIFICATIONS

Input	
Pressure Range	Vacuum to 400 bar (6000 psi)
Proof Pressure	2 x / 4 x Full Scale (FS) (1.5 x Fs for 400 bar, >= 5000 psi)
Burst Pressure	>35 x FS <= 6 bar (100 psi); >20 x FS >=60 bar (1000 psi); >5 x FS <= 400 bar (6000 psi)
Fatigue Life	Designed for more than 100 million FS cycles
Performance	
Long Term Drift	0.2% FS/year (non-cumulative)
Accuracy	0.25% / 0.5% FS typical (optional 0.15%)
Thermal Error	1.5% FS typical (optional 1% FS)
Compensated Temperatures	-20° to 80° C (-5° to 180° F)
Operating Temperatures	-40° to 125° C (-22° to 260° F) for the mini DIN -20° to 80° C (-5° to 180° F) for the NEMA 4 Cable -20° to 50° C (-5° to 125° F) for the IP67 Cable Amplified units >100°C maximum 24 Vdc supply
Zero Tolerance	1% of span
Span Tolerance	1% of span
Response Time	0.5 ms
Mechanical Configuration	
Pressure Port	See ordering chart
Wetted Parts	17-4 PH Stainless Steel
Electrical Connection	See ordering chart
Enclosure	316 ss, 17-4 PH ss IP65 for the mini DIN and NEMA Cable versions IP67 for IP67 Cable version IP68 for Submerssible versions (max. depth 200meters H20)

Source: http://www.transducersdirect.com/HeleoCart/Data/SoftGoodPreview/TDG_01_03.pdf

H.5 Kavlico P4055 Low Cost OEM Pressure Sensor

P4055/P4056
Pressure Transducers



How to Order

P4055 Pressure Transducer | **P4056 Pressure Transducer**

Pressure Ranges

3	0 – 3 PSI (Not available in Absolute)	P2	0 – 200 mBar (Not available in Absolute)
5	0 – 5 PSI (Not available in Absolute)	P3	0 – 300 mBar (Not available in Absolute)
15	0 – 15 PSI	1	0 – 1 BAR
30	0 – 30 PSI	2	0 – 2 BAR
50	0 – 50 PSI	4	0 – 4 BAR
75	0 – 75 PSI	5	0 – 5 BAR
100	0 – 100 PSI	7	0 – 7 BAR
150	0 – 150 PSI	10	0 – 10 BAR
200	0 – 200 PSI	15	0 – 15 BAR
300	0 – 300 PSI	20	0 – 20 BAR

Reference

- A Absolute
- G Gage
- S Sealed Gage

Internal Media Seal Material*

- F Fluorosilicone

*Consult factory about additional seal material options.

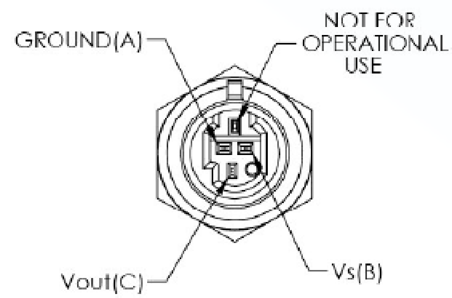
Pressure Connection (Port)

- 1 1/4-18 NPT
- 2 M12x1,5
- 3 M10x1
- 4 1/8-27 NPT
- 5 G1/4 - Male
- 6 G1/4 - Female

Built-in Electrical Connector

- A Packard Connector with Mating Connector and 12" Leads
- C Packard Connector

P4055 75 A E 1 A
Example: P4055-75A-E1A



PACKARD ELECTRICAL
PINOUT

Although possible applications for our product(s) and other statements are presented herein, Kavlico is not expert in the user's technical field and therefore does not warrant the suitability of its product(s) for the user's applications. Therefore, Kavlico will not accept any liability and provides no guarantee, responsibility, or warranties of any kind concerning the suitability or related to the use of its product(s) for the user's applications.

Additionally, Kavlico will not be liable and provides no guarantee, responsibility, or warranties of any kind concerning the suitability or related to the use of its product(s) for the life support market or to be used in life support systems, safety or emergency systems, critical care applications, human implantation, aviation, nuclear facilities or systems or any other applications where product failure could lead to injury to persons, loss of life, harm to the environment, or catastrophic property damage.

Kavlico warrants that its products will be free from defective materials and workmanship for a period of one (1) year from date of delivery to the original purchaser and that its products will conform to Kavlico's specifications or standards. Any product found to be defective will be replaced or repaired at the sole option of Kavlico.

Note: Kavlico reserves the right to change its specifications at any time without notice. Kavlico is not an expert in the customer's technical field and therefore does not warrant the suitability of its product for the application selected by the customer.

Kavlico products are manufactured or covered by one or more of the following patents: 1,799,995, 4,735,098, 4,924,702, 4967.071, 4,974,117, 5,020,377, 5,233,875, 5,275,054, 5,315,877, 5,329,819, 5,349,864, 5,349,865, 5,349,867, 5,369,989, 5,415,036, 5,528,930, 5,540,044, 5,553,502, 5,574,251, 5,576,443, 5,656,740, 5,424,449, 5,907,274, 5,923,952, 5,929,498, 5,929,754, 5,935,189, 6.008.113. 6.041.658. 6.148.674. 6.178.829. 6.211.558 B1, 6,279,407, 6,297,733, 6,311,566, 6,351,132 B1, 6,404,184 B1, 6,495388 B1, 6,581,398 B2, 6,553,812 B2, 6,564,642 B2, 6,581,468 B2, 6,583,631 B2, 6,584,853 B2, 6,685,904 B1, 6,683,464 B2 with other U.S. and foreign patents pending.

Technical Specifications

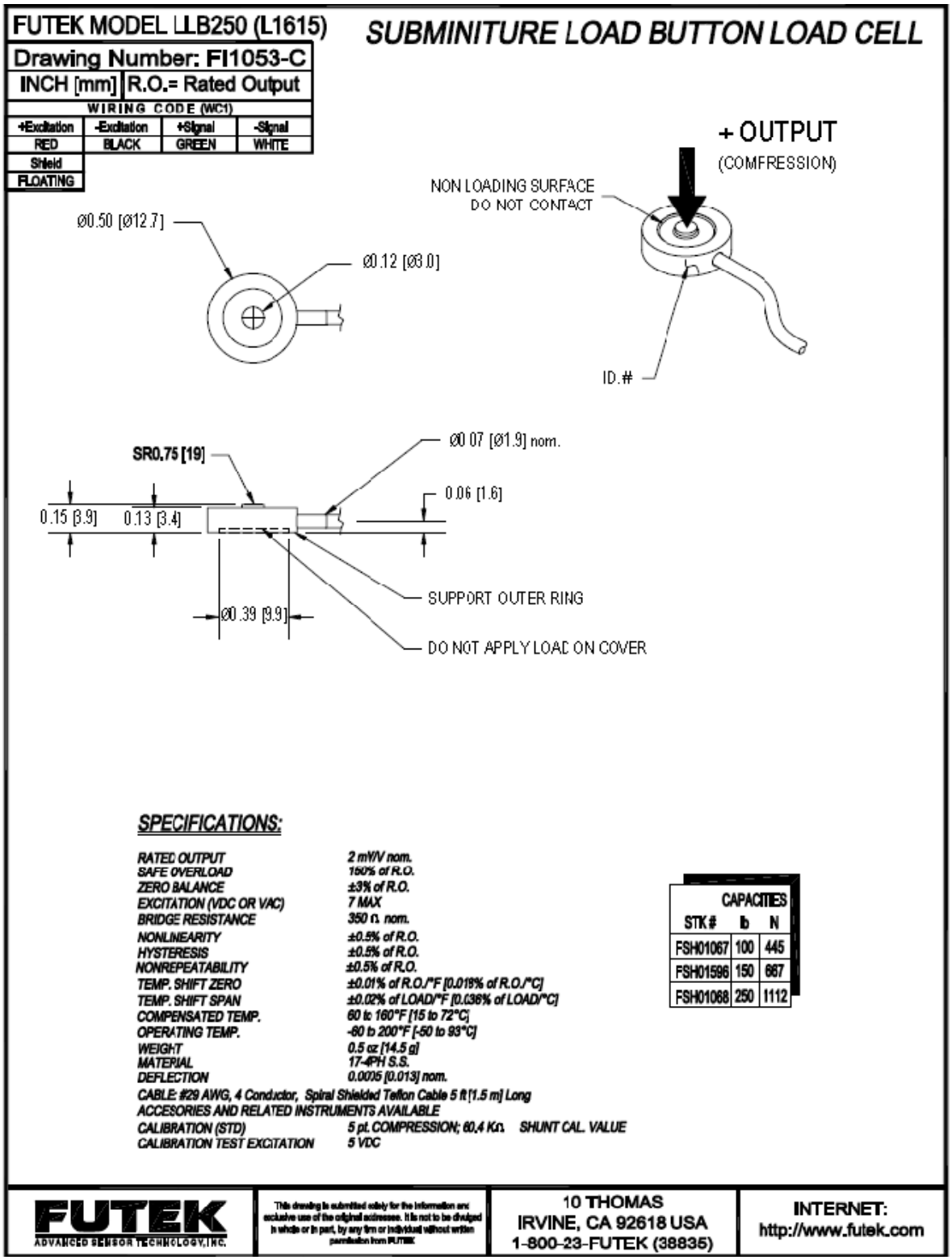
Note: Performance Specifications with 5v ± 0.002 Vdc supply at 25°C

Pressure Ranges:	See "How To Order"	Output Impedance:	< 100 Ω
Proof Pressure:	2x (F.S. Pressure) (P≤175 PSI [12 Bar]) 1.5x (F.S. Pressure) (P>200 PSI [14 Bar])	Operating Temperature:	-20°C to +100°C
		Storage Temperature:	-40°C to +125°C
Burst Pressure:	600 PSI (41 Bar)	Service Life:	10 Million Full Pressure Cycles
Supply Voltage:	5.0± .5 Vdc	Vibration:	10G's P-P Sinusoidal, from 10-2000 Hz
Supply Current:	<5mA	Shock:	75 G's ½ Sine Wave
Response Time:	<10mS to 63% of Output Change with Step Change in Pressure	Weight:	≤40 grams
		Electrical Termination:	See "How to Order"
Normal Output Voltage:		Pressure Connection:	See "How to Order"
Zero/Null Pressure:	0.5 Vdc	Recommended Interface Impedance:	Min. Load 25 kΩ
Full Pressure:	4.5 Vdc		
Linearity Error:	<±0.5% of Full Span	Over-Voltage Protection:	30 V dc
Total Error Band:	≤2.0% of Span (-20°C to +100°C)	Reverse Polarity Protection:	-30 Vdc
		Material - Main Housing:	Brass

Source: http://www.kavlico.com/catalog/P4055_4056.php

I. Force Sensor Specifications

I.1 Futek Miniature Load Button



Source: http://www.futek.com/files/pdf/Product%20Drawings/llb250.pdf

I.2 Omega Miniature Compression Load Cell

MINIATURE HIGH-CAPACITY "TOP HAT" LOAD CELL

STANDARD AND METRIC MODELS

LC307/LCM307 Series

Compression

0-250 lb to 0-100,000 lb

0-1 to 0-500 kN

1 Newton = 0.2248 lb
1 daNewton = 10 Newtons
1 lb = 454 g
1 t = 1000 kg = 2204 lb

Starts at $375

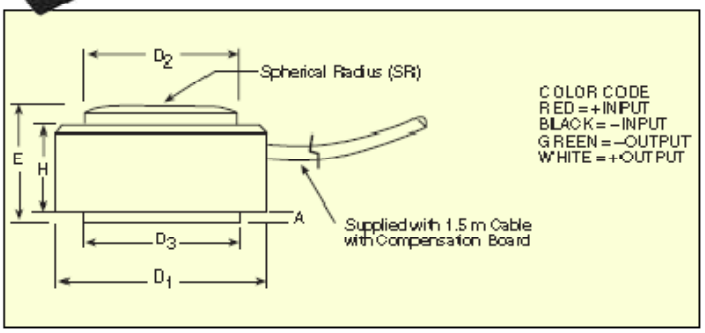
MADE IN USA NIST RoHS

Standard

Small in size but not in performance, Series LC307/LCM307 top hat load cells are designed for applications with minimum space and high-capacity loads up to 100,000 lb. Rugged all stainless steel construction and high-performance strain gages ensure superior linearity and stability. Temperature compensation is done by a miniature circuit board in the load cell's cable. These cells are designed to be mounted on a smooth, flat surface.

SPECIFICATIONS

Excitation: 5 Vdc
Output: 1.5 mV/V nominal
Accuracy: 0.75% FS BFSL (includes linearity, hysteresis and repeatability)
Zero Balance: ±2% FSO
Operating Temp Range: -54 to 121°C (-65 to 250°F)
Compensated Temp Range: 16 to 71°C (60 to 160°F)
Thermal Effects:
Span: ±0.018% rdg/°C
Zero: ±0.018% FSO/°C
Safe Overload: 150% of capacity
Ultimate Overload: 300% of capacity
Bridge Resistance: 350 Ω minimum
Full Scale Deflection: 0.001 to 0.003"
Electrical Connection: 1.5 m (5') 4-conductor cable with compensation board
Protection Class: IP54



STANDARD Dimensions: mm (in)

CAPACITY (lb)	D1	D2	D3	E	H
250	12.7 (0.50)	6.9 (0.27)	10.16 (0.40)	9.7 (0.38)	8.13 (0.320)
500	12.7 (0.50)	7.1 (0.28)	10.16 (0.40)	9.7 (0.38)	8.13 (0.320)
1000	12.7 (0.50)	7.9 (0.31)	10.16 (0.40)	9.7 (0.38)	8.13 (0.320)
2000	12.7 (0.50)	10 (0.41)	10.16 (0.40)	9.7 (0.38)	8.13 (0.320)
3000	12.7 (0.50)	11 (0.45)	10.16 (0.40)	9.7 (0.38)	8.13 (0.320)
5000	16.0 (0.63)	13.5 (0.53)	10.16 (0.40)	15 (0.60)	13.54 (0.533)
7500	22.2 (0.88)	17 (0.67)	10.16 (0.40)	16 (0.63)	13.97 (0.55)
10,000	22.2 (0.88)	19.3 (0.76)	10.16 (0.40)	16 (0.63)	13.97 (0.55)
50,000	44.5 (1.75)	31.8 (1.25)	10.16 (0.40)	35 (1.38)	31.34 (1.234)
100,000	50.8 (2.00)	38.1 (1.50)	10.16 (0.40)	41 (1.63)	37.33 (1.470)

METRIC Dimensions: mm (in)

CAPACITY (kN)	D1	D2	D3	E	H	A
1 to 10	12.7 (0.500)	10.16 (0.400)	7.62 (0.300)	9.53 (0.375)	8.13 (0.320)	0.254 (0.010)
20	16.00 (0.630)	13.46 (0.530)	13.54 (0.533)	12.70 (0.600)	13.54 (0.533)	0.381 (0.015)
50	22.22 (0.875)	19.30 (0.760)	13.97 (0.550)	16.00 (0.630)	13.97 (0.550)	0.381 (0.015)
200	44.45 (1.750)	31.75 (1.250)	25.40 (1.000)	35.05 (1.380)	31.34 (1.234)	0.381 (0.015)
500	50.8 (2.000)	38.10 (1.500)	30.48 (1.200)	41.40 (1.630)	37.33 (1.470)	0.762 (0.030)

F-31

Source: http://www.omega.com/Pressure/pdf/LC307.pdf

I.3 Honeywell Load Cell

Model 73

PERFORMANCE SPECIFICATIONS

Characteristic	Measure
Load ranges[2]	50 lb to 200000 lb
Non-linearity	±0.1 % full scale
Hysteresis	±0.1 % full scale
Non-repeatability	±0.03 % full scale
Output (tolerance)	2 mV/V ±0.5 % full scale
Operation	Compression
Resolution	Infinite
Standard calibration	5-point calibration, 0 %, 50 %, and 100 % F.S. in compression only

ENVIRONMENTAL SPECIFICATIONS

Characteristic	Measure
Temperature, operating	-54 °C to 121 °C [-65 °F to 250 °F]
Temperature, compensated	15 °C to 71 °C [60 °F to 160 °F]
Temperature effect, zero	0.002 % full scale/°F
Temperature effect, span	0.002 % full scale/°F

ELECTRICAL SPECIFICATIONS

Characteristic	Measure
Strain gage type	Bonded foil
Excitation (calibration)	10 Vdc
Insulation resistance	5000 mOhm @ 50 Vdc
Bridge resistance (tolerance)	350 ohm (nominal)
Zero balance (tolerance)	±1 % full scale
Shunt calibration data	Included
Electrical termination (std) 50 lb to 2000 lb	PTIH-10-6P
Electrical termination (std) 3000 lb to 200000 lb	MS3102E-14S-6P
Mating connector 50 lb to 2000 lb (not incl.)	PT06A-10-6S or equiv. (AA111)
Mating connector 3000 to 200000 lb (not incl.)	MS3106A-14S-6S (AA121)

MECHANICAL SPECIFICATIONS

Characteristic	Measure
Maximum allowable load	200 % FS[2]
Weight	See table
Material	17-4PH stainless steel
Life cycles (approx)	> 10^8 cycles fully reversed
Deflection	See table
Natural frequency	See table

RANGE CODES

Range Code	Available ranges	Range Code	Available ranges
BN	50 lb	DV	10000 lb
BR	100 lb	EJ	15000 lb
CN	250 lb	EL	20000 lb
CR	500 lb	EN	30000 lb
CV	1000 lb	EP	50000 lb
DL	2000 lb	ER	75000 lb
DN	3000 lb	ET	100000 lb
DP	4000 lb	FJ	150000 lb
DR	5000 lb	FL	200000 lb
DT	7500 lb		

DEFLECTIONS AND RINGING FREQUENCIES

Capacity (lb)	Deflection @ full scale (in)	Natural ringing frequency (Hz)	Weight g (lb)
50 to 500	0.001	4500	730 [1.6]
1000 to 2000	0.002	8000	952,54 [2.1]
3000 to 10000	0.002	9000	2948,35 [6.5]
15000 to 50000	0.003	10000	2993,70 [6.6]
75000 to 100000	0.004	13000	5443,10 [12.0]
150000 to 200000	0.006	11000	12020,19 [26.5]

WIRING CODES

Connector	Unamplified (Std.)
A	(+) excitation
B	(+) excitation
C	(-) excitation
D	(-) excitation
E	(-) output
F	(+) output

2 Honeywell • Sensing and Control

Source: http://content.honeywell.com/sensing/sensotec/pdf_catalog08/008628-1-EN_Model_73.pdf

I.4 NexGen Tekscan FlexiForce A201 Variable Resistance Sensor

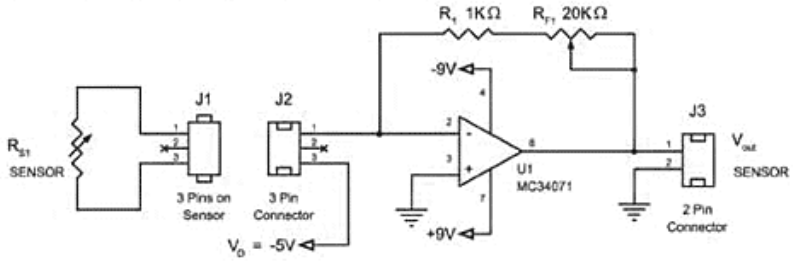
Specifications & Features

Physical Properties	
Thickness	0.008" (.208mm)
Length	8" (203mm) 6" (152mm) 4" (102mm) 2" (51mm)
Width	0.55" (14mm)
Sensing Area	0.375" diameter (9.53mm)
Connector	3-pin male square pin
Thickness	0.008" (.208mm)
Typical Performance	
Linearity Error	< ±5%
Repeatability	< ±2.5% of full scale (conditioned sensor, 80% force applied)
Hysteresis	< 4.5% of full scale (conditioned sensor, 80% force applied)
Drift	< 5% per logarithmic time scale (constant load of 90% sensor rating)
Response Time	< 5 microseconds
Operating Temperatures	15°F - 140°F (-9°C - 60°C)
Force Ranges	0-1 lb. (4.4 N) 0-25 lbs. (110 N) 0-100 lbs. (440 N)*
Temperature Sensitivity	Output variance up to 0.2% per degree F (approx. 0.36% per degree C)

* See recommended drive circuit below. In order to measure forces above 100 lbs. (up to 1000 lbs.), apply a lower drive voltage and reduce the resistance of the feedback resistor (1 kΩ min).

Example of a FlexiForce Excitation Circuit

$V_{out} = -V_D * (R_F / R_{S1})$; where $R_F = R_1 + R_{F1}$



A201 sensors can also be ordered in 2", 4", and 6" lengths for an additional fee.

Source: http://www.nexgenergo.com/ergonomics/tekscana201.html

I.5 Measurement Specialties

FC23 Compression Load Cell

- 50 – 2000 lbf Ranges
- High Level or mV
- Interchangeable
- Compact Load Button Design
- Industry Standard Packaging

STANDARD RANGES

Range	lbf
0 to 50	▪
0 to 100	▪
0 to 250	▪
0 to 500	▪
0 to 1000	▪
0 to 2000	▪

PERFORMANCE SPECIFICATIONS

Supply Voltage: 5.0V, Ambient Temperature: 25°C (unless otherwise specified)

PARAMETERS	MIN	TYP	MAX	UNITS	NOTES
Span (Unamplified)	95	100	105	mV	1
Span (Amplified)	3.8	4.0	4.2	V	1
Zero Force Output (Unamplified)	-20	0	20	mV	1
Zero Force Output (Amplified)	0.3	0.5	0.7	V	1
Accuracy (non linearity, hysteresis, and repeatability)	-1		1	% Span	2
Input Resistance (Unamplified)		3		kΩ	
Output Resistance (Unamplified)		2.2		kΩ	
Temperature Error – Span	-2.5	±1	2.5	% Span	3
Temperature Error – Zero	-2.5	±1	2.5	% Span	3
Supply Voltage (Unamplified)	2	5	10	V	1
Supply Voltage (Amplified)	3.3	5	5.25	V	1
Response Time (10 % to 90 %)		1.0		ms	
Long Term Stability (1 year)		±1		% Span	
Maximum Overload			2.5X	Rated	
Compensated Temperature	0		50	°C	
Operating Temperature	-40		+85	°C	
Storage Temperature	-40		+85	°C	
Isolation Resistance (250Vdc)	50			MΩ	
Deflection at Rated Load			0.05	mm	
Humidity	0		90	%RH	
Weight		47.23		grams	

For custom configurations, consult factory.

Source: http://www.meas-spec.com/product/t_product.aspx?id=2440

J. DAQ Specifications

Technical Sales
United States
(866) 531-6285
info@ni.com

NI USB-6008

12-Bit, 10 kS/s Low-Cost Multifunction DAQ

- 8 analog inputs (12-bit, 10 kS/s)
- 2 analog outputs (12-bit, 150 S/s); 12 digital I/O; 32-bit counter
- Bus-powered for high mobility; built-in signal connectivity
- OEM version available
- Compatible with LabVIEW, LabWindows/CVI, and Measurement Studio for Visual Studio .NET
- NI-DAQmx driver software and NI LabVIEW SignalExpress LE interactive data-logging software

Overview

The National Instruments USB-6008 provides basic data acquisition functionality for applications such as simple data logging, portable measurements, and academic lab experiments. It is affordable for student use, but powerful enough for more sophisticated measurement applications. Use the NI USB-6008 with the included ready-to-run data logger software to begin taking basic measurements in minutes, or program it using LabVIEW or C and the included NI-DAQmx Base measurement services software for a custom measurement system.

To supplement simulation, measurement, and automation theory courses with practical experiments, NI developed a USB-6008 Student Kit that includes a copy of the LabVIEW Student Edition. These kits are exclusively for students, giving them a powerful, low-cost, hands-on learning tool. Visit the NI academic products page for more details.

For faster sampling, more accurate measurements, and higher channel count, consider the NI USB-6210 and NI USB-6211 high-performance USB data acquisition devices.

Every USB data acquisition module includes a copy of NI LabVIEW SignalExpress LE so you can quickly acquire, analyze and present data without programming. In addition to LabVIEW SignalExpress, USB data acquisition devices are compatible with the following versions (or later) of NI application software – LabVIEW 7.x, LabWindows™/CVI 7.x, or Measurement Studio 7.x. USB data acquisition modules are also compatible with Visual Studio .NET, C/C++, and Visual Basic 6.

K. Bill of Materials

Item	Quantity	Source	Catalog Number	Cost ($)
Pressure Sensor	2	Measurement Specialties, Inc.	MSP-300-030-P-2-N-1	235.22
Force Sensor	2	Measurement Specialties, Inc.	FX1901-0001-0050-L	60.00
J-B Weld Mini Clear Epoxy	1	Ace Hardware	N/A	4.49
#20 x 1/4” x 1” Bolts	4	Meijer	MS-115 (148085)	0.97
#4 x 5/8” Wood Screws	6	Meijer	N/A	0.97
# 20 x 1/4" Nuts	4	Meijer	N/A	0.97
1/4” Thick Fiberglass	2 ft^2	University of Michigan	N/A	N/A
1/8” Thick Fiberglass	0.5 ft^2	University of Michigan	N/A	N/A
Water Bottle	2	Meijer	N/A	2.49
1/4” Rubber Plug	2	Jack’s Hardware	52025	0.17
7/16” O-Ring	2	Jack’s Hardware	N/A	0.17
7/16” Female Nut	2	Jack’s Hardware	N/A	4.00
24 Gauge Wire	50 ft	Ace Hardware	30191	6.13
Operational Amplifier	1	University of Michigan	LM324	N/A
Operational Amplifier	1	DigiKey	AD60	6.07
Soldering Board	1	Radio Shack	N/A	10.00
Solder	1	University of Michigan	N/A	N/A

L. FMEA

Part Number, Name, & Functions	Potential Failure Mode	Potential Effect of Failure	**Severity (S)**	Potential Cause/ Mechanism of Failure	**Occurrence (O)**	Current Design Controls / Tests	**Detection (D)**	Recommended Action	**RPN (= S x O x D)**
#2: Grasping Device Container. Container used to measure pressure change	Rupture from applied pressure	Noise, flying debris	7	Improper assembly, manufacturing defects, over stressing	2	Built to withstand 5 psi	2	Inspect device, manually test by applying pressure	28
	Seal Breaking	Noise, flying debris	5	Improper assembly, manufacturing defects	3	Visual inspection of connection, manual tightness	2	Inspect assembly, manaully test by applying pressure	30
#3: Pressure Sensor. Used to measure applied force to grasping device	To much applied force	Failure of device	9	Improper selection of pressure gauge	3	Research maximum grasping force	2	Request safety and functionality test data from supplier	54
	Improper supplied voltage	Failure of device, possible fire / sparks	9	Improper assembly, program error	1	Program error checking, inspection of wire connections	3	Program error checking	27
	Improper wiring	Possible fire / sparks	8	Improper assembly	2	Visual inspection of wire connections	2	Visual inspection of wire connections	32
#4: Force Sensor. Used to measure applied force to pinching device	To much applied force	Failure of device	9	Improper selection of pressure gauge	3	Research maximum grasping force	2	Request safety and functionality test data from supplier	54
	Improper supplied voltage	Failure of device, possible fire / sparks	9	Improper assembly, program error	1	Program error checking, inspection of wire connections	3	Program error checking	27
	Improper wiring	Possible fire / sparks	8	Improper assembly	2	Visual inspection of wire connections	2	Visual inspection of wire connections	32

M. Designsafe

Designsafe Report for Pinching Device Button Panel

designsafe Report

Application:	Pinching Device	Analyst Name(s):	
Description		Company	
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		

Limits

Sources:

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment: Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : pinch point Between housing and button	Slight Remote Possible	Moderate	fixed enclosures / barriers	Minimal None Negligible	Low	ME 450 Team 14
All Users All Tasks	mechanical : fatigue Reptition of tasks	Slight Remote Possible	Moderate	Select material with high yield strength	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	mechanical : break up during operation Excessive force applied by patient	Slight Remote Unlikely	Low	Select material with high yield strength	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	ergonomics / human factors : excessive force / exertion Excessive force applied by patient	Slight Occasional Possible	Moderate	instruction manuals: make sure patient knows how to properly preform tasks	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	ergonomics / human factors : repetition Various tasks performed by patients	Slight Occasional Possible	Moderate	instruction manuals: make sure patient knows how to properly preform tasks	Minimal Remote Unlikely	Low	ME 450 Team 14

designsafe Report

Application: Pinching Device

Analyst Name(s):

Description:

Company:

Product Identifier:

Facility Location:

Assessment Type: Detailed

Limits:

Sources:

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : crushing Buckling under pinching force	Slight Remote Unlikely	Low	Select material with high yield strength	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	mechanical : cutting / severing Fractured pieces	Slight Remote Unlikely	Low	Select material with high yield strength	Minimal Remote Negligible	Low	ME 450 Team 14
All Users All Tasks	mechanical : pinch point Between housing and button	Slight Remote Possible	Moderate	fixed enclosures / barriers	Minimal None Negligible	Low	ME 450 Team 14
All Users All Tasks	mechanical : stabbing / puncture Sharp corners	Minimal Remote Negligible	Low	Router and sand the edges	Minimal None Negligible	Low	ME 450 Team 14
All Users All Tasks	mechanical : fatigue Reptition of tasks	Slight Remote Possible	Moderate	Select material with high fatigue strength	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	mechanical : break up during operation Excessive force applied by patient	Slight Remote Unlikely	Low	Select material with high yield strength	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	ergonomics / human factors : excessive force / exertion Excessive force applied by patient	Slight Occasional Possible	Moderate	instruction manuals: make sure patient knows how to properly preform tasks	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	ergonomics / human factors : repetition Various tasks performed by patients	Slight Occasional Possible	Moderate	instruction manuals: make sure patient knows how to properly preform tasks	Minimal Remote Unlikely	Low	ME 450 Team 14

Designsafe Report for Grasping Container (Bottle)

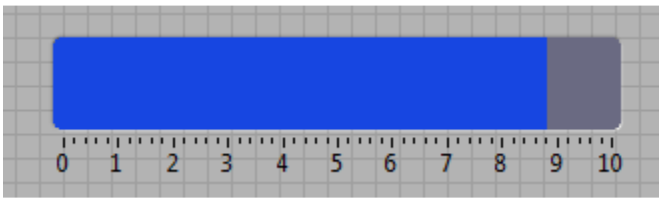
designsafe Report

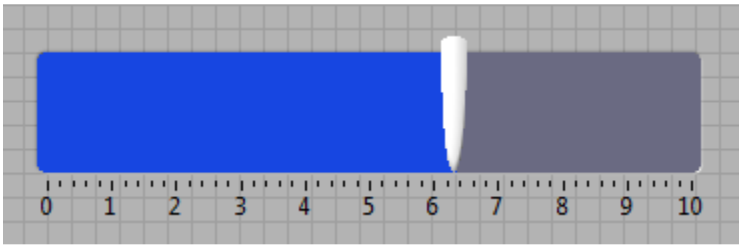
Application:	Pinching Device	Analyst Name(s):	
Description:		Company:	
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			

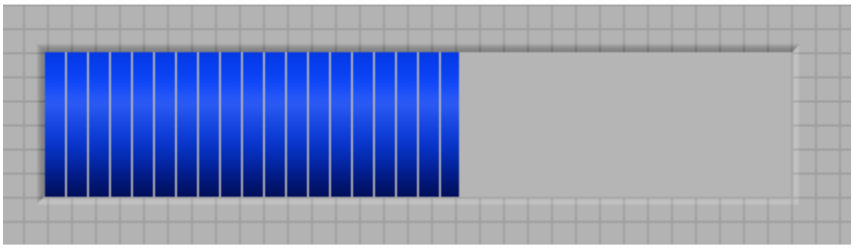
Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : pinch point Between housing and button	Slight Remote Possible	Moderate	fixed enclosures / barriers	Minimal None Negligible	Low	ME 450 Team 14
All Users All Tasks	mechanical : fatigue Reptition of tasks	Slight Remote Possible	Moderate	Select material with high yield strength	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	mechanical : break up during operation Excessive force applied by patient	Slight Remote Unlikely	Low	Select material with high yield strength	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	ergonomics / human factors : excessive force / exertion Excessive force applied by patient	Slight Occasional Possible	Moderate	instruction manuals: make sure patient knows how to properly preform tasks	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	ergonomics / human factors : repetition Various tasks performed by patients	Slight Occasional Possible	Moderate	instruction manuals: make sure patient knows how to properly preform tasks	Minimal Remote Unlikely	Low	ME 450 Team 14
All Users All Tasks	fluid / pressure : high pressure air Ruptured seal	Slight Remote Possible	Moderate	Use o-rings and glue seals	Slight Remote Unlikely	Low	ME 450 Team 14

N. Horizontal Sliding Bars







O. Instruction Manual

Welcome!

Welcome to the hand manipulation portion of ULTrA! This program will guide you through four modules that will help assist in your rehabilitation process. Each module can be reached by clicking on the Module Tab on the top of your screen. Please proceed through each module in numerical order and complete the instructions provided.
All four modules will need to be completed twice, once using the grasping device and again with the pinching device.

Thanks and have fun!

Module One

1. To turn on the program click the Start arrow at the top left of the screen 
2. Then click the start button on the before picking up the device.

3. Pick up the device and grasp/pinch as hard as possible until the light on the screen is goes out
4. Return the device to the table

Congratulations you have completed Module One!

Module Two

1. Once you have completed Module One and are ready to begin Module Two Click the start button before picking up the device.

2. Grasp/Pinch the device until the first light is illuminated. The bar will move to the right as you grasp/pinch the device. The light will illuminate when you have provide enough force to get the sliding bar into the gates. The color of the bar will indicate which gate to move to next.
3. After the first light is illuminated, maintain hold until the second light is illuminated. This indicates you've held the correct force for the required amount of time.
4. After the second light is illuminated, release the device so the slider returns back to the beginning.
5. Repeat steps 2-4 for the next two gates.
6. After getting the final light to illuminate for the third gate, return the device to the table.

Congratulations you have completed Module Two!

Module Three

1. Once you have completed Module One and Module Two Click the start button before picking up the device.

2. Pick up one device in each hand.
3. Grasp/Pinch both devices until the first light is illuminated. The bars will move to the right as you grasp/pinch the device. The light will illuminate when you provide enough force to get both sliding bars into the same gate. The color of the bars will indicate which gate to move to next.
4. After the first light is illuminated, maintain hold until the second light is illuminated. This indicates you've held the correct force for the required amount of time.
5. After the second light is illuminated, release both devices so the sliders return back to the beginning.
6. Repeat steps 3-5 for the next two gates.
7. After getting the final light to illuminate for the third gate, return the devices to the table.

Congratulations you have completed Module Three!

Module Four

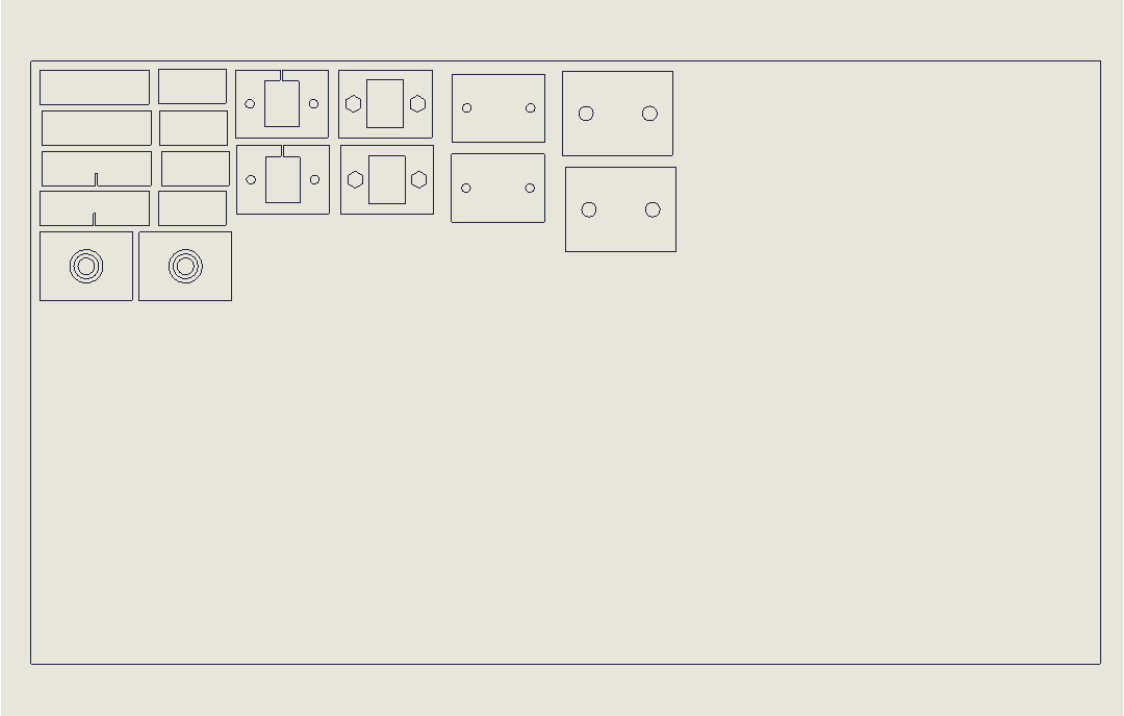
1. Once you have completed Module One, Two and Three Click the start button

before picking up the device  2. Pick up one device in each hand. 3. Grasp/Pinch one device until the first light is illuminated. The color of the bars will indicate which gate to move to next. 4. Once the first light is illuminated, release hold and then grasp/pinch with the other hand immediately until the other sliding bar reaches the gate and the second light illuminates. Note: The lights will not illuminate if the second sliding bar is begin grasped/pinched i.e. you can only grasp/pinch one device at a time. 5. Once both lights are illuminated, release your hold on the second device and grasp/pinch the first device. 6. Repeat steps 3-5 for the next two gates. 7. After getting the final light to illuminate for the third gate, return the devices to the table and press the Program Complete button  *Congratulations you have completed Module Four!*	After completing modules one – four with both the pinching and grasping devices, you have completed the program. ***CONGRATULATIONS!***

P. CAD Drawing for the Laser Cuter

This section shows the necessary CAD drawings created to use the laser cutter and cut out the pieces.

P.1 CAD Drawing for the Pinching Device



P.2 CAD Drawing for the Lip of the Pinching Device

Q. Data Sheets for Operational Amplifiers

Q.1 Data Sheet for AD620

ANALOG DEVICES

Low Cost Low Power Instrumentation Amplifier

AD620

FEATURES

Easy to use
- Gain set with one external resistor (Gain range 1 to 10,000)
- Wide power supply range (±2.3 V to ±18 V)
- Higher performance than 3 op amp IA designs
- Available in 8-lead DIP and SOIC packaging
- Low power, 1.3 mA max supply current

Excellent dc performance (B grade)
- 50 µV max, input offset voltage
- 0.6 µV/°C max, input offset drift
- 1.0 nA max, input bias current
- 100 dB min common-mode rejection ratio (G = 10)

Low noise
- 9 nV/√Hz @ 1 kHz, input voltage noise
- 0.28 µV p-p noise (0.1 Hz to 10 Hz)

Excellent ac specifications
- 120 kHz bandwidth (G = 100)
- 15 µs settling time to 0.01%

APPLICATIONS

Weigh scales
ECG and medical instrumentation
Transducer interface
Data acquisition systems
Industrial process controls
Battery-powered and portable equipment

CONNECTION DIAGRAM

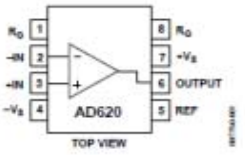


Figure 1. 8-Lead PDIP (N), CERDIP (Q), and SOIC (R) Packages

PRODUCT DESCRIPTION

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 10,000. Furthermore, the AD620 features 8-lead SOIC and DIP packaging that is smaller than discrete designs and offers lower power (only 1.3 mA max supply current), making it a good fit for battery-powered, portable (or remote) applications.

The AD620, with its high accuracy of 40 ppm maximum nonlinearity, low offset voltage of 50 µV max, and offset drift of 0.6 µV/°C max, is ideal for use in precision data acquisition systems, such as weigh scales and transducer interfaces. Furthermore, the low noise, low input bias current, and low power of the AD620 make it well suited for medical applications, such as ECG and noninvasive blood pressure monitors.

The low input bias current of 1.0 nA max is made possible with the use of Superβeta processing in the input stage. The AD620 works well as a preamplifier due to its low input voltage noise of 9 nV/√Hz at 1 kHz, 0.28 µV p-p in the 0.1 Hz to 10 Hz band, and 0.1 pA/√Hz input current noise. Also, the AD620 is well suited for multiplexed applications with its settling time of 15 µs to 0.01%, and its cost is low enough to enable designs with one in-amp per channel.

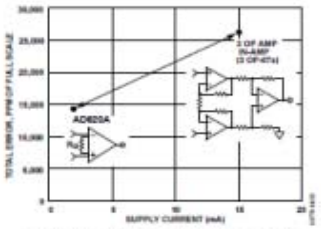


Figure 2. Three Op Amp IA Designs vs. AD620

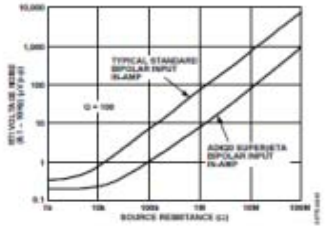


Figure 3. Total Voltage Noise vs. Source Resistance

Rev. G
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SPECIFICATIONS

Typical @ 25°C, V_S = ±15 V, and R_L = 2 kΩ, unless otherwise noted.

Table 1.

Parameter	Conditions	AD620A Min	AD620A Typ	AD620A Max	AD620B Min	AD620B Typ	AD620B Max	AD620S[1] Min	AD620S[1] Typ	AD620S[1] Max	Unit
GAIN	G = 1 + (49.4 kΩ/R_G)										
Gain Range		1		10,000	1		10,000	1		10,000	
Gain Error[2]	V_{OUT} = ±10 V										
G = 1			0.03	0.10		0.01	0.02		0.03	0.10	%
G = 10			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 100			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 1000			0.40	0.70		0.35	0.50		0.40	0.70	%
Nonlinearity	V_{OUT} = −10 V to +10 V										
G = 1–1000	R_L = 10 kΩ		10	40		10	40		10	40	ppm
G = 1–100	R_L = 2 kΩ		10	95		10	95		10	95	ppm
Gain vs. Temperature											
	G = 1			10			10			10	ppm/°C
	Gain >1[2]			−50			−50			−50	ppm/°C
VOLTAGE OFFSET	(Total RTI Error = V_{OSI} + V_{OSO}/G)										
Input Offset, V_{OSI}	V_S = ±5 V to ± 15 V		30	125		15	50		30	125	µV
Overtemperature	V_S = ±5 V to ± 15 V			185			85			225	µV
Average TC	V_S = ±5 V to ± 15 V		0.3	1.0		0.1	0.6		0.3	1.0	µV/°C
Output Offset, V_{OSO}	V_S = ±15 V		400	1000		200	500		400	1000	µV
	V_S = ± 5 V			1500			750			1500	µV
Overtemperature	V_S = ±5 V to ± 15 V			2000			1000			2000	µV
Average TC	V_S = ±5 V to ± 15 V		5.0	15		2.5	7.0		5.0	15	µV/°C
Offset Referred to the Input vs. Supply (PSR)	V_S = ±2.3 V to ±18 V										
G = 1		80	100		80	100		80	100		dB
G = 10		95	120		100	120		95	120		dB
G = 100		110	140		120	140		110	140		dB
G = 1000		110	140		120	140		110	140		dB
INPUT CURRENT											
Input Bias Current			0.5	2.0		0.5	1.0		0.5	2	nA
Overtemperature				2.5			1.5			4	nA
Average TC			3.0			3.0			8.0		pA/°C
Input Offset Current			0.3	1.0		0.3	0.5		0.3	1.0	nA
Overtemperature				1.5			0.75			2.0	nA
Average TC			1.5			1.5			8.0		pA/°C
INPUT											
Input Impedance											
Differential			10||2			10||2			10||2		GΩ_pF
Common-Mode			10||2			10||2			10||2		GΩ_pF
Input Voltage Range[3]	V_S = ±2.3 V to ±5 V	$-V_S$ + 1.9		$+V_S$ − 1.2	$-V_S$ + 1.9		$+V_S$ − 1.2	$-V_S$ + 1.9		$+V_S$ − 1.2	V
Overtemperature		$-V_S$ + 2.1		$+V_S$ − 1.3	$-V_S$ + 2.1		$+V_S$ − 1.3	$-V_S$ + 2.1		$+V_S$ − 1.3	V
	V_S = ± 5 V to ±18 V	$-V_S$ + 1.9		$+V_S$ − 1.4	$-V_S$ + 1.9		$+V_S$ − 1.4	$-V_S$ + 1.9		$+V_S$ − 1.4	V
Overtemperature		$-V_S$ + 2.1		$+V_S$ − 1.4	$-V_S$ + 2.1		$+V_S$ + 2.1	$-V_S$ + 2.3		$+V_S$ − 1.4	V

Parameter	Conditions	AD620A Min	AD620A Typ	AD620A Max	AD620B Min	AD620B Typ	AD620B Max	AD620S[1] Min	AD620S[1] Typ	AD620S[1] Max	Unit
Common-Mode Rejection											
Ratio DC to 60 Hz with											
1 kΩ Source Imbalance	V_{CM} = 0 V to ± 10 V										
G = 1		73	90		80	90		73	90		dB
G = 10		93	110		100	110		93	110		dB
G = 100		110	130		120	130		110	130		dB
G = 1000		110	130		120	130		110	130		dB
OUTPUT											
Output Swing	R_L = 10 kΩ										
	V_S = ±2.3 V to ± 5 V	$-V_S$ + 1.1		$+V_S$ – 1.2	$-V_S$ + 1.1		$+V_S$ – 1.2	$-V_S$ + 1.1		$+V_S$ – 1.2	V
Overtemperature		$-V_S$ + 1.4		$+V_S$ – 1.3	$-V_S$ + 1.4		$+V_S$ – 1.3	$-V_S$ + 1.6		$+V_S$ – 1.3	V
	V_S = ±5 V to ± 18 V	$-V_S$ + 1.2		$+V_S$ – 1.4	$-V_S$ + 1.2		$+V_S$ – 1.4	$-V_S$ + 1.2		$+V_S$ – 1.4	V
Overtemperature		$-V_S$ + 1.6		$+V_S$ – 1.5	$-V_S$ + 1.6		$+V_S$ – 1.5	$-V_S$ + 2.3		$+V_S$ – 1.5	V
Short Circuit Current			±18			±18			±18		mA
DYNAMIC RESPONSE											
Small Signal –3 dB Bandwidth											
G = 1			1000			1000			1000		kHz
G = 10			800			800			800		kHz
G = 100			120			120			120		kHz
G = 1000			12			12			12		kHz
Slew Rate		0.75	1.2		0.75	1.2		0.75	1.2		V/µs
Settling Time to 0.01%	10 V Step										
G = 1–100			15			15			15		µs
G = 1000			150			150			150		µs
NOISE											
Voltage Noise, 1 kHz	$Total\ RTI\ Noise = \sqrt{(e_{ni}^2) + (e_{no}/G)^2}$										
Input, Voltage Noise, e_{ni}			9	13		9	13		9	13	nV/√Hz
Output, Voltage Noise, e_{no}			72	100		72	100		72	100	nV/√Hz
RTI, 0.1 Hz to 10 Hz											
G = 1			3.0			3.0	6.0		3.0	6.0	µV p-p
G = 10			0.55			0.55	0.8		0.55	0.8	µV p-p
G = 100–1000			0.28			0.28	0.4		0.28	0.4	µV p-p
Current Noise	f = 1 kHz		100			100			100		fA/√Hz
0.1 Hz to 10 Hz			10			10			10		pA p-p
REFERENCE INPUT											
R_{IN}			20			20			20		kΩ
I_{IN}	V_{IN+}, V_{REF} = 0		50	60		50	60		50	60	µA
Voltage Range		$-V_S$ + 1.6		$+V_S$ – 1.6	$-V_S$ + 1.6		$+V_S$ – 1.6	$-V_S$ + 1.6		$+V_S$ – 1.6	V
Gain to Output		1 ± 0.0001			1 ± 0.0001			1 ± 0.0001			
POWER SUPPLY											
Operating Range[4]		±2.3		±18	±2.3		±18	±2.3		±18	V
Quiescent Current	V_S = ±2.3 V to ±18 V		0.9	1.3		0.9	1.3		0.9	1.3	mA
Overtemperature			1.1	1.6		1.1	1.6		1.1	1.6	mA
TEMPERATURE RANGE											
For Specified Performance		–40 to +85			–40 to +85			–55 to +125			°C

[1] See Analog Devices military data sheet for 883B tested specifications.
[2] Does not include effects of external resistor R_G.
[3] One input grounded. G = 1.
[4] This is defined as the same supply range that is used to specify PSR.

ABSOLUTE MAXIMUM RATINGS

Table 2.

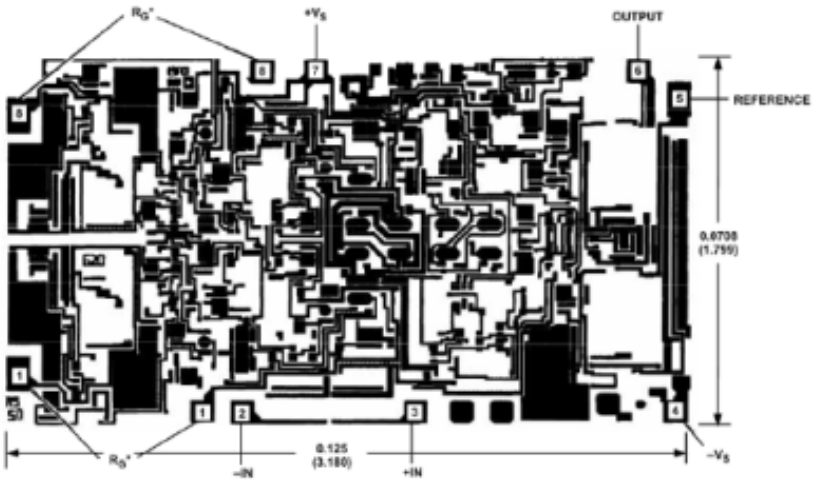
Parameter	Rating
Supply Voltage	±18 V
Internal Power Dissipation[1]	650 mW
Input Voltage (Common-Mode)	±Vs
Differential Input Voltage	25 V
Output Short-Circuit Duration	Indefinite
Storage Temperature Range (Q)	−65°C to +150°C
Storage Temperature Range (N, R)	−65°C to +125°C
Operating Temperature Range	
AD620 (A, B)	−40°C to +85°C
AD620 (S)	−55°C to +125°C
Lead Temperature Range	
(Soldering 10 seconds)	300°C

[1] Specification is for device in free air:
8-Lead Plastic Package: θ_{JA} = 95°C
8-Lead CERDIP Package: θ_{JA} = 110°C
8-Lead SOIC Package: θ_{JA} = 155°C

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other condition s above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



*FOR CHIP APPLICATIONS: THE PADS 1R_G AND 8R_G MUST BE CONNECTED IN PARALLEL TO THE EXTERNAL GAIN REGISTER R_G. DO NOT CONNECT THEM IN SERIES TO R_G. FOR UNITY GAIN APPLICATIONS WHERE R_G IS NOT REQUIRED, THE PADS 1R_G MAY SIMPLY BE BONDED TOGETHER, AS WELL AS THE PADS 8R_G.

Figure 4. Metallization Photograph.
Dimensions shown in inches and (mm).

Contact sales for latest dimensions.

TYPICAL PERFORMANCE CHARACTERISTICS

(@ 25°C, V_S = ±15 V, R_L = 2 kΩ, unless otherwise noted.)

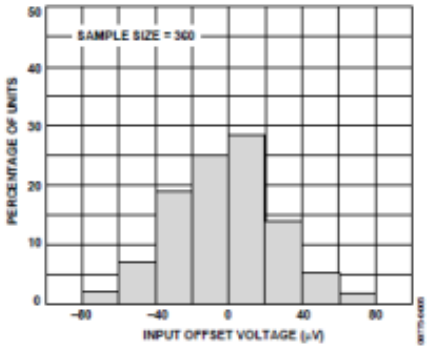


Figure 5. Typical Distribution of Input Offset Voltage

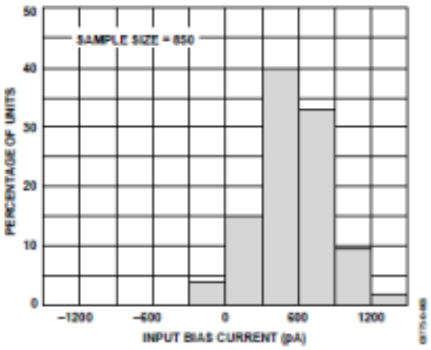


Figure 6. Typical Distribution of Input Bias Current

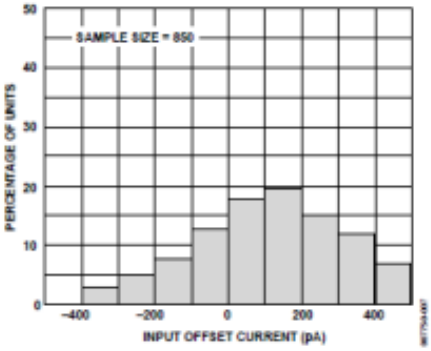


Figure 7. Typical Distribution of Input Offset Current

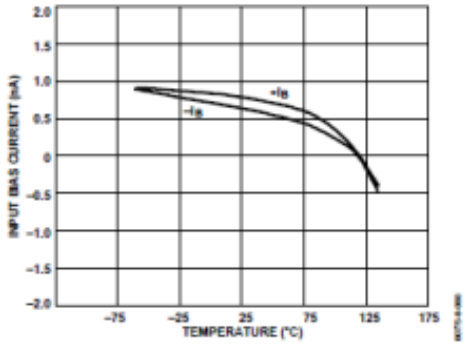


Figure 8. Input Bias Current vs. Temperature

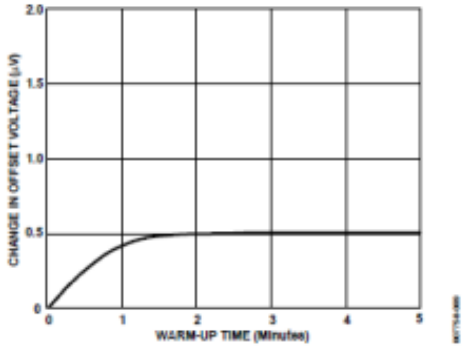


Figure 9. Change in Input Offset Voltage vs. Warm-Up Time

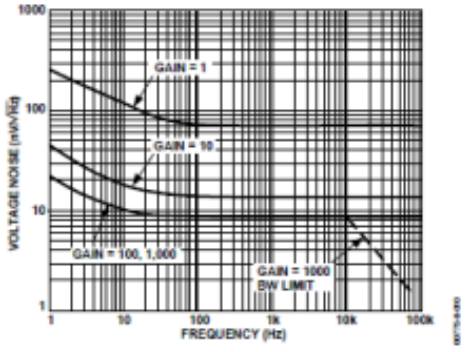


Figure 10. Voltage Noise Spectral Density vs. Frequency (G = 1–1000)

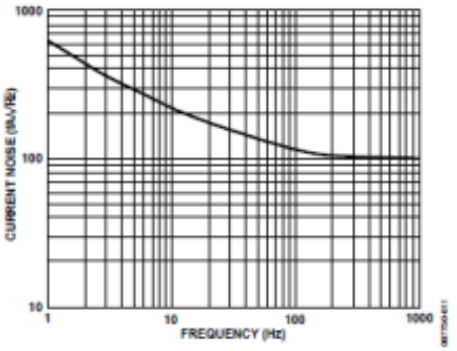


Figure 11. Current Noise Spectral Density vs. Frequency

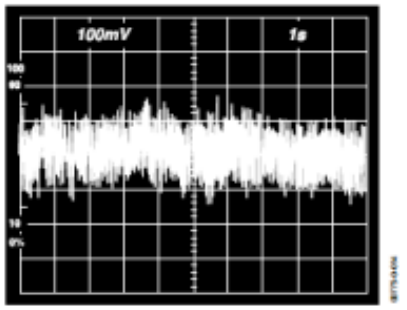


Figure 14. 0.1 Hz to 10 Hz Current Noise, 5 pA/Div

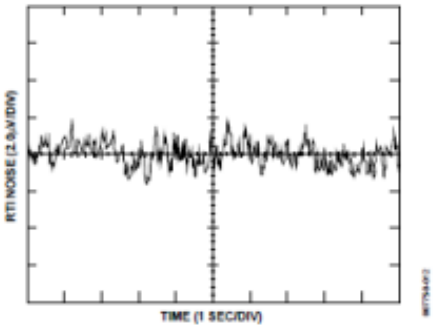


Figure 12. 0.1 Hz to 10 Hz RTI Voltage Noise (G = 1)

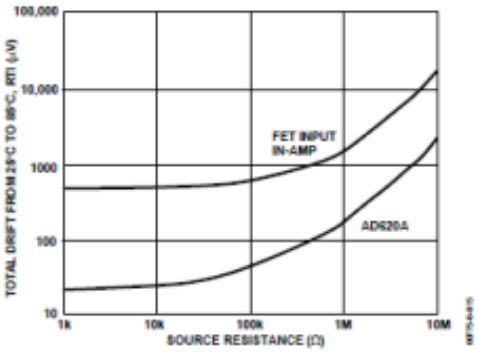


Figure 15. Total Drift vs. Source Resistance

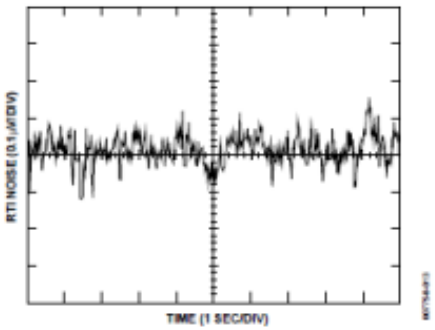


Figure 13. 0.1 Hz to 10 Hz RTI Voltage Noise (G = 1000)

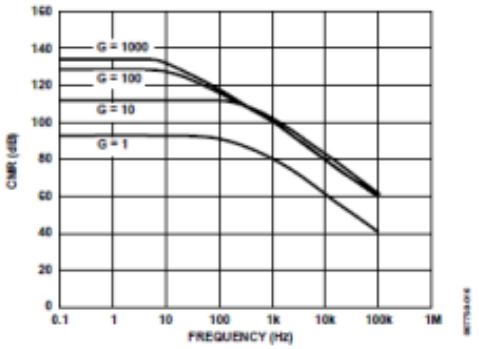


Figure 16. Typical CMR vs. Frequency, RTI, Zero to 1 kΩ Source Imbalance

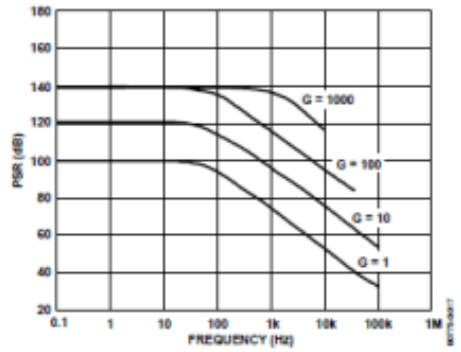


Figure 17. Positive PSR vs. Frequency, RTI (G = 1–1000)

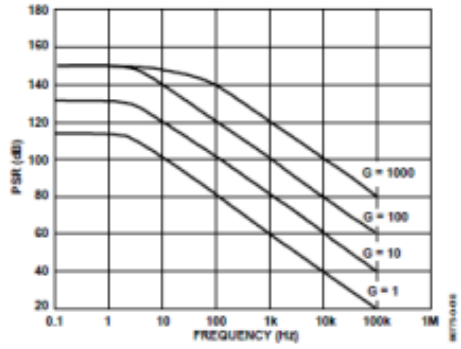


Figure 18. Negative PSR vs. Frequency, RTI (G = 1–1000)

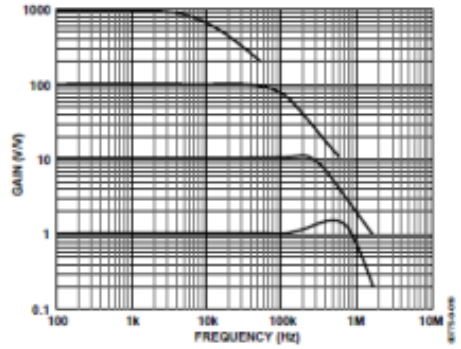


Figure 19. Gain vs. Frequency

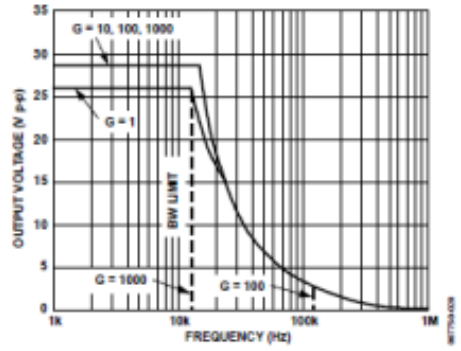


Figure 20. Large Signal Frequency Response

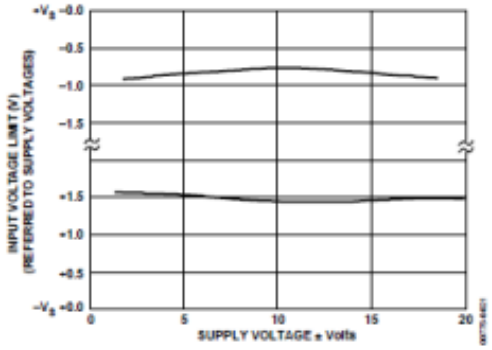


Figure 21. Input Voltage Range vs. Supply Voltage, G = 1

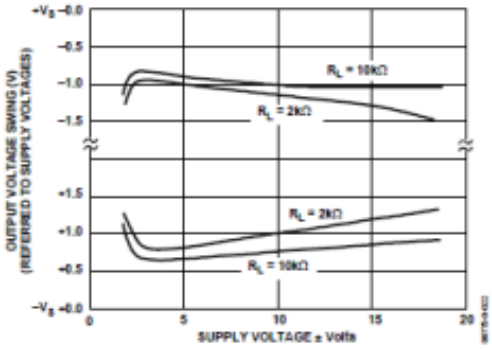


Figure 22. Output Voltage Swing vs. Supply Voltage, G = 10

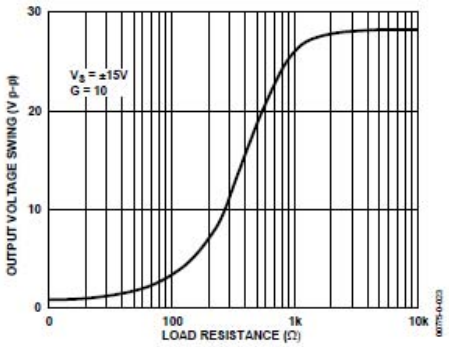


Figure 23. Output Voltage Swing vs. Load Resistance

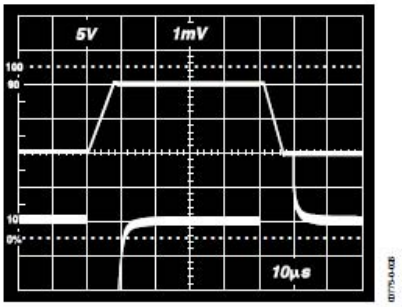


Figure 26. Large Signal Response and Settling Time, G = 10 (0.5 mV = 0.01%)

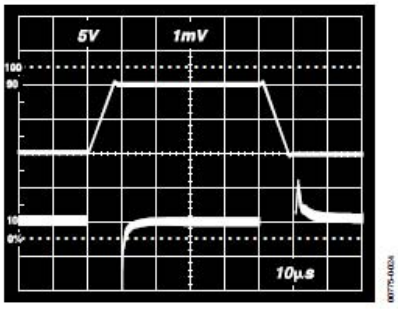


Figure 24. Large Signal Pulse Response and Settling Time
G = 1 (0.5 mV = 0.01%)

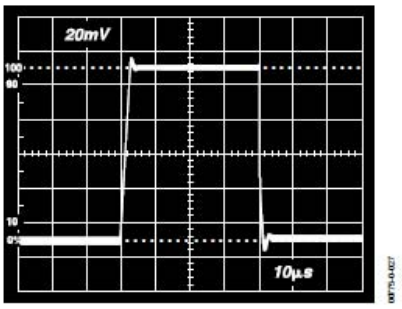


Figure 27. Small Signal Response, G = 10, R_L = 2 kΩ, C_L = 100 pF

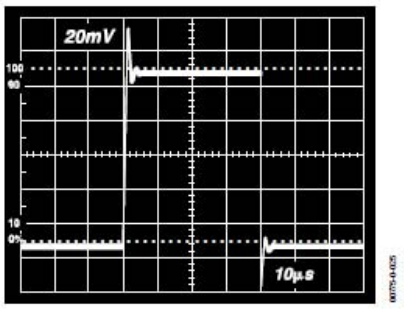


Figure 25. Small Signal Response, G = 1, R_L = 2 kΩ, C_L = 100 pF

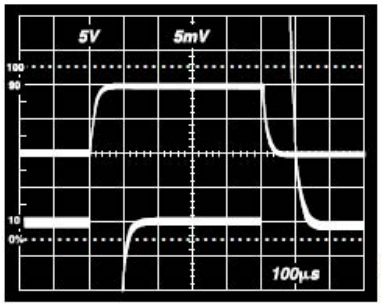


Figure 28. Large Signal Response and Settling Time, G = 100 (0.5 mV = 0.01%)

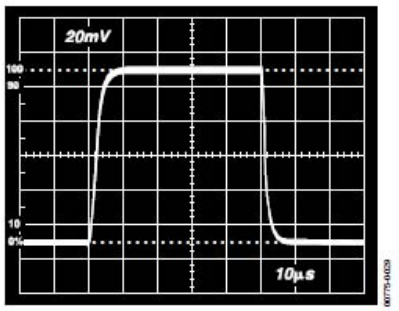


Figure 29. Small Signal Pulse Response, G = 100, R_L = 2 kΩ, C_L = 100 pF

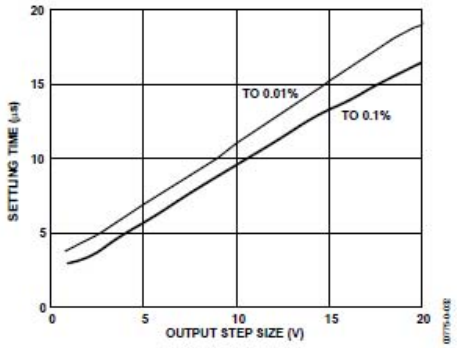


Figure 32. Settling Time vs. Step Size (G = 1)

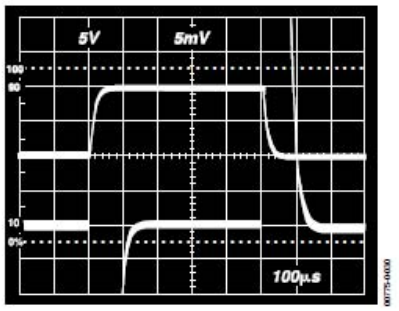


Figure 30. Large Signal Response and Settling Time, G = 1000 (0.5 mV = 0.01%)

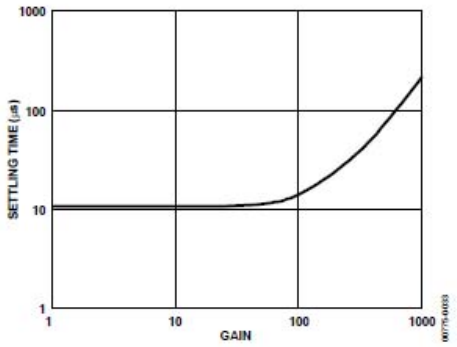


Figure 33. Settling Time to 0.01% vs. Gain, for a 10 V Step

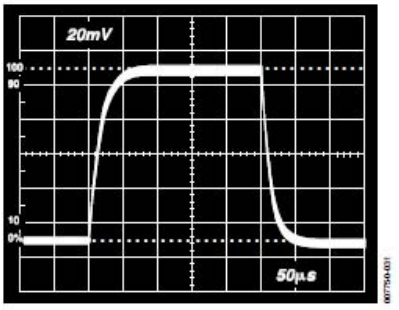


Figure 31. Small Signal Pulse Response, G = 1000, R_L = 2 kΩ, C_L = 100 pF

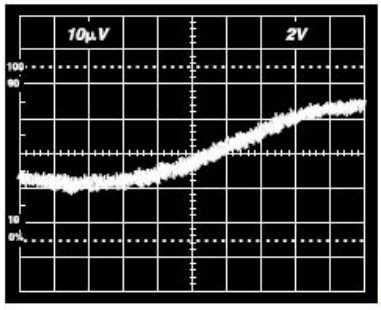


Figure 34. Gain Nonlinearity, G = 1, R_L = 10 kΩ (10 µV = 1 ppm)

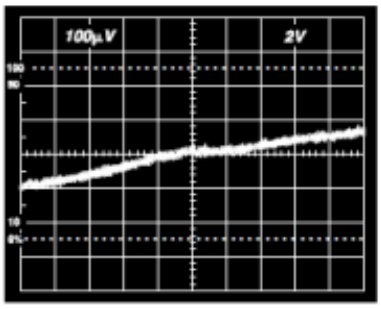


Figure 35. Gain Nonlinearity, G = 100, R_L = 10 kΩ
(100 µV = 10 ppm)

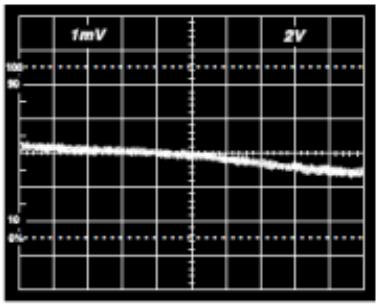


Figure 36. Gain Nonlinearity, G = 1000, R_L = 10 kΩ
(1 mV = 100 ppm)

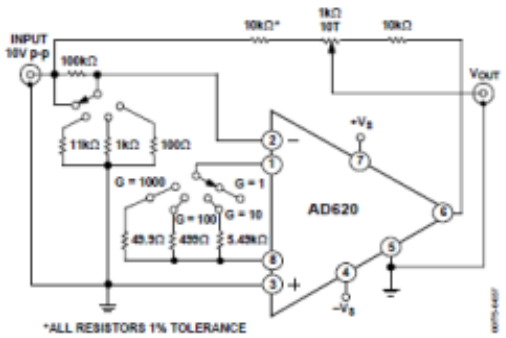


Figure 37. Settling Time Test Circuit

THEORY OF OPERATION

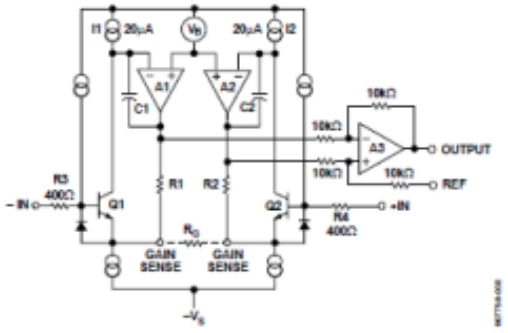


Figure 38. Simplified Schematic of AD620

The AD620 is a monolithic instrumentation amplifier based on a modification of the classic three op amp approach. Absolute value trimming allows the user to program gain *accurately* (to 0.15% at G = 100) with only one resistor. Monolithic construction and laser wafer trimming allow the tight matching and tracking of circuit components, thus ensuring the high level of performance inherent in this circuit.

The input transistors Q1 and Q2 provide a single differential-pair bipolar input for high precision (Figure 38), yet offer 10× lower input bias current thanks to Superβeta processing. Feedback through the Q1-A1-R1 loop and the Q2-A2-R2 loop maintains constant collector current of the input devices Q1 and Q2, thereby impressing the input voltage across the external gain setting resistor R_G. This creates a differential gain from the inputs to the A1/A2 outputs given by $G = (R1 + R2)/R_G + 1$. The unity-gain subtractor, A3, removes any common-mode signal, yielding a single-ended output referred to the REF pin potential.

The value of R_G also determines the transconductance of the preamp stage. As R_G is reduced for larger gains, the transconductance increases asymptotically to that of the input transistors. This has three important advantages: (a) Open-loop gain is boosted for increasing programmed gain, thus reducing gain related errors. (b) The gain-bandwidth product (determined by C1 and C2 and the preamp transconductance) increases with programmed gain, thus optimizing frequency response. (c) The input voltage noise is reduced to a value of 9 nV/√Hz, determined mainly by the collector current and base resistance of the input devices.

The internal gain resistors, R1 and R2, are trimmed to an absolute value of 24.7 kΩ, allowing the gain to be programmed accurately with a single external resistor.

The gain equation is then

$$G = \frac{49.4k\Omega}{R_G} + 1$$

$$R_G = \frac{49.4k\Omega}{G-1}$$

Make vs. Buy: a Typical Bridge Application Error Budget

The AD620 offers improved performance over "homebrew" three op amp IA designs, along with smaller size, fewer components, and 10× lower supply current. In the typical application, shown in Figure 39, a gain of 100 is required to amplify a bridge output of 20 mV full-scale over the industrial temperature range of −40°C to +85°C. Table 3 shows how to calculate the effect various error sources have on circuit accuracy.

Regardless of the system in which it is being used, the AD620 provides greater accuracy at low power and price. In simple systems, absolute accuracy and drift errors are by far the most significant contributors to error. In more complex systems with an intelligent processor, an autogain/autozero cycle will remove all absolute accuracy and drift errors, leaving only the resolution errors of gain, nonlinearity, and noise, thus allowing full 14-bit accuracy.

Note that for the homebrew circuit, the OP07 specifications for input voltage offset and noise have been multiplied by √2. This is because a three op amp type in-amp has two op amps at its inputs, both contributing to the overall input error.

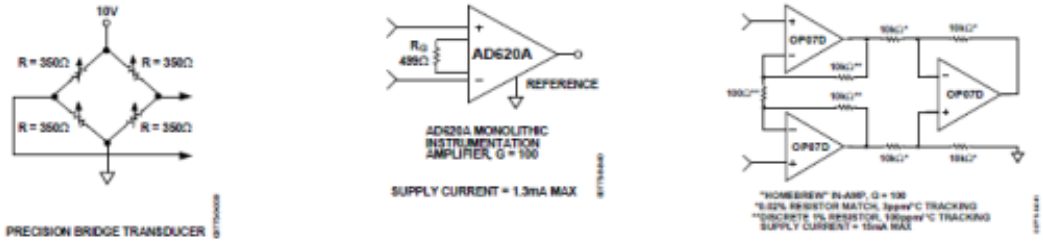


Figure 39. Make vs. Buy

Table 3. Make vs. Buy Error Budget

Error Source	AD620 Circuit Calculation	"Homebrew" Circuit Calculation	Error, ppm of Full Scale	
			AD620	Homebrew
ABSOLUTE ACCURACY at T_A = 25°C				
Input Offset Voltage, µV	125 µV/20 mV	(150 µV × √2)/20 mV	6,250	10,607
Output Offset Voltage, µV	1000 µV/100 mV/20 mV	((150 µV × 2)/100)/20 mV	500	150
Input Offset Current, nA	2 nA ×350 Ω/20 mV	(6 nA ×350 Ω)/20 mV	18	53
CMR, dB	110 dB(3.16 ppm) ×5 V/20 mV	(0.02% Match × 5 V)/20 mV/100	791	500
		Total Absolute Error	7,559	11,310
DRIFT TO 85°C				
Gain Drift, ppm/°C	(50 ppm + 10 ppm) ×60°C	100 ppm/°C Track × 60°C	3,600	6,000
Input Offset Voltage Drift, µV/°C	1 µV/°C × 60°C/20 mV	(2.5 µV/°C × √2 × 60°C)/20 mV	3,000	10,607
Output Offset Voltage Drift, µV/°C	15 µV/°C × 60°C/100 mV/20 mV	(2.5 µV/°C × 2 × 60°C)/100 mV/20 mV	450	150
		Total Drift Error	7,050	16,757
RESOLUTION				
Gain Nonlinearity, ppm of Full Scale	40 ppm	40 ppm	40	40
Typ 0.1 Hz to 10 Hz Voltage Noise, µV p-p	0.28 µV p-p/20 mV	(0.38 µV p-p × √2)/20 mV	14	27
		Total Resolution Error	54	67
		Grand Total Error	14,663	28,134

G = 100, V_S = ±15 V.
(All errors are min/max and referred to input.)

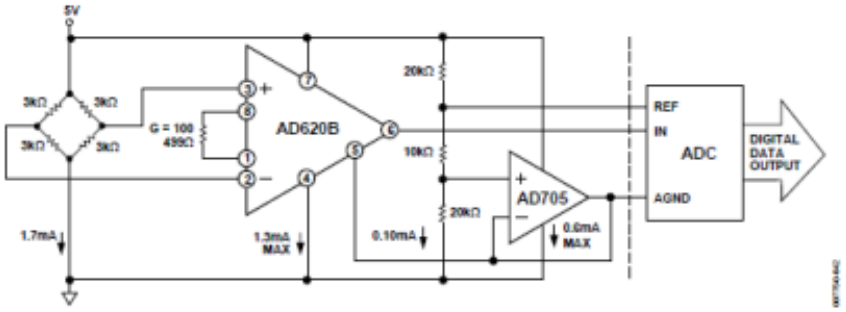


Figure 40. A Pressure Monitor Circuit that Operates on a 5 V Single Supply

Pressure Measurement

Although useful in many bridge applications, such as weigh scales, the AD620 is especially suitable for higher resistance pressure sensors powered at lower voltages where small size and low power become more significant.

Figure 40 shows a 3 kΩ pressure transducer bridge powered from 5 V. In such a circuit, the bridge consumes only 1.7 mA. Adding the AD620 and a buffered voltage divider allows the signal to be conditioned for only 3.8 mA of total supply current.

Small size and low cost make the AD620 especially attractive for voltage output pressure transducers. Since it delivers low noise and drift, it will also serve applications such as diagnostic noninvasive blood pressure measurement.

Medical ECG

The low current noise of the AD620 allows its use in ECG monitors (Figure 41) where high source resistances of 1 MΩ or higher are not uncommon. The AD620's low power, low supply voltage requirements, and space-saving 8-lead mini-DIP and SOIC package offerings make it an excellent choice for battery-powered data recorders.

Furthermore, the low bias currents and low current noise, coupled with the low voltage noise of the AD620, improve the dynamic range for better performance.

The value of capacitor C1 is chosen to maintain stability of the right leg drive loop. Proper safeguards, such as isolation, must be added to this circuit to protect the patient from possible harm.

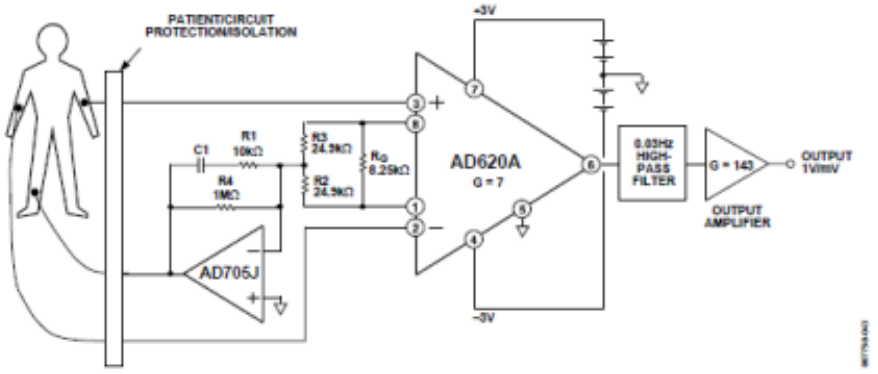


Figure 41. A Medical ECG Monitor Circuit

Precision V-I Converter

The AD620, along with another op amp and two resistors, makes a precision current source (Figure 42). The op amp buffers the reference terminal to maintain good CMR. The output voltage, V_X, of the AD620 appears across R1, which converts it to a current. This current, less only the input bias current of the op amp, then flows out to the load.

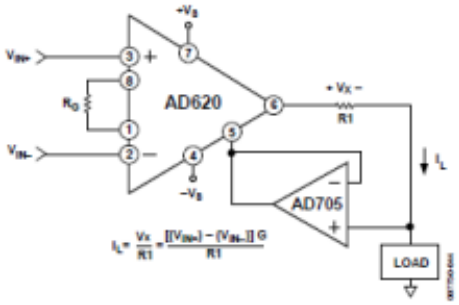


Figure 42. Precision Voltage-to-Current Converter (Operates on 1.8 mA, ±3 V)

GAIN SELECTION

The AD620's gain is resistor-programmed by R_G, or more precisely, by whatever impedance appears between Pins 1 and 8. The AD620 is designed to offer accurate gains using 0.1% to 1% resistors. Table 4 shows required values of R_G for various gains. Note that for G = 1, the R_G pins are unconnected ($R_G = \infty$). For any arbitrary gain, R_G can be calculated by using the formula:

$$R_G = \frac{49.4\,k\Omega}{G-1}$$

To minimize gain error, avoid high parasitic resistance in series with R_G; to minimize gain drift, R_G should have a low TC—less than 10 ppm/°C—for the best performance.

Table 4. Required Values of Gain Resistors

1% Std Table Value of R_G(Ω)	Calculated Gain	0.1% Std Table Value of R_G(Ω)	Calculated Gain
49.9 k	1.990	49.3 k	2.002
12.4 k	4.984	12.4 k	4.984
5.49 k	9.998	5.49 k	9.998
2.61 k	19.93	2.61 k	19.93
1.00 k	50.40	1.01 k	49.91
499	100.0	499	100.0
249	199.4	249	199.4
100	495.0	98.8	501.0
49.9	991.0	49.3	1,003.0

INPUT AND OUTPUT OFFSET VOLTAGE

The low errors of the AD620 are attributed to two sources, input and output errors. The output error is divided by G when referred to the input. In practice, the input errors dominate at high gains, and the output errors dominate at low gains. The total V_{OS} for a given gain is calculated as

Total Error RTI = input error + (output error/G)

Total Error RTO = (input error × G) + output error

REFERENCE TERMINAL

The reference terminal potential defines the zero output voltage and is especially useful when the load does not share a precise ground with the rest of the system. It provides a direct means of injecting a precise offset to the output, with an allowable range of 2 V within the supply voltages. Parasitic resistance should be kept to a minimum for optimum CMR.

INPUT PROTECTION

The AD620 features 400 Ω of series thin film resistance at its inputs and will safely withstand input overloads of up to ±15 V or ±60 mA for several hours. This is true for all gains and power on and off, which is particularly important since the signal source and amplifier may be powered separately. For longer time periods, the current should not exceed 6 mA ($I_{IN} \leq V_{IN}/400\ \Omega$). For input overloads beyond the supplies, clamping the inputs to the supplies (using a low leakage diode such as an FD333) will reduce the required resistance, yielding lower noise.

RF INTERFERENCE

All instrumentation amplifiers rectify small out of band signals. The disturbance may appear as a small dc voltage offset. High frequency signals can be filtered with a low pass R-C network placed at the input of the instrumentation amplifier. Figure 43 demonstrates such a configuration. The filter limits the input signal according to the following relationship:

$$FilterFreq_{DIFF} = \frac{1}{2\pi R(2C_D + C_C)}$$

$$FilterFreq_{CM} = \frac{1}{2\pi RC_C}$$

where $C_D \geq 10C_C$

C_D affects the difference signal. C_C affects the common-mode signal. Any mismatch in $R \times C_C$ will degrade the AD620's CMRR. To avoid inadvertently reducing CMRR-bandwidth performance, make sure that C_C is at least one magnitude smaller than C_D. The effect of mismatched C_{C}s is reduced with a larger C_D:C_C ratio.

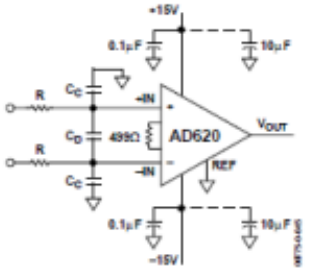


Figure 43. Circuit to Attenuate RF Interference

COMMON-MODE REJECTION

Instrumentation amplifiers, such as the AD620, offer high CMR, which is a measure of the change in output voltage when both inputs are changed by equal amounts. These specifications are usually given for a full-range input voltage change and a specified source imbalance.

For optimal CMR, the reference terminal should be tied to a low impedance point, and differences in capacitance and resistance should be kept to a minimum between the two inputs. In many applications, shielded cables are used to minimize noise; for best CMR over frequency, the shield should be properly driven. Figure 44 and Figure 45 show active data guards that are configured to improve ac common-mode rejections by "bootstrapping" the capacitances of input cable shields, thus minimizing the capacitance mismatch between the inputs.

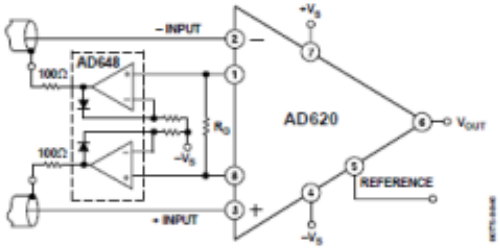


Figure 44. Differential Shield Driver

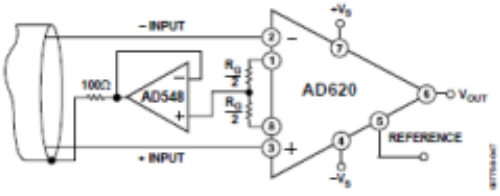


Figure 45. Common-Mode Shield Driver

GROUNDING

Since the AD620 output voltage is developed with respect to the potential on the reference terminal, it can solve many grounding problems by simply tying the REF pin to the appropriate "local ground."

To isolate low level analog signals from a noisy digital environment, many data-acquisition components have separate analog and digital ground pins (Figure 46). It would be convenient to use a single ground line; however, current through ground wires and PC runs of the circuit card can cause hundreds of millivolts of error. Therefore, separate ground returns should be provided to minimize the current flow from the sensitive points to the system ground. These ground returns must be tied together at some point, usually best at the ADC package shown in Figure 46.

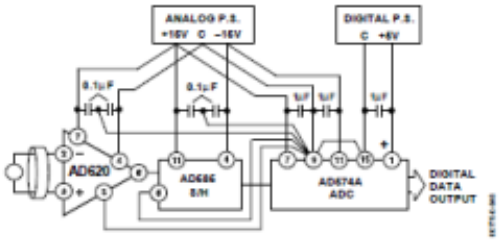


Figure 46. Basic Grounding Practice

GROUND RETURNS FOR INPUT BIAS CURRENTS

Input bias currents are those currents necessary to bias the input transistors of an amplifier. There must be a direct return path for these currents. Therefore, when amplifying "floating" input sources, such as transformers or ac-coupled sources, there must be a dc path from each input to ground, as shown in Figure 47, Figure 48, and Figure 49. Refer to *A Designer's Guide to Instrumentation Amplifiers* (free from Analog Devices) for more information regarding in-amp applications.

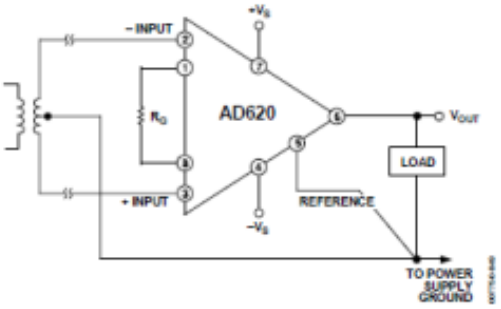


Figure 47. Ground Returns for Bias Currents with Transformer-Coupled Inputs

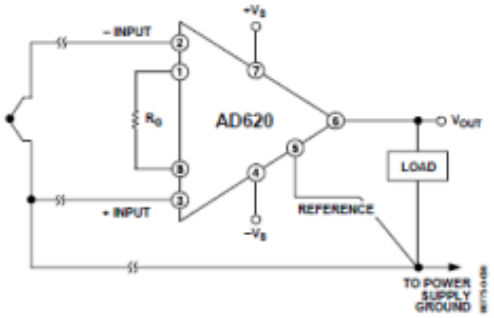


Figure 48. Ground Returns for Bias Currents with Thermocouple Inputs

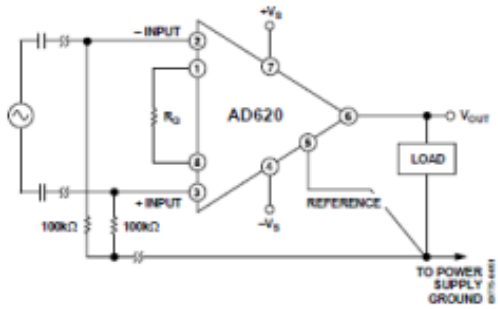
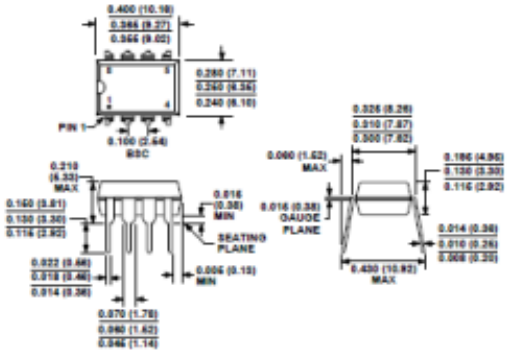


Figure 49. Ground Returns for Bias Currents with AC-Coupled Inputs

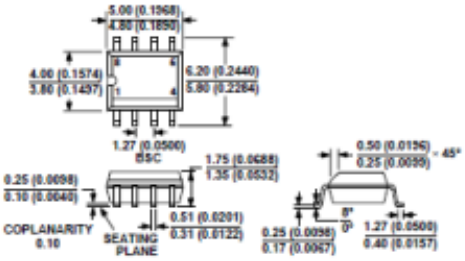
OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MS-001-BA
CONTROLLING DIMENSIONS ARE IN INCHES; MILLIMETER DIMENSIONS (IN PARENTHESES) ARE ROUNDED-OFF INCH EQUIVALENTS FOR REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN. CORNER LEADS MAY BE CONFIGURED AS WHOLE OR HALF LEADS.

Figure 50. 8-Lead Plastic Dual In-Line Package [PDIP]

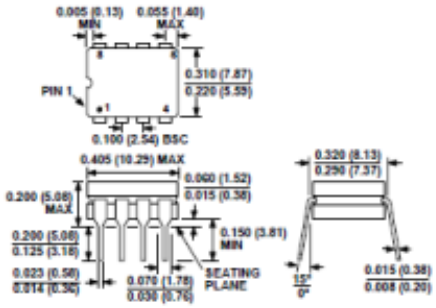
Narrow Body (N-8).
Dimensions shown in inches and (millimeters)



COMPLIANT TO JEDEC STANDARDS MS-012AA
CONTROLLING DIMENSIONS ARE IN MILLIMETERS; INCH DIMENSIONS (IN PARENTHESES) ARE ROUNDED-OFF MILLIMETER EQUIVALENTS FOR REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN

Figure 52. 8-Lead Standard Small Outline Package [SOIC]

Narrow Body (R-8)
Dimensions shown in millimeters and (inches)



CONTROLLING DIMENSIONS ARE IN INCHES; MILLIMETER DIMENSIONS (IN PARENTHESES) ARE ROUNDED-OFF INCH EQUIVALENTS FOR REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN

Figure 51. 8-Lead Ceramic Dual In-Line Package [CERDIP] (Q-8)
Dimensions shown in inches and (millimeters)

ORDERING GUIDE

Model	Temperature Range	Package Option[1]
AD620AN	−40°C to +85°C	N-8
AD620ANZ[2]	−40°C to +85°C	N-8
AD620BN	−40°C to +85°C	N-8
AD620BNZ[2]	−40°C to +85°C	N-8
AD620AR	−40°C to +85°C	R-8
AD620ARZ[2]	−40°C to +85°C	R-8
AD620AR-REEL	−40°C to +85°C	13" REEL
AD620ARZ-REEL[2]	−40°C to +85°C	13" REEL
AD620AR-REEL7	−40°C to +85°C	7" REEL
AD620ARZ-REEL7[2]	−40°C to +85°C	7" REEL
AD620BR	−40°C to +85°C	R-8
AD620BRZ[2]	−40°C to +85°C	R-8
AD620BR-REEL	−40°C to +85°C	13" REEL
AD620BRZ-RL[2]	−40°C to +85°C	13" REEL
AD620BR-REEL7	−40°C to +85°C	7" REEL
AD620BRZ-R7[2]	−40°C to +85°C	7" REEL
AD620ACHIPS	−40°C to +85°C	Die Form
AD620SQ/883B	−55°C to +125°C	Q-8

[1] N = Plastic DIP; Q = CERDIP; R = SOIC.
[2] Z = Pb-free part.

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C00775–0–12/04(G)

Q.2 Data Sheet for LM324

FAIRCHILD SEMICONDUCTOR®

www.fairchildsemi.com

LM2902,LM324/LM324A,LM224/ LM224A

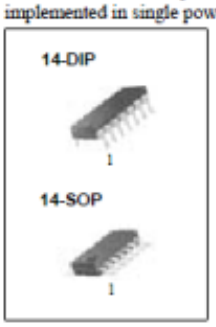
Quad Operational Amplifier

Features

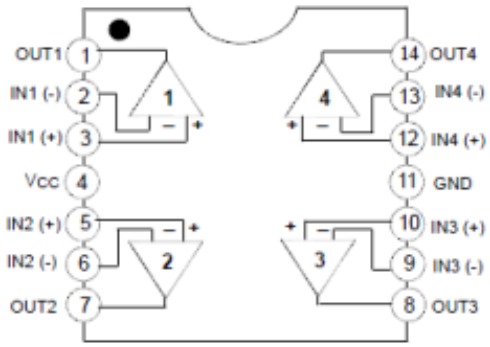
- Internally Frequency Compensated for Unity Gain
- Large DC Voltage Gain: 100dB
- Wide Power Supply Range:
  LM224/LM224A, LM324/LM324A : 3V~32V (or ±1.5 ~ 16V)
  LM2902: 3V~26V (or ±1.5V ~ 13V)
- Input Common Mode Voltage Range Includes Ground
- Large Output Voltage Swing: 0V to VCC -1.5V
- Power Drain Suitable for Battery Operation

Description

The LM324/LM324A,LM2902,LM224/LM224A consist of four independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide voltage range. operation from split power supplies is also possible so long as the difference between the two supplies is 3 volts to 32 volts. Application areas include transducer amplifier, DC gain blocks and all the conventional OP Amp circuits which now can be easily implemented in single power supply systems.



Internal Block Diagram



Rev. 1.0.4

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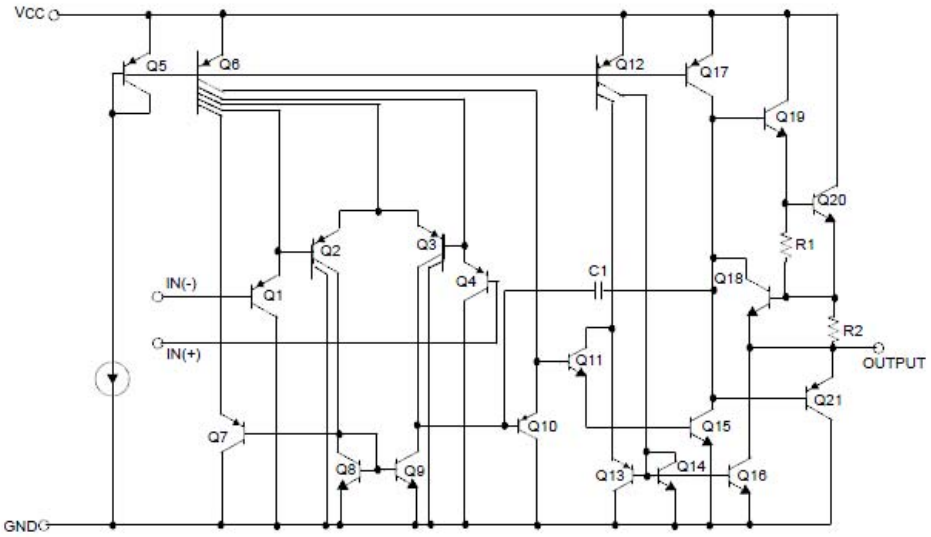
Schematic Diagram

(One Section Only)



Absolute Maximum Ratings

Parameter	Symbol	LM224/LM224A	LM324/LM324A	LM2902	Unit
Power Supply Voltage	V_{CC}	±16 or 32	±16 or 32	±13 or 26	V
Differential Input Voltage	$V_{I(DIFF)}$	32	32	26	V
Input Voltage	V_I	-0.3 to +32	-0.3 to +32	-0.3 to +26	V
Output Short Circuit to GND Vcc≤15V, T_A=25°C(one Amp)	-	Continuous	Continuous	Continuous	-
Power Dissipation, T_A=25°C 14-DIP 14-SOP	P_D	 1310 640	 1310 640	 1310 640	mW
Operating Temperature Range	T_{OPR}	-25 ~ +85	0 ~ +70	-40 ~ +85	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	-65 ~ +150	-65 ~ +150	°C

Thermal Data

Parameter	Symbol	Value	Unit
Thermal Resistance Junction-Ambient Max. 14-DIP 14-SOP	Rθja	 95 195	°C/W

Electrical Characteristics

(V_{CC} = 5.0V, V_{EE} = GND, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Conditions	LM224			LM324			LM2902			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω (Note1)	-	1.5	5.0	-	1.5	7.0	-	1.5	7.0	mV
Input Offset Current	I_{IO}	V_{CM} = 0V	-	2.0	30	-	3.0	50	-	3.0	50	nA
Input Bias Current	I_{BIAS}	V_{CM} = 0V	-	40	150	-	40	250	-	40	250	nA
Input Common-Mode Voltage Range	$V_{I(R)}$	Note1	0	-	V_{CC} -1.5	0	V_{CC} -1.5	-	0	-	V_{CC} -1.5	V
Supply Current	I_{CC}	R_L = ∞,V_{CC} = 30V (LM2902,V_{CC}=26V)	-	1.0	3	-	1.0	3	-	1.0	3	mA
		R_L = ∞,V_{CC} = 5V	-	0.7	1.2	-	0.7	1.2	-	0.7	1.2	mA
Large Signal Voltage Gain	G_V	V_{CC} = 15V,R_L=2kΩ $V_{O(P)}$ = 1V to 11V	50	100	-	25	100	-	25	100	-	V/mV
Output Voltage Swing	$V_{O(H)}$	Note1, R_L = 2kΩ	26	-	-	26	-	-	22	-	-	V
		Note1, R_L=10kΩ	27	28	-	27	28	-	23	24	-	V
	$V_{O(L)}$	V_{CC} = 5V,R_L=10kΩ	-	5	20	-	5	20	-	5	100	mV
Common-Mode Rejection Ratio	CMRR	-	70	85	-	65	75	-	50	75	-	dB
Power Supply Rejection Ratio	PSRR	-	65	100	-	65	100	-	50	100	-	dB
Channel Separation	CS	f = 1kHz to 20kHz (Note2)	-	120	-	-	120	-	-	120	-	dB
Short Circuit to GND	I_{SC}	V_{CC} = 15V	-	40	60	-	40	60	-	40	60	mA
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V $V_{O(P)}$ = 2V	20	40	-	20	40	-	20	40	-	mA
	I_{SINK}	$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V V_{CC} = 15V $V_{O(P)}$ = 2V	10	13	-	10	13	-	10	13	-	mA
		$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V V_{CC} = 5V,$V_{O(R)}$ = 200mV	12	45	-	12	45	-	-	-	-	µA
Differential Input Voltage	$V_{I(DIFF)}$	-	-	-	V_{CC}	-	-	V_{CC}	-	-	V_{CC}	V

Note :

1. V_{CC}=30V for LM224 and LM324 , V_{CC} = 26V for LM2902
2. This parameter, although guaranteed, is not 100% tested in production.

Electrical Characteristics (Continued)

(V_{CC} = 5.0V, V_{EE} = GND, unless otherwise specified)
The following specification apply over the range of -25°C ≤ T_A ≤ + 85°C for the LM224; and the 0°C ≤ T_A ≤ +70°C for the LM324 ; and the -40°C ≤ T_A ≤ +85°C for the LM2902

Parameter	Symbol	Conditions	LM224			LM324			LM2902			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{ICM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω (Note1)	-	-	7.0	-	-	9.0	-	-	10.0	mV
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	R_S = 0Ω (Note2)	-	7.0	-	-	7.0	-	-	7.0	-	µV/°C
Input Offset Current	I_{IO}	V_{CM} = 0V	-	-	100	-	-	150	-	-	200	nA
Input Offset Current Drift	$\Delta I_{IO}/\Delta T$	R_S = 0Ω (Note2)	-	10	-	-	10	-	-	10	-	pA/°C
Input Bias Current	I_{BIAS}	V_{CM} = 0V	-	-	300	-	-	500	-	-	500	nA
Input Common-Mode Voltage Range	$V_{I(R)}$	Note1	0	-	V_{CC} -2.0	0	-	V_{CC} -2.0	0	-	V_{CC} -2.0	V
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L = 2.0kΩ $V_{O(P)}$ = 1V to 11V	25	-	-	15	-	-	15	-	-	V/mV
Output Voltage Swing	$V_{O(H)}$	Note1, R_L=2kΩ	26	-	-	26	-	-	22	-	-	V
		Note1, R_L=10kΩ	27	28	-	27	28	-	23	24	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L=10kΩ	-	5	20	-	5	20	-	5	100	mV
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, VO(P) = 2V	10	20	-	10	20	-	10	20	-	mA
	I_{SINK}	$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V V_{CC} = 15V, $V_{O(P)}$ = 2V	10	13	-	5	8	-	5	8	-	mA
Differential Input Voltage	$V_{I(DIFF)}$	-	-	-	V_{CC}	-	-	V_{CC}	-	-	V_{CC}	V

Note:
1. V_{CC}=30V for LM224 and LM324 , V_{CC} = 26V for LM2902
2. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (Continued)

(V_{CC} = 5.0V, V_{EE} = GND, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Conditions	LM224A			LM324A			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω (Note1)	-	1.0	3.0	-	1.5	3.0	mV
Input Offset Current	I_{IO}	V_{CM} = 0V	-	2	15	-	3.0	30	nA
Input Bias Current	I_{BIAS}	V_{CM} = 0V	-	40	80	-	40	100	nA
Input Common-Mode Voltage Range	$V_{I(R)}$	V_{CC} = 30V	0	-	V_{CC} -1.5	0	-	V_{CC} -1.5	V
Supply Current	I_{CC}	V_{CC} = 30V, R_L = ∞	-	1.5	3	-	1.5	3	mA
		V_{CC} = 5V, R_L = ∞	-	0.7	1.2	-	0.7	1.2	mA
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L= 2kΩ $V_{O(P)}$ = 1V to 11V	50	100	-	25	100	-	V/mV
Output Voltage Swing	$V_{O(H)}$	Note1, R_L = 2kΩ	26	-	-	26	-	-	V
		Note1, R_L = 10kΩ	27	28	-	27	28	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L=10kΩ	-	5	20	-	5	20	mV
Common-Mode Rejection Ratio	CMRR	-	70	85	-	65	85	-	dB
Power Supply Rejection Ratio	PSRR	-	65	100	-	65	100	-	dB
Channel Separation	CS	f = 1kHz to 20kHz (Note2)	-	120	-	-	120	-	dB
Short Circuit to GND	I_{SC}	V_{CC} = 15V	-	40	60	-	40	60	mA
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} =15V, $V_{O(P)}$ = 2V	20	40	-	20	40	-	mA
	I_{SINK}	$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V V_{CC} = 15V, $V_{O(P)}$ = 2V	10	20	-	10	20	-	mA
		$V_{I(+)}$ = 0v, $V_{I(-)}$ = 1V V_{CC} = 5V $V_{O(P)}$ = 200mV	12	50	-	12	50	-	µA
Differential Input Voltage	$V_{I(DIFF)}$	-	-	-	V_{CC}	-	-	V_{CC}	V

Note:

1. V_{CC}=30V for LM224A, LM324A
2. This parameter, although guaranteed, is not 100% tested in production.

Electrical Characteristics (Continued)

(V_{CC} = 5.0V, V_{EE} = GND, unless otherwise specified)
The following specification apply over the range of -25°C ≤ T_A ≤ +85°C for the LM224A; and the 0°C ≤ T_A ≤ +70°C for the LM324A

Parameter	Symbol	Conditions	LM224A			LM324A			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	
Input Offset Voltage	V_{IO}	V_{CM} = 0V to V_{CC} -1.5V $V_{O(P)}$ = 1.4V, R_S = 0Ω (Note1)	-	-	4.0	-	-	5.0	mV
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	R_S = 0Ω (Note2)	-	7.0	20	-	7.0	30	µV/°C
Input Offset Current	I_{IO}	V_{CM} = 0V	-	-	30	-	-	75	nA
Input Offset Current Drift	$\Delta I_{IO}/\Delta T$	R_S = 0Ω (Note2)	-	10	200	-	10	300	pA/°C
Input Bias Current	I_{BIAS}	-	-	40	100	-	40	200	nA
Input Common-Mode Voltage Range	$V_{I(R)}$	Note1	0	-	V_{CC} -2.0	0	-	V_{CC} -2.0	V
Large Signal Voltage Gain	G_V	V_{CC} = 15V, R_L= 2.0kΩ	25	-	-	15	-	-	V/mV
Output Voltage Swing	$V_{O(H)}$	Note1, R_L = 2kΩ	26	-	-	26	-	-	V
		Note1, R_L = 10kΩ	27	28	-	27	28	-	V
	$V_{O(L)}$	V_{CC} = 5V, R_L= 10kΩ	-	5	20	-	5	20	mV
Output Current	I_{SOURCE}	$V_{I(+)}$ = 1V, $V_{I(-)}$ = 0V V_{CC} = 15V, $V_{O(P)}$ = 2V	10	20	-	10	20	-	mA
	I_{SINK}	$V_{I(+)}$ = 0V, $V_{I(-)}$ = 1V V_{CC} = 15V, $V_{O(P)}$ = 2V	5	8	-	5	8	-	mA
Differential Input Voltage	$V_{I(DIFF)}$	-	-	-	V_{CC}	-	-	V_{CC}	V

Note:
1. V_{CC}=30V for LM224A and LM324A.
2. These parameters, although guaranteed, are not 100% tested in production.

Typical Performance Characteristics

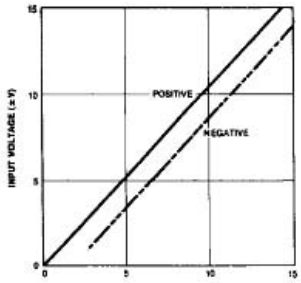


Figure 1. Input Voltage Range vs Supply Voltage

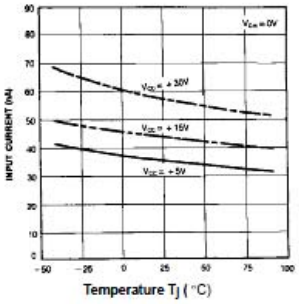


Figure 2. Input Current vs Temperature

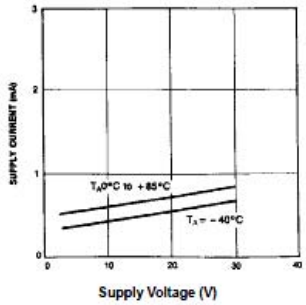


Figure 3. Supply Current vs Supply Voltage

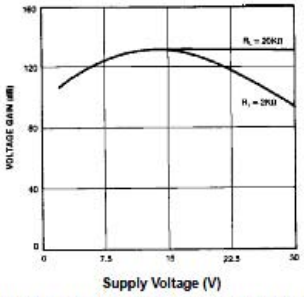


Figure 4. Voltage Gain vs Supply Voltage

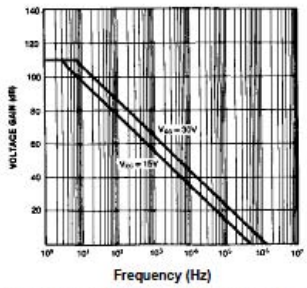


Figure 5. Open Loop Frequency Response

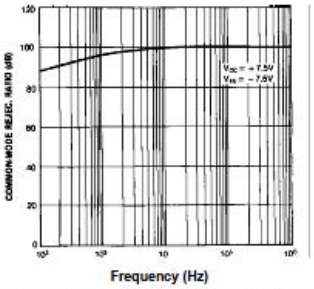


Figure 6. Common mode Rejection Ratio

Typical Performance Characteristics (Continued)

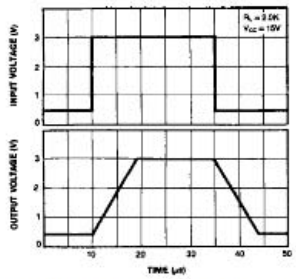


Figure 7. Voltage Follower Pulse Response

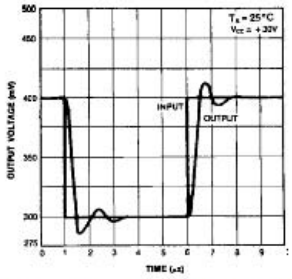


Figure 8. Voltage Follower Pulse Response (Small Signal)

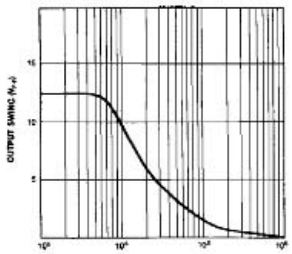


Figure 8. Large Signal Frequency Response

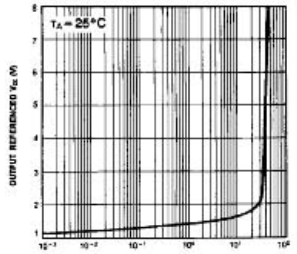


Figure 9. Output Characteristics vs Current Sourcing

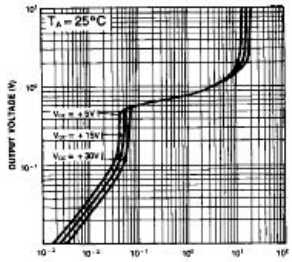


Figure 10. Output Characteristics vs Current Sinking

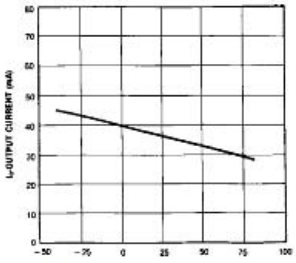


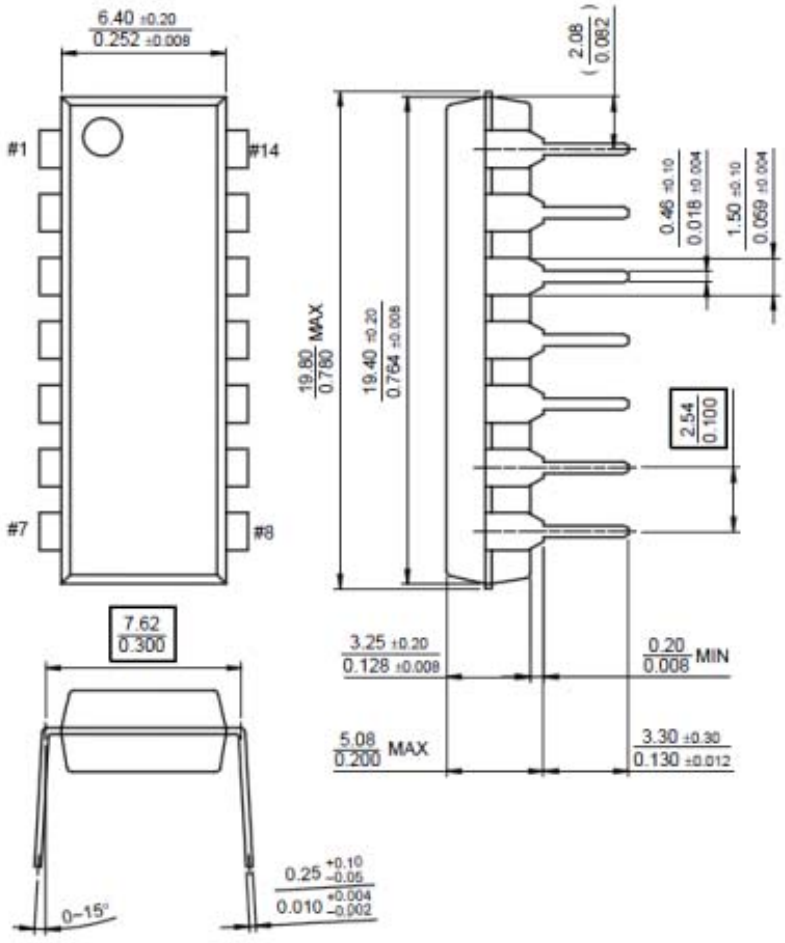
Figure 11. Current Limiting vs Temperature

Mechanical Dimensions

Package

Dimensions in millimeters

14-DIP

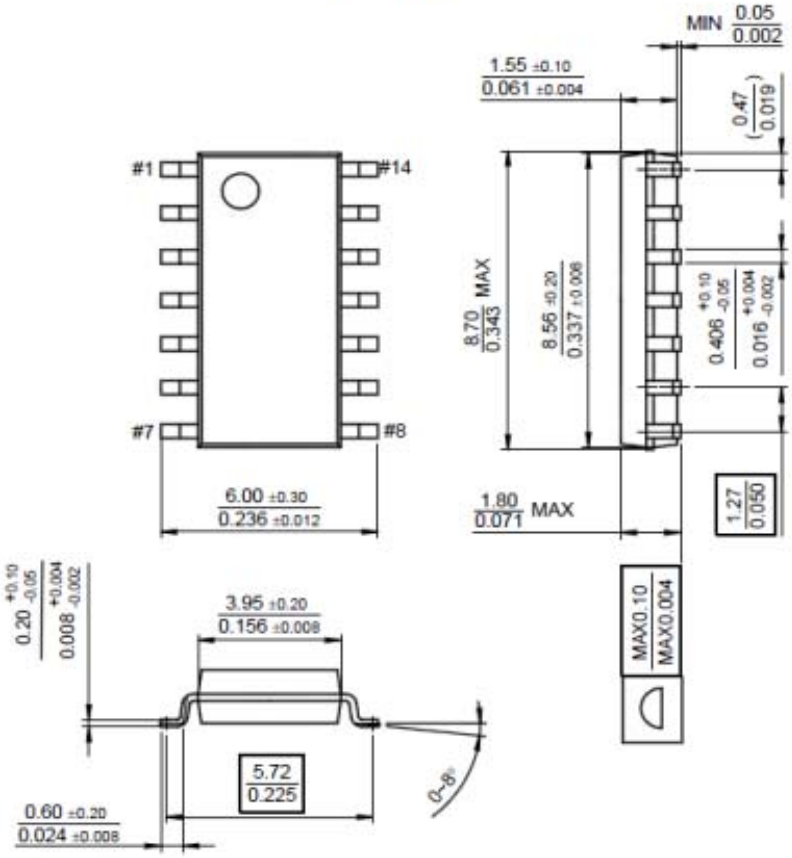


Mechanical Dimensions (Continued)

Package

Dimensions in millimeters

14-SOP



Ordering Information

Product Number	Package	Operating Temperature
LM324N	14-DIP	0 ~ +70°C
LM324AN		
LM324M	14-SOP	
LM324AM		
LM2902N	14-DIP	-40 ~ +85°C
LM2902M	14-SOP	
LM224N	14-DIP	-25 ~ +85°C
LM224AN		
LM224M	14-SOP	
LM224AM		

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2. A critical component in any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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R. Gantt Chart

Task Name	Duration	Start	Finish	Resource Names
DESIGN REVIEW TWO	0 days?	Mon 2/15/10	Mon 2/15/10	
Individual Brainstorm	2 days?	Tue 2/2/10	Wed 2/3/10	Team
Team Brainstorm	1 day?	Thu 2/4/10	Thu 2/4/10	Team
Pugh Charts	1 day?	Tue 2/9/10	Tue 2/9/10	Team
Alpha Design Selected	0 days?	Tue 2/9/10	Tue 2/9/10	Team
Pinch Device Material Selection	3 days?	Tue 2/9/10	Thu 2/11/10	Nicole
Grasp Device Material Selection	3 days?	Tue 2/9/10	Thu 2/11/10	Nicole
Update Safety Report	1 day?	Mon 2/1/10	Mon 2/1/10	Mike
Program Flow Chart	3 days?	Tue 2/9/10	Thu 2/11/10	Bailey
Paper: Individual Rough Drafts	2 days?	Mon 2/15/10	Tue 2/16/10	Team
Paper: Split Up Individual Parts	1 day?	Fri 2/12/10	Fri 2/12/10	Team
Paper: Team Rough Draft	1 day?	Tue 2/16/10	Tue 2/16/10	Team
Paper: Team Editing	1 day?	Wed 2/17/10	Wed 2/17/10	Team
Paper: Individual Editing	1 day?	Wed 2/17/10	Wed 2/17/10	Team
Paper: Completion	1 day?	Thu 2/18/10	Thu 2/18/10	Team
Presentation: Split Up Individual Parts	1 day?	Fri 2/12/10	Fri 2/12/10	Team
Presentation: Individual Rough Drafts	2 days?	Mon 2/15/10	Tue 2/16/10	Team
Presentation: Team Rough Draft	1 day?	Tue 2/16/10	Tue 2/16/10	Team
Presentation: Team Editing	1 day?	Wed 2/17/10	Wed 2/17/10	Team
Presentation: Reserve Room	1 day?	Mon 2/15/10	Mon 2/15/10	Team
Presentation: Practice Presentation	1 day?	Wed 2/17/10	Wed 2/17/10	Team
Presentation: Completion	1 day?	Thu 2/18/10	Thu 2/18/10	Team
DAQ Selection	3 days?	Tue 2/9/10	Thu 2/11/10	Tim
Function Deployment Diagram	3 days?	Tue 2/9/10	Thu 2/11/10	Mike
Measurement Device Selection	1 day?	Tue 2/9/10	Tue 2/9/10	Team
Research Measurement Devices	3 days?	Tue 2/9/10	Thu 2/11/10	Tim
Paper: Outline	1 day?	Mon 2/15/10	Mon 2/15/10	
Presentation: Outline	1 day?	Mon 2/15/10	Mon 2/15/10	
DESIGN REVIEW THREE	26 days?	Wed 2/17/10	Mon 3/22/10	Team
Create Paper and Presentation Outline	1 day?	Fri 2/26/10	Fri 2/26/10	
Split Up Paper and Presentation Topics	1 day?	Fri 2/26/10	Fri 2/26/10	Team
Brainstorm initial LabVIEW ideas	3 days?	Mon 3/8/10	Wed 3/10/10	Bailey/Nicole
Meet with Dr. Bress Regarding LabVIEW	1 day?	Thu 3/11/10	Thu 3/11/10	Bailey/Nicole
Initial work with LabVIEW	2 days?	Fri 3/12/10	Sun 3/14/10	Bailey/Nicole
Paper: Rough Draft LabVIEW	1 day?	Sun 3/14/10	Sun 3/14/10	Bailey/Nicole
Paper: Draft 2 LabVIEW	1 day?	Tue 3/16/10	Tue 3/16/10	Bailey/Nicole
Parameter Research	3 days?	Mon 3/8/10	Wed 3/10/10	Tim/Mike
Sensor Research	3 days?	Tue 3/9/10	Thu 3/11/10	Tim/Mike
Create Mathematical Model	3 days?	Wed 3/10/10	Fri 3/12/10	Tim/Mike
Material Selector	2 days?	Thu 3/11/10	Sat 3/13/10	Tim/Mike
Create Manufacturing & Assembly Plans	2 days?	Fri 3/12/10	Sun 3/14/10	Tim/Mike
Paper: Rough Draft Device Section	1 day?	Sun 3/14/10	Sun 3/14/10	Tim/Mike
Paper: Draft 2 Device Section	1 day?	Mon 2/1/10	Mon 2/1/10	Tim/Mike
Paper: Compile Paper	1 day?	Tue 3/16/10	Tue 3/16/10	Team
Paper: Editing	2 days?	Tue 3/16/10	Wed 3/17/10	Team
Paper: Final Draft Editing	3 days?	Thu 3/18/10	Sun 3/21/10	Team
Paper: Final Draft Due	1 day?	Mon 3/22/10	Mon 3/22/10	Team
Presentation: Compile	1 day?	Mon 3/15/10	Mon 3/15/10	Team
Presentation: Editing	3 days?	Mon 3/15/10	Wed 3/17/10	Team
Presentation: Practice	2 days?	Wed 3/17/10	Thu 3/18/10	Team
Presentation: Give Presentation	1 day?	Thu 3/18/10	Thu 3/18/10	Team

S. Assignment One: Material Selection Assignment (Functional Performance)

Component One: Grasping Device Housing

Function: The main function of the grasping device housing is to provide an object that the patient can apply a force through a squeezing motion. This object needs to be of appropriate size to allow all patients to wrap their hands around and the appropriate material so that it can be squeezed and elastically deform.
Objective: The objective of the grasping device housing is to elastically deform, due to an applied force. The elastic deformation will cause a change in volume of the grasping device housing, which will cause a change in pressure within the device. The change in pressure reading will be measured by a pressure sensor within the grasping device housing and will provide this information to the computer program.
Constraints: As mentioned above, two major constraints to the grasping device housing is the size and ability to elastically deform. Whatever material is chosen it needs to be able to be manufactured to a size that will fit within a normal sized hand. In addition, it must have material properties that allow for elastic deformation during applied forces up to the maximum force a human hand can exert. Not only does the material need to elastically deform due to the applied pressure, but it also needs to withstand breaking due to yielding caused by the increase pressure in the device. Another major constraint is price. This device needs to be made as inexpensive as possible. Eventually the sponsor's of this project would like to make many of these devices to send home with their patients. If the device is very expensive, this won't be an option. Finally, a requirement expressed by the sponsor's would be that the device resembles a common object. The common object chosen was a water bottle.
Appropriate Material Indices: The appropriate material indices are expressed in the table shown below.

Material Property	Value	
	Minimum	***Maximum***
Young's Modulus (E)	2.8e9 Pa	
Yield Strength (s_Y)	55 Pa	1e8 Pa
Density (ρ)		1500 kg/m^3

Table 5: Material Properties of Grasping Device Housing

These material properties were chosen because they quantified the constraints explained above. The Young's Modulus is a measure of the stiffness of the material. This quantified the ability of the device to be squeezed to create a change in volume within the device. The value of 2.8e9 was chosen because this is the average value of plastic water bottles commercially available. The yield strength was also chosen because it quantified the strength of the material. The material needs to not plastically deform during the applied force. The value chosen was between 55 Pa and 1e8 Pa. These values were determined by doing a force analysis and determining the minimum and maximum tensile forces that could result in the material. The yield strength was chosen over the tensile strength because the yield strength determines where the material will yield and the tensile strength where the material will break. Both values are important, but yielding will occur before breaking. The final property chosen was density. The value chosen was 1500 kg/m^3 because this is the average value of the density of commercially available water bottles.
Top Five Material Choices: Using CES, the top five material choices were (1) Polyvinylchloride (tpPVS), (2) Polyethylene terephthalate (PET), (3) Phenolics, (4) Acrylonitrile butadiene styrene (ABS), and (5) Polymethyl methacrylate (Acrylic, PMMA).
Explanation of Final Choice: The final choice of material for the grasping device housing was Polymethyl methacrylate (Acrylic, PMMA). This material was chosen because after research it was discovered that commericially available water bottles are made from this material. Choosing this material allows us to purchase a water bottle and alter it as opposed to creating the device housing from scratch. In addition, because this material is what commercially available water bottles are made of, it is very easy and inexpensive to purchase.

Component Two: Pinching Device Housing

Function: The main function of the pinching device housing is to provide an object that the patient can apply a force through a pinching motion. This object needs to be of the appropriate size to allow all

patients to grasp between the thumb and another finger and the appropriate material so as not to yield or break.

Objective: The object of the pinching device housing is to provide a rigid surface to apply force to. When the patient provides force to the button panel, part of the pinching device housing, the button panel will move through a small displacement and transfer the force applied to a load sensor. The load season will then provide this information to the computer program.

Constraints: As mentioned above, two major constraints to the pinching device housing is the size and inability to yield, plastically or elastically, due to an applied force. Whatever material is chosen needs to be able to be manufactured to a size that would be appropriate for the pinching motion. In addition, it must have material properties that do not allow for yielding under the maximum force a human hand can exert. Another major constraint is the price. This device needs to be made as inexpensive as possible. As explained in the grasping device housing section, the sponsor's would eventually like to make many of these devices and this won't be possible if they are expensive. Finally, as with the grasping device housing, the sponsor's require that this device resembles a common object. The common object chosen was a garage door opener remote.

Appropriate Material Indices: The appropriate material indices are expressed in the table shown below.

Material Property	**Value**	
	Minimum	***Maximum***
Yield Strength (s_Y)	1.1e8 Pa	
Tensile Strength (s_T)	6.2e7 Pa	
Compressive Strength (s_C)	9.0e7 Pa	
Density (ρ)	80 kg/m^3	8000 kg/m^3

Table 6: Material Properties of Pinching Device Housing

These material properties were chosen because they quantified the constraints explained above. The yield strength was chosen because it quantified the ability of the material to resist yielding. The tensile and compressive strength was chosen to quantify the ability to resist breaking due to the applied force. The values chosen were 1.1e8 Pa for yield strength, 6.2e7 Pa for tensile strength, and 9.0e7 Pa for compressive strength. These values were determined from a force analysis. Finally, the density was used ensure the material chosen was similar to commercially available garage door openers. This value was determined to be 80 – 8000 8000 kg/m^3 after research.

Top Five Material Choices: Using CES, the top five material choices were (1) cast iron, gray, (2) low alloy steel, (3) cast magnesium alloys, (4) silicon carbide, and (5) GFRP, epoxy matrix (isotropic).

Explanation of Final Choice: The final choice of material for the pinching device housing was GFRP, epoxy matrix. This material was selected due to its availability and price. A local hardware store provided this material at a discounted price. This material was also chosen because it was much more lightweight, but still durable, as compared to some of the alloy options.

T. Assignment Two: Material Selection Assignment (Environmental Performance)

Environmental Performance

To evaluate the environmental impact of the potential materials, SimaPro software was used. Two of the potential materials for each device were compared using SimaPro's EcoIndicator 99 (EI 99) test. The results are split into two sections, one for the grasping device and one for the pinching device.

Grasping Device Environmental Performance Results

From the Material Selection Section, the two potential materials for the grasping device were PMMA sheet E and PET (bottle grade) E. The required material mass for the completion of the final grasping design was estimated to be approximately 100 grams. An EcoIndicator 99 test was performed to compare the environmental impact of the two materials using SimaPro software and the estimated masses. The total mass of air emissions, water emissions, use of raw materials, and (solid) waster were determined using the EI 99 test. The calculated total mass of the two materials can be seen in Figure 43, below. As seen in the figure, the total mass from the use of raw materials has the greatest mass for both materials with PET having a lower total mass compared to PMMA. This implies that the PET has a lower mass contributing to environmental hazards and is less harmful.

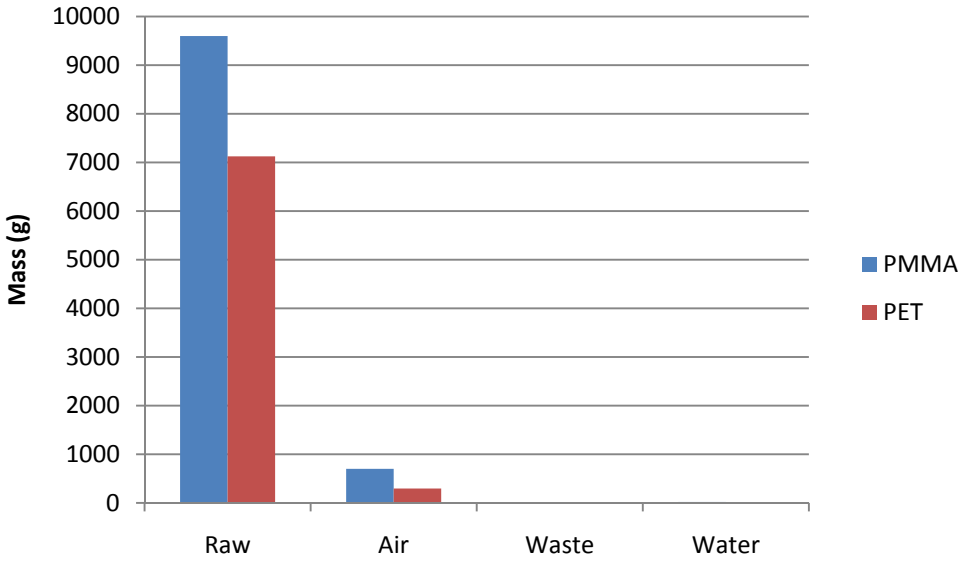

Figure 43: Total Mass of the Raw Materials for Grasping Device

The characterization section of the EI 99 test sorts the two materials according to the different emission categories and their environmental impact. This section uses relative results since not all the compared categories have the same units. The various categories are plotted on a percentage scale where 100 percent is the most hazardous to the environment and zero percent is the least hazardous. The results of the relative contribution of the two materials can be seen in Figure 44, on page 119. The emissions categories that the two materials are compared against can be seen in the figure. The most important emissions categories are the ones that have reached 100 percent because they are the most harmful and they can be seen in the figure. It can be seen in the figure that PMMA has a greater impact on the environment in all of the categories, thus it is more hazardous.

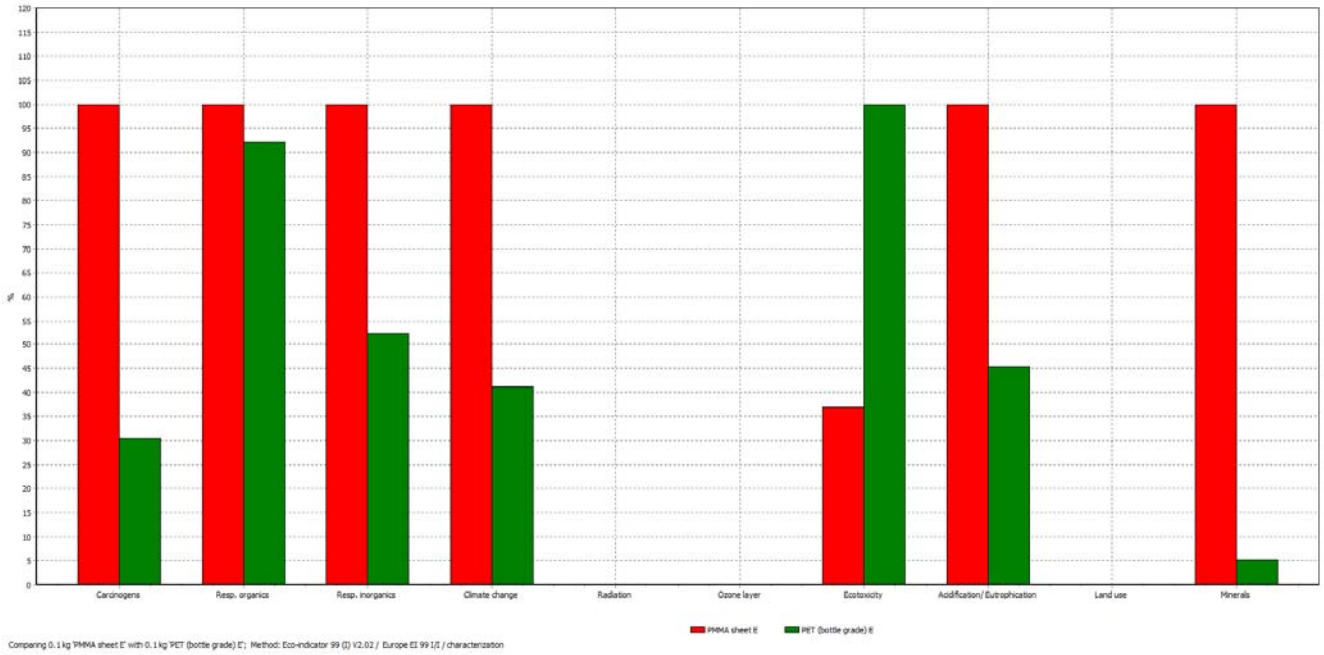

Figure 44: Characterization Results for Grasping Device

The normalization section of the EI 99 test compares the damage assessment results to a fixed benchmark. This provides a ratio which determines the most important environmental impact categories for the compared materials. A large ratio implies the category has a higher environmental impact and a small ratio means a lower environmental impact. The results of the two materials can be seen in Figure 45, below. From the results the most important categories are respiratory inorganics, climate change, and acidification. The PMMA has a higher environmental impact for these categories according to the results.

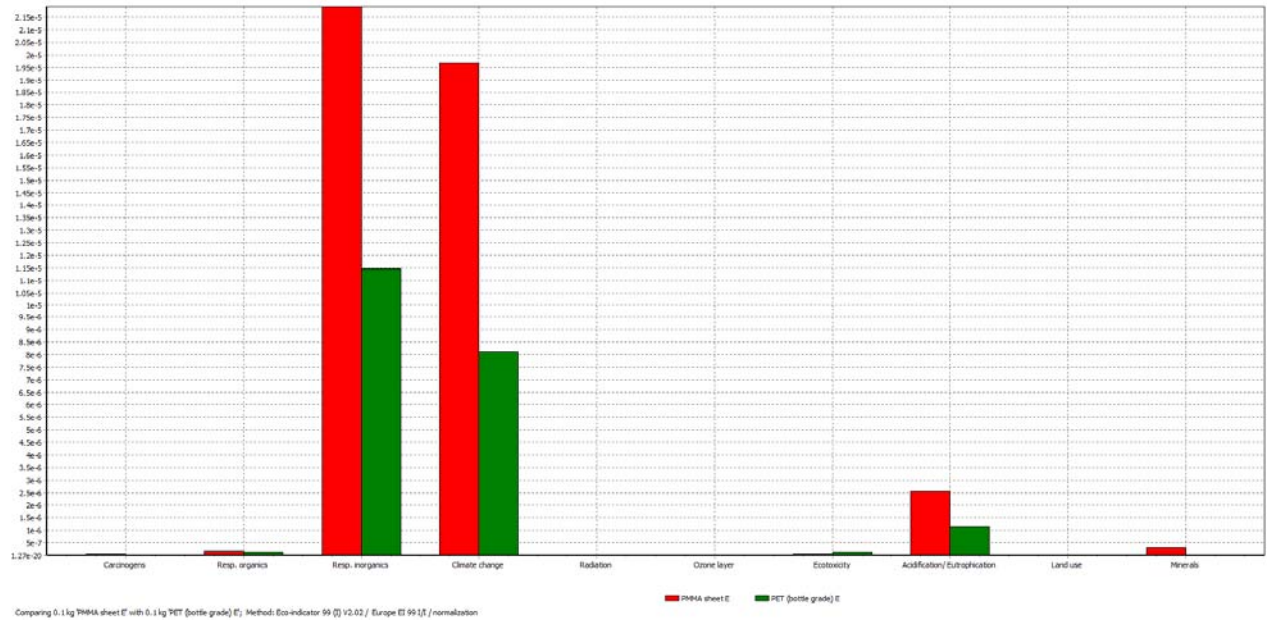

Figure 45: Normalization Results for the Grasping Device

The single score results of the EI 99 test compile the results from all the categories into one total result for each material. The single score results are then compared on a point scale. The results can be seen in

Figure 46, below. The figure shows that PMMA has a higher single score point total which implies it is more environmentally hazardous than PET.

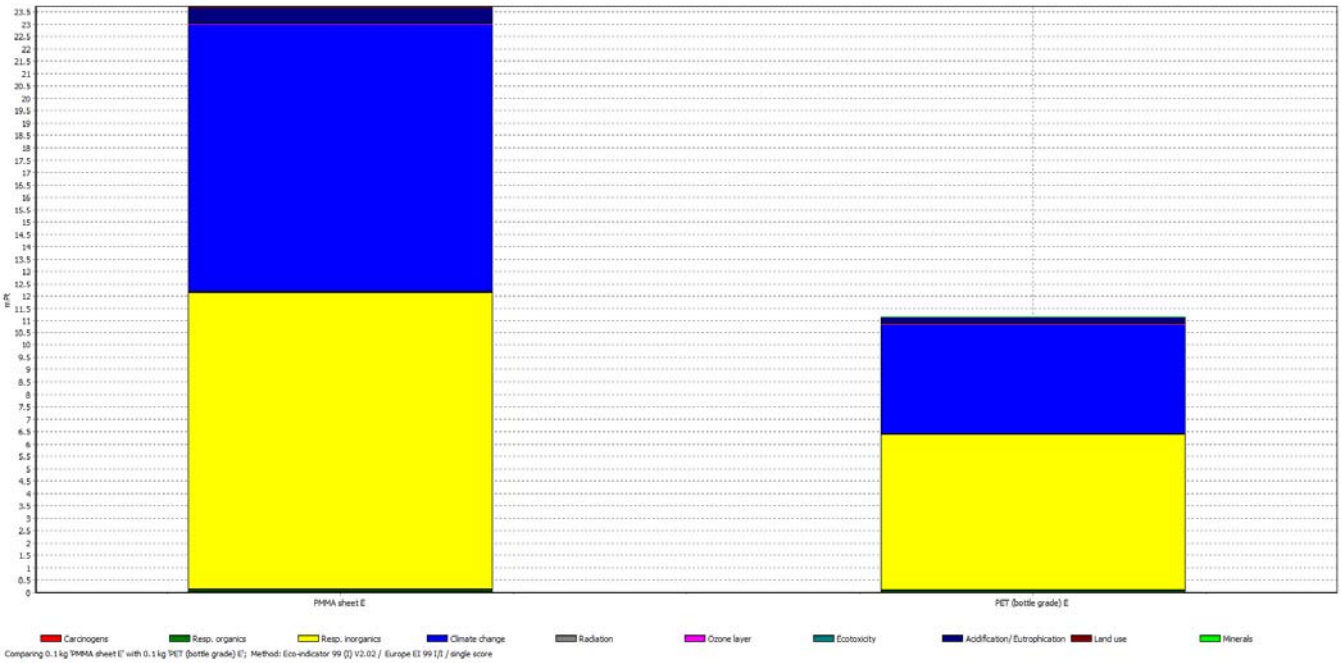

Figure 46: Single Score Results for the Grasping Device

From the complete results of the EI 99 test, the PMMA was determined to be the more environmentally hazardous material. This means that the selected material, PET, has the lower environmental impact for the grasping device. When considering the life cycle of the whole product, the PET would again have a lower environmental impact. The results of the EI 99 test show that the PET has a lower environmental impact in respiratory inorganics and climate change. Considering the life cycle of the grasping device, these categories would be the most important.

Pinching Device Environmental Performance Results

From the Material Selection Section, the two potential materials were Cast Iron GG 15 I and Epoxy Resin I. The required material mass for completion of the final pinching device design was estimated to be approximately 500 grams. An EcoIndicator 99 test was performed to compare the environmental impact of the two materials using SimaPro software and the estimated masses. The total mass of air emissions, water emissions, water emissions, use of raw materials, and (solid) waste of the two materials were calculated using the EI 99 test. The calculated total masses can be seen in Figure 47, on page 121. As seen in the figure, the use of raw materials and air emissions total masses are the most significant and from the results Epoxy Resin was determined to have the larger total mass. The larger mass of the Epoxy Resin means that it is more harmful compared to the GG 15 I.

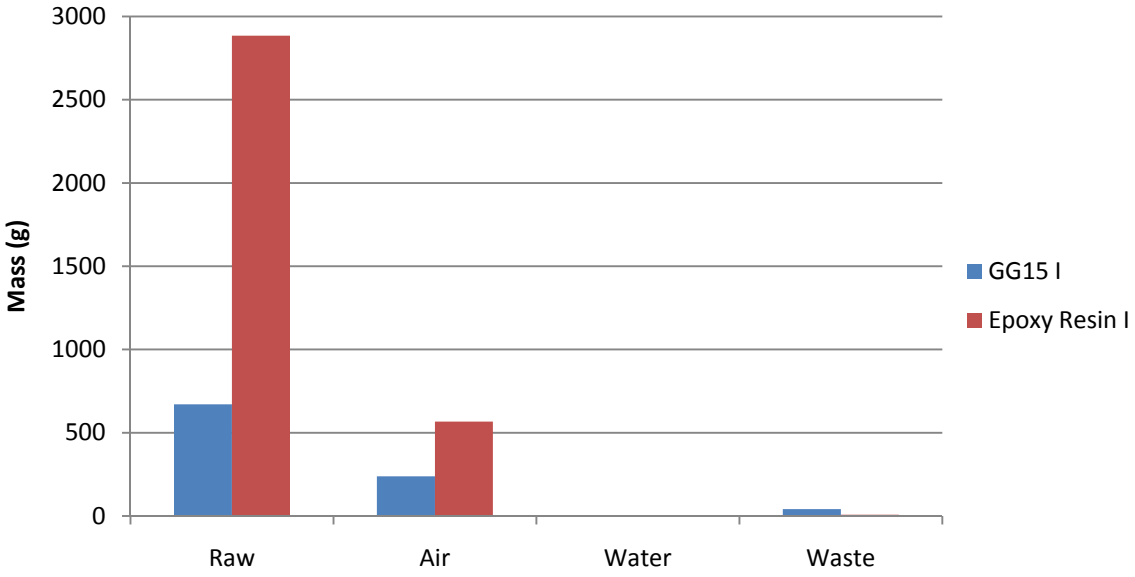

Figure 47: Total mass of the Raw Materials for Pinching Device

The characterization section of the EI 99 test sorts the two materials according to their various emissions categories environmental impact. This section uses relative results because not all the categories have the same units. The various emissions categories are plotted on a percentage scale where 100 percent is the most hazardous to the environment and zero percent is the least hazardous. The results of the two materials relative contribution can be seen in Figure 48, below. The categories which the two materials are compared can also be seen in the figure and the only category not contributing to environmental impact is the radiation category. Although the different categories have one material that is more environmentally hazardous, the results are ambiguous and one material cannot be determined more hazardous.

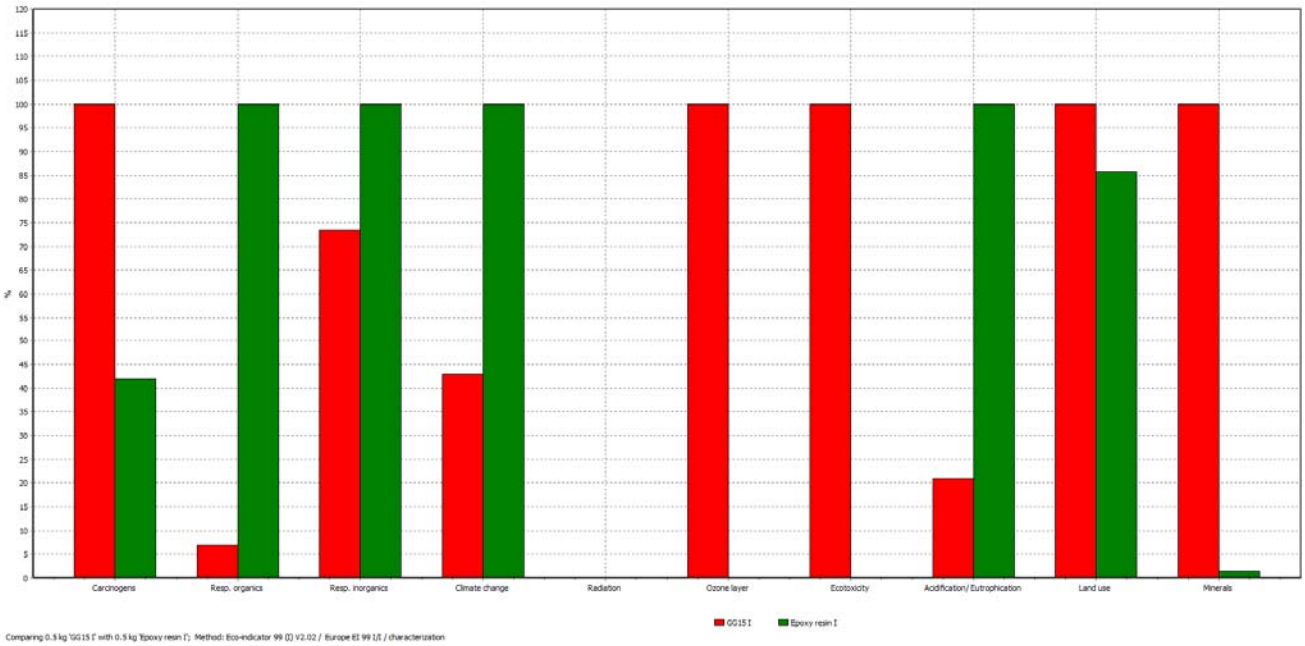

Figure 48: Characterization Results for Pinching Device

The normalization section of the EI 99 test compares the damage assessment results to a fixed benchmark. This provides a ratio to determine which categories have the greatest environmental impact for the compared materials. A larger ratio means the category has a higher environmental impact the results can be seen in Figure 49, below. From the results, the most important categories are minerals, land use, acidification, climate change, and respiratory inorganics. The Cast Iron is significantly more hazardous to the environment when comparing the materials in the minerals category. From this it is determined that Cast Iron has a greater impact on the environment although the Epoxy Resin has a slightly higher impact on the environment in the other categories.

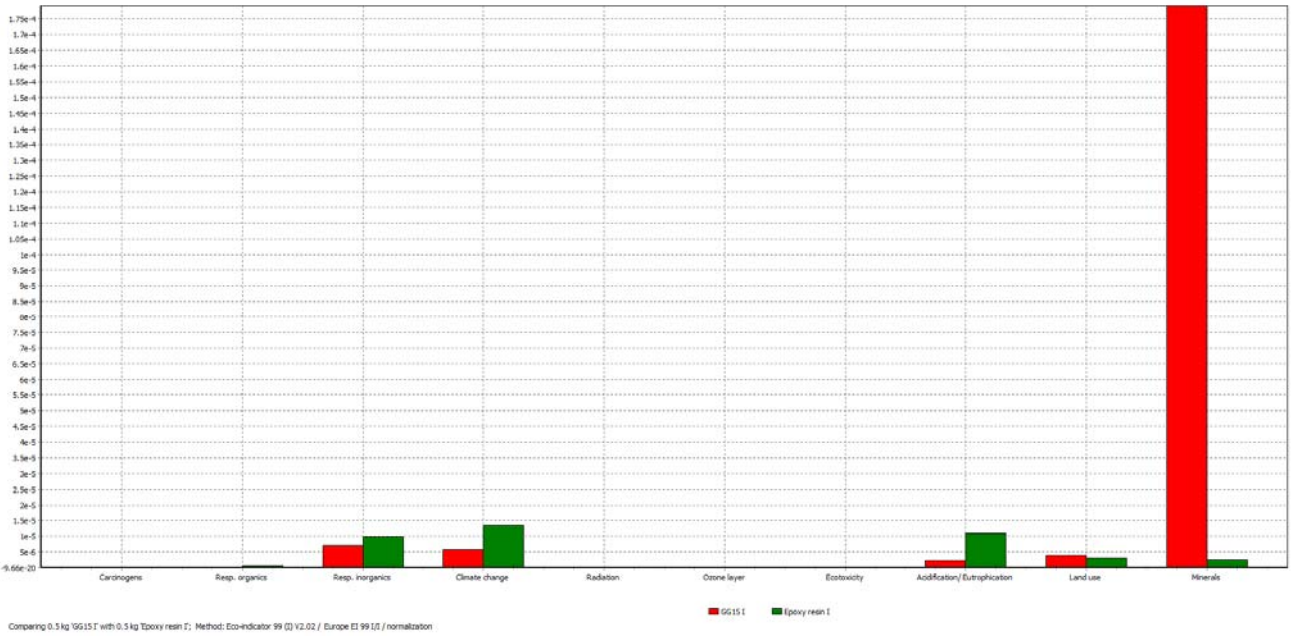

Figure 49: Normalization Results for the Pinching Device

The single score results of the EI 99 test compile the results from all the categories into a single result for each material. The results from both materials are then compared on a point scale. These results can be seen in Figure 50, on page 123. From the figure, the Cast Iron was determined to have the higher single score point total. This means that the Cast Iron is more environmentally hazardous than the Epoxy Resin.

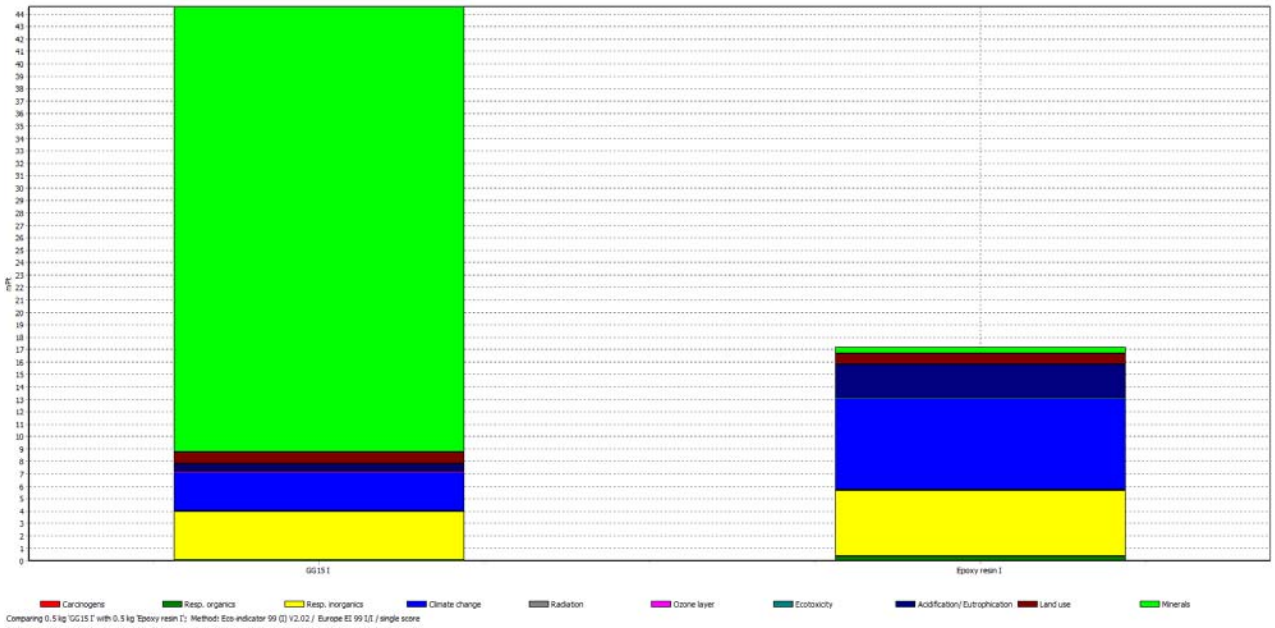

Figure 50: Single Score Results for the Pinching Device

Since Cast Iron GG 15 I is more hazardous to the environment this supports that the material selection of Epoxy Resin over Cast Iron GG 15 I. When considering the life cycle of the whole product, the Epoxy Resin would still have a lower environmental impact. The life cycle of the whole product would be a few years and the major environmental impact from the life cycle would be from the possibility of a part breaking or from the pinching device being thrown away. If a part breaks or the complete pinching device is thrown away, the major impact would be from the material decomposing. When considering this, the Cast Iron would have a greater environmental impact making the Epoxy Resin a better material choice.

U. Assignment Three: Manufacturing Process Selection Assignment

Batch Size: An approximate production volume for the grasping and pinching devices is about 100. This is because there are other University's looking into a similar system. Ten would not be enough however 1,000 would be too many. One hundred would be enough to allow the patients to take home the devices and also let the labs have some to improve upon.

Grasping Device Process: Using CES Process Universe Injection Blow Molding was selected for as the manufacturing process for the grasping device. This was based on the shape of the grasping device which is a hollow 3-D, the thickness of the device which needs to be less than 0.003 meters, and the low labor intensity. The batch size for injection blow molding is way larger than currently predicted; however, this will allow for growth without having to develop a new manufacturing process. The characteristics of injection blow molding can be seen below in Figure 51.

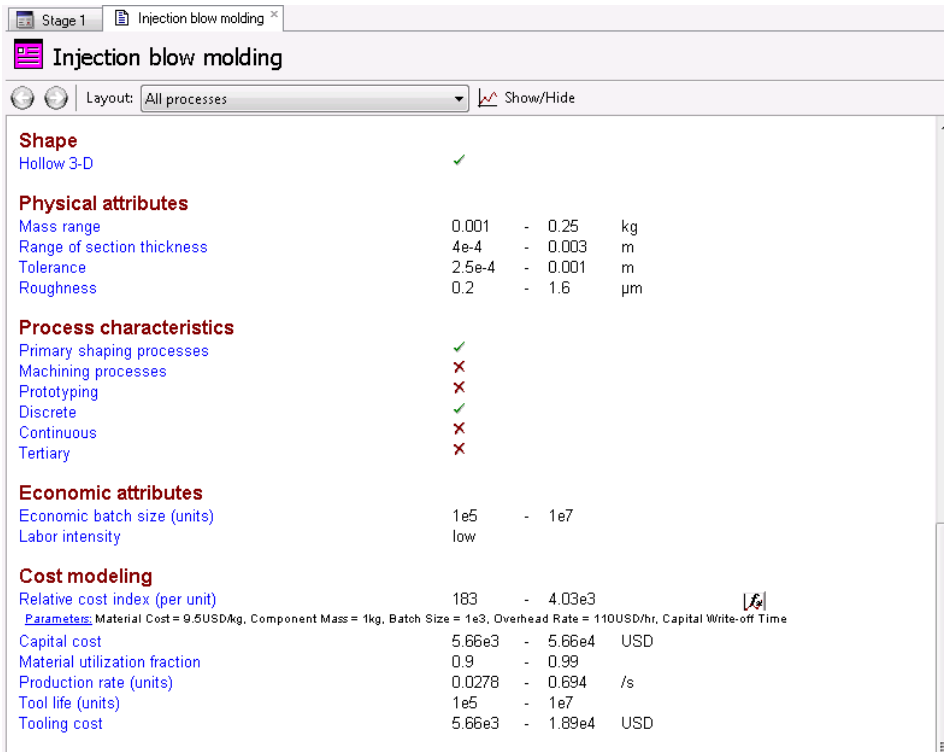

Figure 51: Characteristics of Injection Blow Molding

Pinching Device Process: Using CES Process Universe the process selected for the pinching device is Injection Molding. This was based on the shape of the device which is a solid 3-D, the thickness of the device which is about 0.006 meters, and the low labor intensity. The batch size for injection molding is larger the current batch size; however, like with the grasping device this will allow for improvement. The characteristics of injection molding can be in Figure 52 on page 125.

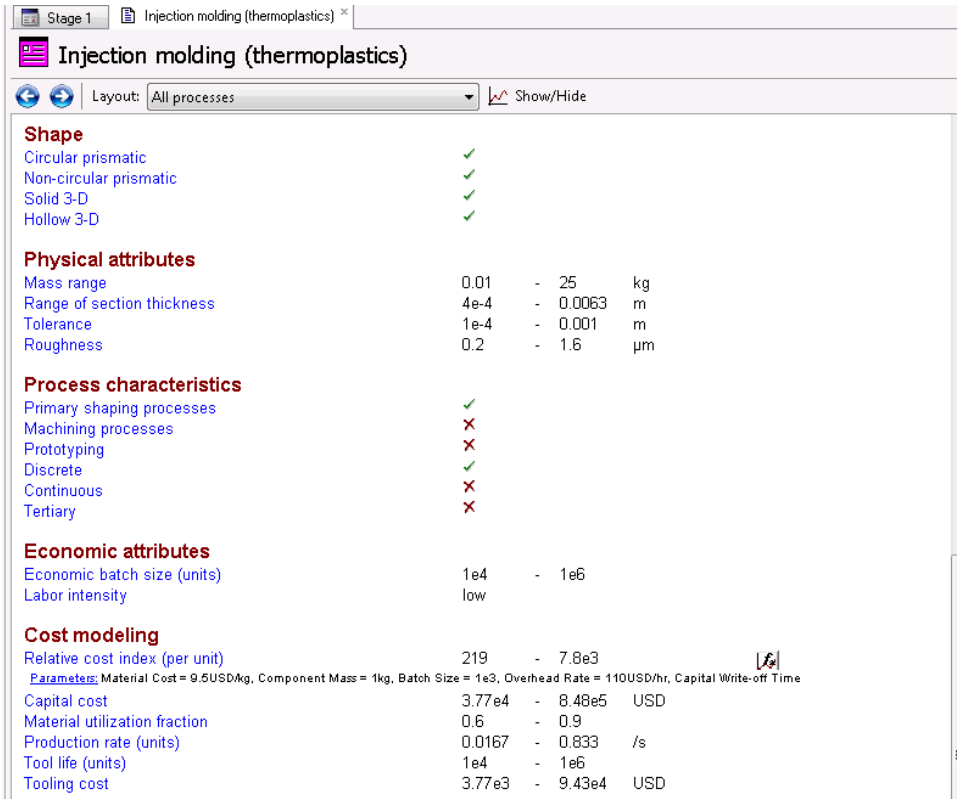

Figure 52: Characteristic of Injection Molding

V. Description of Engineering Changes since Design Review #3

This appendix intends to discuss what has changed in the project since design review 3. It will cover both the devices as well as the program.

Grasping Device

The grasping device has experienced a few changes since the last design review. First, initially there was supposed to be a supporting part between the pressure sensor and the bottle cap. This was removed because it was determined that it did not significantly affect the structural integrity of the device, nor did it add anything which would make it worthy of keeping. However an o-ring was added between the female bushing and the bottle cap. This was added as a countermeasure as a means to improve the seal. Also added to improve the seal was Teflon tape. This tape was added around the threads of the bottle cap in order to improve the seal. An important new development in the grasping device is that it now is being filled with water, as opposed to before when it was using air. This drastically improves the lag time as well as the accuracy of the voltage signal output. The final thing which needed to be added to the grasping device was an amplifier in order for the program to be able to work with the voltage signal. This is explained in detail in the Device Discussion section above on page 40.

Pinching Device

The pinching device has experienced a few changes since the last design review. First, after speaking with the sponsors, it was determined that the device was too large. As a countermeasure, the device dimensions were significantly decreased. This is explained in detail in the Manufacturing section above on page 23. Sharp corners on the device also needed to be addressed. All edges on the device were sanded such that no sharp points were remaining. Another thing that changed since the last design review was that the device no longer needed to be accessed from the button panel. It needed only to be accessed from the bottom by removing the bolts. This was a request from the sponsors, so that the patients were not distracted by moving parts on the top of the device. The final thing which needed to be added to the pinching device was an amplifier in order for the program to be able to work with the voltage signal. This is explained in detail in the Device Discussion section above on page 40.

Program

The program has changed significantly since design review three. In design review three the program was still being simulated using a dial, the program is now run using the devices and their sensors. The modules are now cleaned up and the sliding bars are located on top of each other instead of one after the other. This allows the patient to only have to look at one location on the program screen. In module one the doctor now has the option to take the maximum force or use a predetermined force. The block diagram now contains the preferences section which previously had its own tab on the front panel; however, by placing it on the front panel the doctors had to input the values every time they used the program. The doctors preferred to not have it this way so we moved them to the block diagram but put them in the same location for easy access. This is explained in detail in the Program Discussion section above on page 41.