Concept Generation and Selection

EML 4551C – Senior Design – Fall 2011 Deliverable

Group # 1
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Air Bearing Upgrade for the Split-Hopkinson Pressure Bar Experiment

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Introduction

The Mechanical Engineering senior design team 1 has been asked to complete an air bearing upgrade for the split Hopkinson pressure bar experiment for the Eglin Air Force Research Laboratory. The following report is an overview of the concept description and selection criterion that have been developed for the project. The individual sub systems are independent of one another and as such will be treated as individual projects, with their own concepts and selection criteria. The sub systems are as follows: the striker bar mechanism, the incident and transmitter bar, the bearing and compressed air system, the base, the bearing alignment system, the momentum trap, the strain gauges, and the data acquisition system.

Striker Bar Mechanism

The striker bar mechanism is the first component of the split-Hopkinson pressure bar experiment; it sets the entire mechanism in motion. The concept of this experiment is to plastically deform the specimen. In order to do so, high velocities are needed, which lead to the use of a light gas gun mechanism for the launch of the striker bar. The light gas gun mechanism is used in the current set up for most SHPB experiments.

The light gas gun mechanism is essentially a tube that is closed at one end with a nozzle at the other. At the end of the nozzle is a barrel that the striker bar rests inside. This tube and barrel is aligned horizontally with the incident and transmitted bars of the system. Inside the tube is gun powder, a piston and hydrogen gas as shown in figure 1. A spark in the gun powder sends energy to the system to push the piston through the tube. The piston pushes the hydrogen gas through the nozzle, which forces the striker bar through the barrel until it impacts the incident bar starting the process.

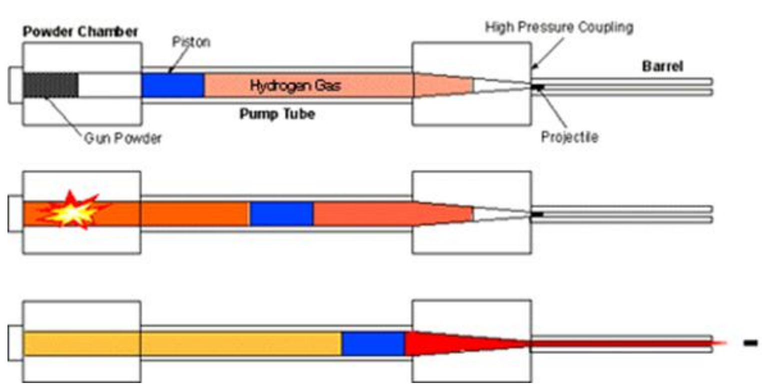


Figure 1- Light gas gun mechanism

Being that a small scale version of the SHPB is required of us, this light gas gun mechanism is more complex than what is needed. In this case, three concepts have been generated for the decision process that are more along the lines of what this project will require.

The first concept is much like a paintball gun mechanism in that it uses compressed CO_2 to move the striker bar. Essentially it is a tube that is closed at one end with CO_2 and the striker bar housed inside. The CO_2 is compressed at the back of the tube with a closure to hold it in, then the striker bar rests on the opposite side of the closure. A trigger is pressed, which releases a pin that opens the closure releasing the compressed CO_2. The energy from the compressed CO_2 forces the striker bar through the tube until it impacts the incident bar setting the procedure in motion. This concept is complex and not entirely cost efficient as far as what the project is capable of allotting, therefore it may not be used, but it is still a viable option.

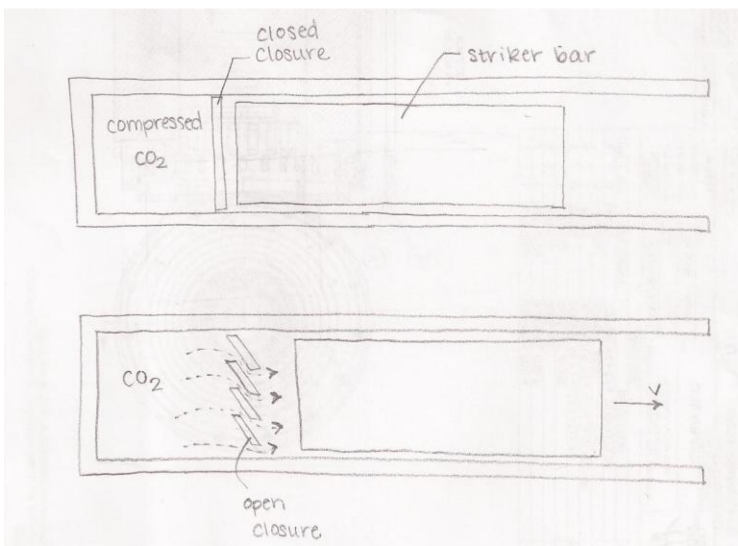


Figure 2 - Modified gas gun mechanism

The second concept involves a swinging pendulum to impact the striker bar and set it in motion; it can be viewed in figure 2. The striker bar will be set in a housing of sorts that is horizontally aligned with the incident and transmitted bars. The pendulum, when at rest, will also be horizontally aligned with the system to assure optimum performance. The pendulum will be held at a ninety degree angle and when released, will swing down to impact the striker bar. This impact will transfer kinetic energy from the pendulum to the striker bar, which sets the bar in motion through its housing until it impacts the incident bar. This mechanism is simple and cost efficient, but may not be very accurate because of human errors.

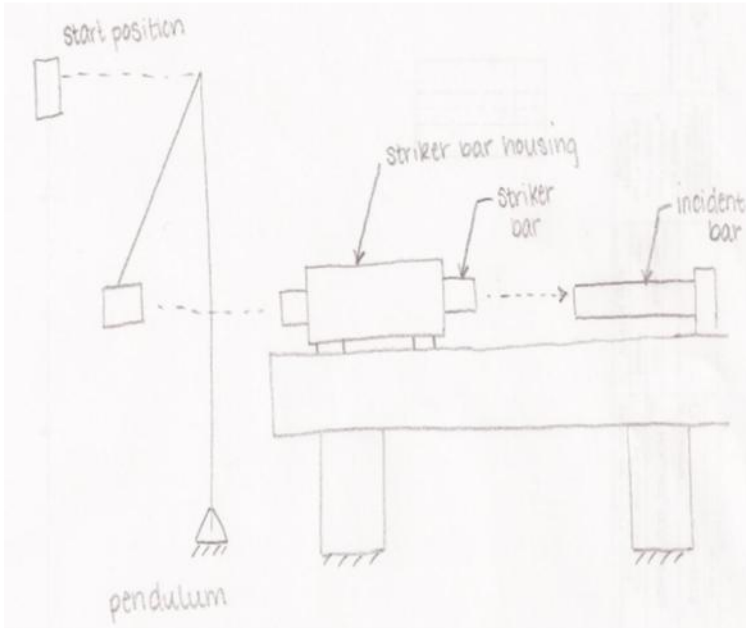


Figure 3 - Pendulum striker bar mechanism

The third concept is a spring launcher mechanism that allows the kinetic energy from a compressed spring to send the striker bar in motion, which is shown in figure 3. Essentially, there is a tube with one closed end that houses a compressed spring and striker bar held in by a pin. When the pin is released, the compressed spring expands forcing the striker bar out until it impacts the incident bar. This mechanism is simple and cost efficient as well, but may not provide enough force to generate the desired results of the experiment.

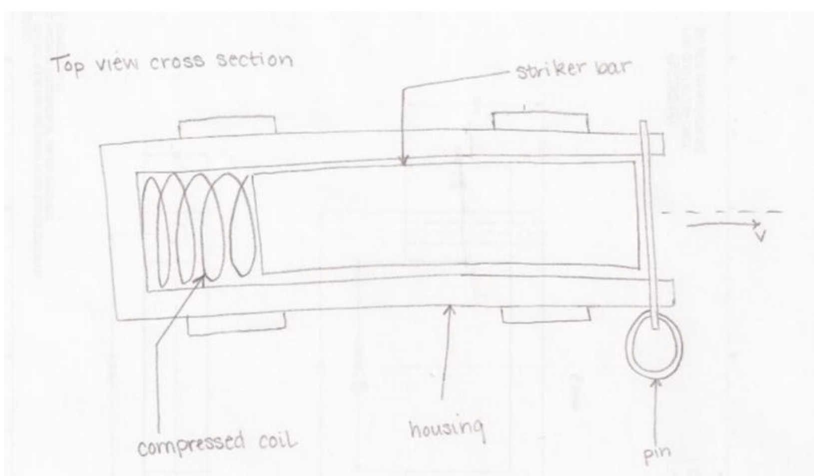


Figure 4 - Spring launcher mechanism

Air Bushing Housings

The critical role that air bushings have in the Split Hopkinson Pressure Bar (Kolsky) Experiment requires that they are securely housed. As the pressure bar slides, the bushing and the housing must be stationary. For choosing an air bushing diameter that corresponds to the bar size; the proper air bushing housing must be chosen as well. At the Eglin Air Force Research Laboratory, a 0.625 inch Split Hopkinson Pressure bar is expected to be used for material testing. However, there is the possibility that a bar with a smaller or larger diameter may be used because of the availability of the air bushings and air bushing houses. For the model apparatus that is to be built at the FAMU-FSU College of Engineering, a bar size has to be chosen as well the bushings and housings that best suits the group's needs. Aluminum is the most common material for the block houses or block mountings. Due to the lack of 0.625 in bushings and housings that are available, an air bushing housing of this size is to be custom made. For the scaled down Kolsky Bar model three possible housing sizes will be examined based on the bar and bushing size that is selected. The sizes include 0.25", 0.5", and 0.75" housings.

Air Bushing Housing/Mounting

There are two common ways of mounting air bushings inside of housings or mounting blocks. One method is the O-Ring Press Fitting (Flexible Mount). Air bushings come with four o-rings (two inner and two outer). Pressurized air supplies the air bearing through a seal formed by the two inner o-rings. An air supply hole is usually placed between the two inner o-rings on the mounting block. This flexible mounting allows the busing to float in the housing in which the bushing can align along the axis of the shaft. A misalignment of up to 0.002 inches can be accounted for between the air bushing and the shaft. The two outer o-rings are used for a flexible mount with added stiffness. Isopropyl Alcohol should be used for lubrication when fitting the air bushings inside of the mounting block.

The other way to mount an air bushing inside of a mounting block is the Bonded in Place (Hard Mount) method. There are also four o-rings used in this configuration. Two annular cavities are formed between the two inner and outer o-rings. The cavities are provided with an epoxy which will align the bushing and the shaft in precision. The housing will cover the 4 o-rings that are located on the air bushings. Isopropyl Alcohol is also used for lubrication when fitting the air bearings in the mounting block housings. Compressed air is supplied to the bushing through the hole between the two inner o-rings. The cavities between the inner and outer o-rings are filled with epoxy which is injected through the housing. If custom housings are used, and additional hole should be used to allow air to escape as the epoxy is injected.

The two methods for mounting an air bushing with its housing will be viewed and one will be selected for the assembly.

Air Supply

The air supply to the air bearings will come from a compressed air source. The air flows from the source into the tubes and then into the bearing through fittings. It is recommended that clear polyurethane tubing is used for the distribution of clean, dry pressurized air from the air compression source to the air bearings. Air supply tubing sizes are based on inner diameters and outer diameters (I.D. / O.D.). The air supply tubing will be chosen from 3 different sizes of I.D. /O.D. : 0.170/0.250, 0.125/0.250, and 0.078/0.156.

Polyurethane tubing

Air supply fittings are components that connect to the air bearings and allow them to receive air from the supply tube. There are 6 different fittings that will be discussed and one will be chosen that best fits the demands of the project. All of the air supply fittings are available in nine different sizes.

Straight air fittings are the easiest option for connecting an airline to an air bearing. On one end of the fitting is a barb which allows the air supply tube to fit securely on the fitting. The other end is threaded to allow the fitting to be installed into the bearing.

Straight Air Fitting

A right angle air fitting has more flexibility when needed to connect an air bearing in a small space. The threaded end is the supply connection to the air bearing.

Right Angle Air Fitting

The T-style air fitting is used to connect more than one bearing by using a single airline. One end is threaded for insertion into the air bearing mounting block housing. The T-shape allows for several bearings to be connected sequentially to a single airline.

T-style Air Fitting

Thread less connection air fittings are used as inline connections. This fitting is not threaded into the air bearing housing.

Thread less Connection Air Fitting

A quick disconnect air fitting makes it easier to connect and disconnect air supply lines. The threaded end is fixed into the air bearing housing. The other end has no external barb unlike the other fittings. The air supply tube is connected to the orange fastener on the fitting.

Quick Disconnect Air Fitting

Bar material /size

The bar material that will be used for the Split Hopkinson Pressure Bar Experiment must be very strong and allow little ductility. A high yield strength is needed so that the bars can remain at its original state after striking the specimen. Plastic deformation is not desired because the bars would not slide properly through the air bearings.

A specific bar length and diameter for the smaller model are to be determined by the group members. The yield and ultimate tensile strengths of three possible materials are given below. Also, the corresponding prices of the diameters and lengths are tabulated for the materials.

1114 Cold Drawn Stressproof Steel

- Yield Strength- 100,000 psi

- Ultimate Tensile Strength- 115,000 psi

Diameter (in)	Length (in)	Price ($)
0.25	36	2.32
	48	2.75
	60	3.27
0.50	36	4.63
	48	5.49
	60	6.52
0.75	36	10.42
	48	12.35
	60	14.67

4340 (chromyl) Normalized Alloy Steel (Air Melt)

- Yield Strength- 125,000 psi
- Ultimate Tensile Strength- 186,000 psi

Diameter (in)	Length (in)	Price ($)
0.25	N/A	N/A
0.50	36	10.93
	48	12.95
	60	15.38
0.75	36	24.59
	48	29.15
	60	34.61

17-4 Stainless Steel

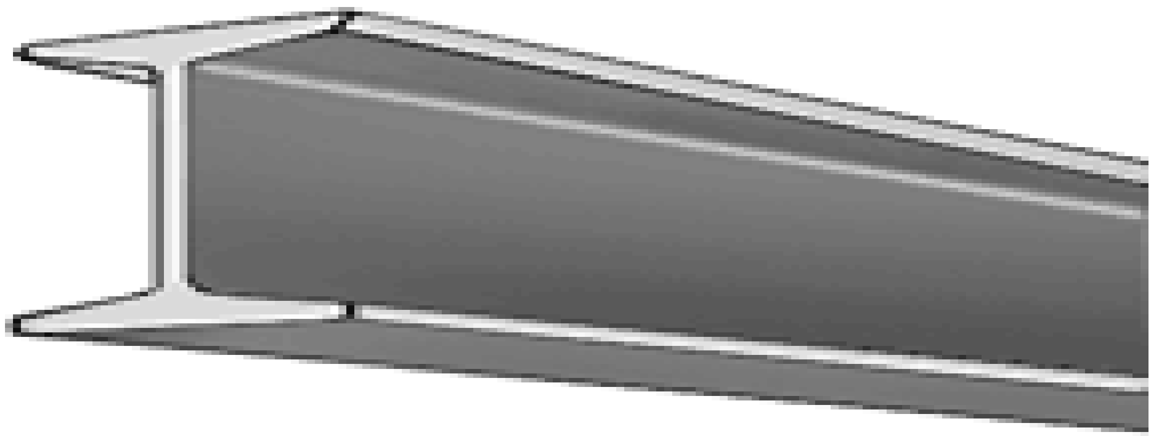
- Yield Strength- 145,000 psi
- Ultimate Tensile Strength- 160,000 psi

Diameter (in)	**Length (in)**	**Price ($)**
0.25	36	13.47
	48	15.97
	60	18.96
0.50	36	28.95
	48	34.31
	60	40.74
0.75	36	25.96
	48	30.77
	60	36.54

Base

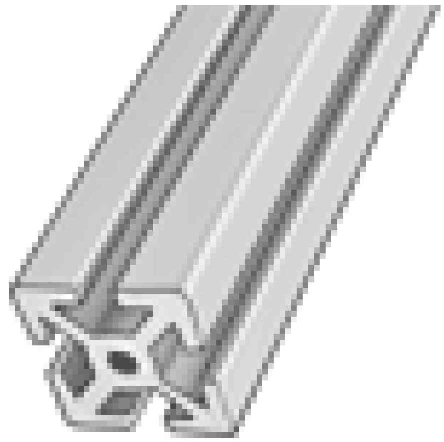
The base design for the SHPB experiment is more than simply a physical method for holding the system off the ground. The base must act as a method to maintain alignment. It has been noted that the base may itself be a method of alignment, especially with concept #2. The actual SHPB experiment at Eglin currently rests on an I-beam support, and as such the concepts are for the prototype only. The prototype itself must be portable, scalable and affordable. The following concepts will be decided upon in the next deliverable.

Concept #1 I-beam

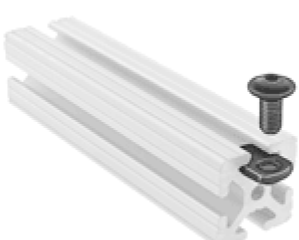


As this is the support structure currently being used by Eglin AFRL, it is the most obvious first choice. It is historically been proven to be a strong structural member, especially in bending. They are widely available in many sizes, and are mass produced making them both scalable and affordable. A single I-beam can be purchased of satisfactory length to carry and maintain the alignment of all sub systems of the hoppy bar experiment. This would make it more portable, though the weight from the steel in the I-beam would not aid to its portability.

Concept #2 T-Slotted Framing

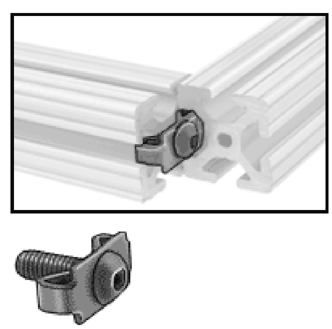



T-Slotted Framing is an extruded Aluminum product. This aids in its affordability and portability. The structure comes in lengths up to 8 foot, which is sufficient for the prototype of the hoppy bar experiment. The addition of the shaped groves in the structure is important for the alignment of all the individual subsystems. The manufacturers make a series of bolts, brackets, connectors, and fasteners to align separate bars, or any object to the top or side or bottom of the frame itself. This is a very important quality to have when the design parameter of alignment is paramount.



Fastener

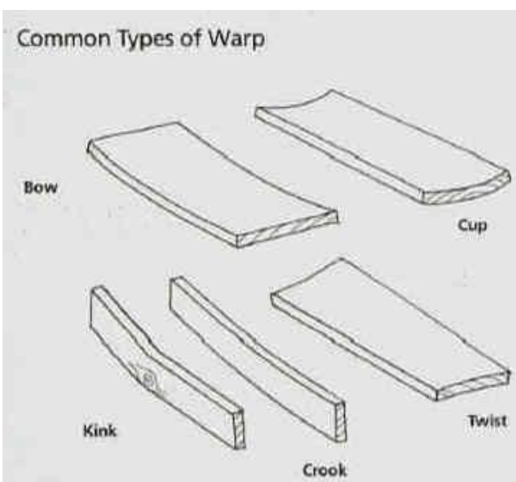
Bracket



Connector

Concept #3 Wooden table

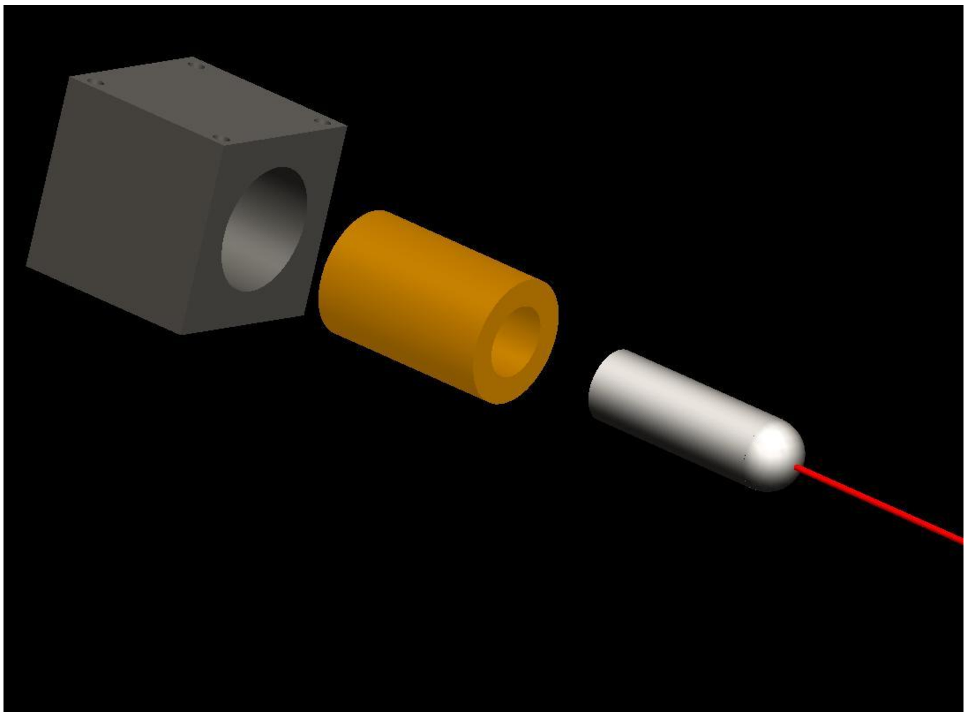
Wood is the most widely used engineering material. The low cost of wood makes it very affordable. Wood is also easily worked, which makes it customizable, and cheaper to manufacture. Wood is light weight and cheaply bought in long sections, making it scalable and portable. Wood, however is very sensitive to moisture, temperature, and physical deformation. These sensitivities lead to the wood being warped. This is typically an irreversible process of deformation which would inevitably leave the hoppy bar experiment out of line, due to the high temperatures being used in the actual Eglin hoppy bar experiment. The following shows several types of wood deformation:



Bearing Alignment

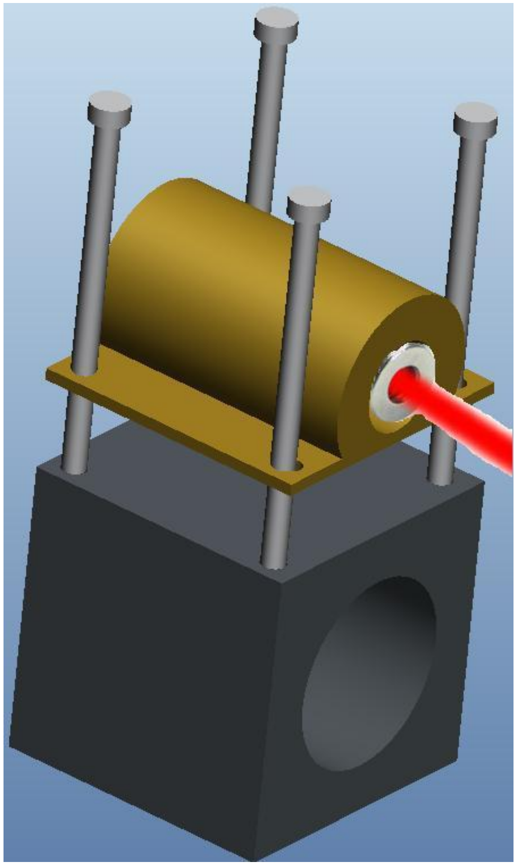
One of the principle design requests from Dr. House was that the bearings be aligned. Through research, it was discovered that all high end alignment systems are laser based, seeing as how the lasers can be highly accurate from far distances, while being unaffected by gravity. There is a secondary approach, which is the concept of a tensioned cable that would help align the bearings by itself. Proper bearing alignment is needed for any decrease in friction to be maintained. Properly aligned bars will also extend the life of the beaings. Misalignment will also give false data due to friction.

Concept #1 Center Bore Alignment



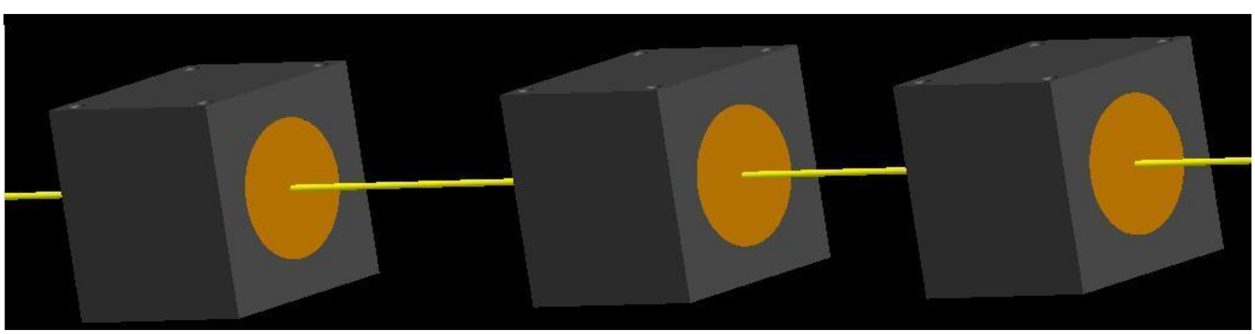
A center bore Alignment has several advantages and disadvantages. With the addition of the precision machined insert this concept allows for easy insertions, and it fully constrains the laser. This can be done so as to perfectly center the laser's beam and the center of the bearings themselves. However, the insert may damage the porous material inside of the bushings. The inserts may also become lodged inside of the bearing. If the larger 0.75 inch air bearing is used, then that gives a maximum insert thickness of 0.13 inches. This makes it difficult to machine to any accuracy. This concept though is easily transferred from one lab to another.

Concept #2 Exterior Mount Alignment:



The precision machined attachment is more easily manufactured and will be fully constrained by the four bolt holes. With quality machining this method can give extremely accurate readings from one bearing to another. This also allows for very tight constraints on the laser. There is also less potential for damage to the porous material. Also this design is very easily transferred from one bearing block to the next using the through bolt holes for alignment.

Concept 3 Tensioned Cable Alignment

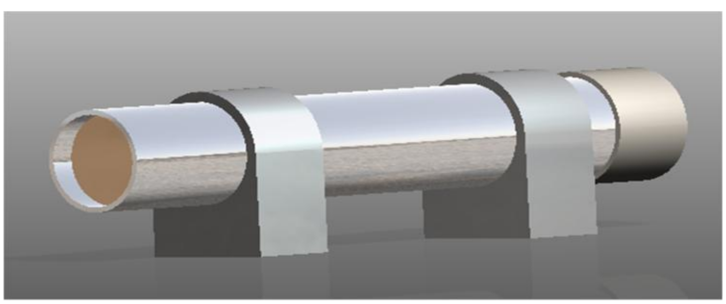


The tensioned cable alignment system concept is a very good competitor for final design. Using a highly tensioned cable an exact distance from the counter top, one can align all the bearings at once. The use of an insert block is far less difficult than the previous center bore alignment, because of the thickness of the insert. The insert will have sufficient thickness to support the weight of the bearing blocks themselves. However there is a danger of damaging the porous material in the bushing, or getting the insert lodged inside.

Momentum Trap

The momentum trap is a crucial part of a SHPB experiment. By capturing energy from the bars, the momentum trap prevents damage to the apparatus. In the case of a malfunction, uncaptured energy could cause damage to the experimental system, shortening its effective lifespan and reduce future data quality. Therefore, in order to assure and maintain the integrity of the SHPB apparatus, an effective, reliable momentum trap must be constructed.

There are a number of options for the design of the trap. One choice is to fill a container with an readily deformable material. When the incident and transmission bars translate, they would come in contact with the softer trap material. The force of the impact would deform the trap material, removing the energy of the bars from the system. In order to keep the price of the trap material down, low cost options will be explored. Possible choices for this are clay, sand, and cork. All of these substances have the prospect of acting as a reliable impact cushion while also being cheap and easily obtained. For any of these materials, the momentum trap could be constructed out of a short piece of tubing. One end of which would be left open while the other was sealed. The open end of the tubing would be placed a short distance from the end of the transmission bar so the bar would come in contact with the impact absorbing material. One drawback to these substances, especially clay and cork, is that during impact, they would likely be plastically deformed. This would require for a check to be done after each test to assure that the material had not been deformed so far as to allow the transmission bar to over-travel during the next test. Even with this possible drawback, these cheap and easily attainable substances may offer the best choice for constructing a cheap, reliable momentum trap.



Custom Impact Bumper

Another option for the trap's design is to place an impact absorbing mechanism at the end of the transmission bar that elastically deforms when struck. Instead of using a material that would be plastically deformed after every test, this design would have the material reform itself after each test. One choice would be to place a flexible bumper constructed of soft rubber, or some similar material, at the end of the setup to absorb the unwanted energy. This option would be very similar to what was stated above but should not require the frequent checks associated with a material which plastically deforms during impact.

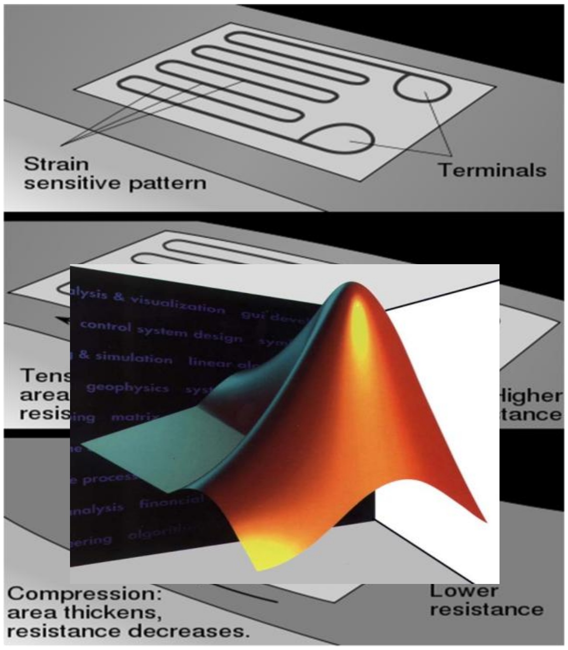
Pre-Manufactured Bumpers

A third choice for a devise to capture the energy is to use a small piston. Compression of the piston would act as the method by which the unwanted energy was removed from the system. This idea could be used in conjunction with the flexible bumper mentioned above. This setup would place the bumper on the end of the piston and allow for an extra layer of shock protection to both the transmission bar and the piston. It would also allow for no contact between the bar and any hard surfaces which could, through repeated tests, damage the end of the bar. A pair of viable choices for the piston design is pneumatic pistons and springs. A helpful trait of a pneumatic piston would be its adjustable rate of return. Springs would be useful because of their availability in a wide range of load ratings but may not be applicable because of the speed at which they return to their original length. If the return rate is too high, it could result in the transmission bar being driven back to and beyond its original position. This type of event could possibly result in damage to the bars, strain gauges, striker bar, and air bushings.

Shock Absorber

Strain Gauges and DAQ

In order to gather useable data from the SHPB experiment, the correct data acquisition equipment must be used. A crucial step in gathering useable data from a SHPB test is the correct choice of strain gauges. Although mechanical types of strain gauges exist, resistance, superconductor, or capacitive based strain gauges will be used for this project. The size, weight, accuracy, and response time of the resistance based strain gauges make them well suited for tests such as the SHPB experiment. There are three main types of electrical strain gauges: piezoelectric, capacitive, and foil. Piezoelectric, also called semiconductor, strain gauges are often used when measuring extremely small values of strain. However, they are more costly, temperature sensitive and fragile than foil and capacitive gauges. . Foil strain gauges are the most common type. They are reliable and accurate while still being the least costly of the three types. Capacitance strain gauges are not as applicable to this project because of the method by which they operate. They use a sensor which creates one side of a capacitor while the other half is formed by a small, flat plate located on the strained material. Because of the curvature of the bars, a capacitance gauge may not function correctly. The choice of type and specifications of the strain gauges that will be used in the final design have not been made and will be chosen based on the final design of the bar system.



Foil Strain Gauge Mechanism

Another integral piece of the data acquisition process is the choice of a computer-based data acquisition (DAQ) system to record test data. Two choices for this system are LabVIEW by National Instruments and the MatLab data acquisition toolbox. Either system should provide acceptable data recording rates and a choice must be made between the two systems as to which will be most suited to this project. For now, both options are being considered and a choice will be made in time to setup and implement the chosen system for use in testing of the final design.

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