MSMA Lateral Loading Device

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Concept Generation and Selection

Document

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CONTENTS

1.0 ABSTRACT

This report will provide a brief background into the Magnetic Shape Memory Alloy (MSMA) lateral loading project. After reviewing the task at hand concept generations for the proposed designs will be explained in detail. To construct this device a basic design has been chosen, from this two design areas were identified and specific concepts were generated. These two areas of interest are the device's actuators and force sensors. Three designs were selected for each area as possible solutions, these ideas were then evaluated using specifically defined criteria. Using decision matrices, the selected design criteria, and associated weighting factors a final design was selected. This design will undergo analysis and revision to eventually become the proposed project design.

2.0 BACKROUND

At Northern Arizona University, Dr. Ciocanel is conducting research on MSMA's. This material is fairly new and because of that, most of its mechanical properties are not known. It is Dr. Ciocanel's main goal is to discover these properties through testing. To conduct these tests, Dr. Ciocanel and his team of graduate students use an Instron machine. The Instron machine loads the selected material vertically, while applying a magnetic field horizontally, seen in **Fig. 1** and **Fig. 2**. However, this experimental set up leaves an entire third dimension unexplored.

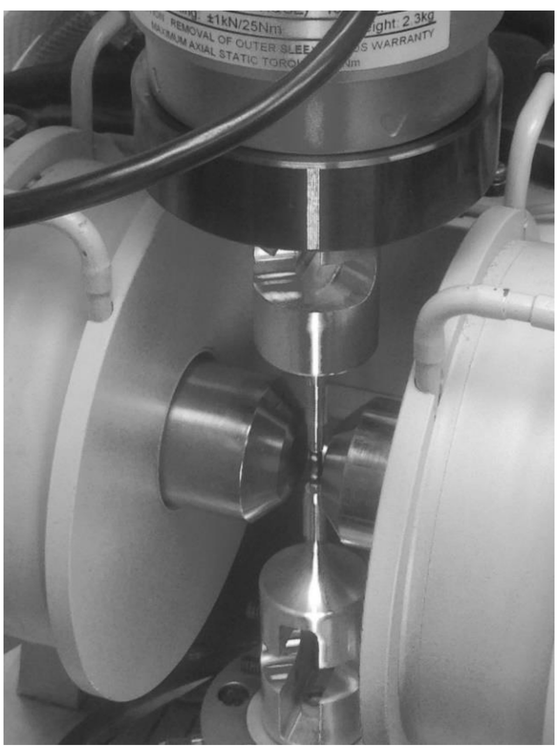

Figure 1: Close up of Instron machine

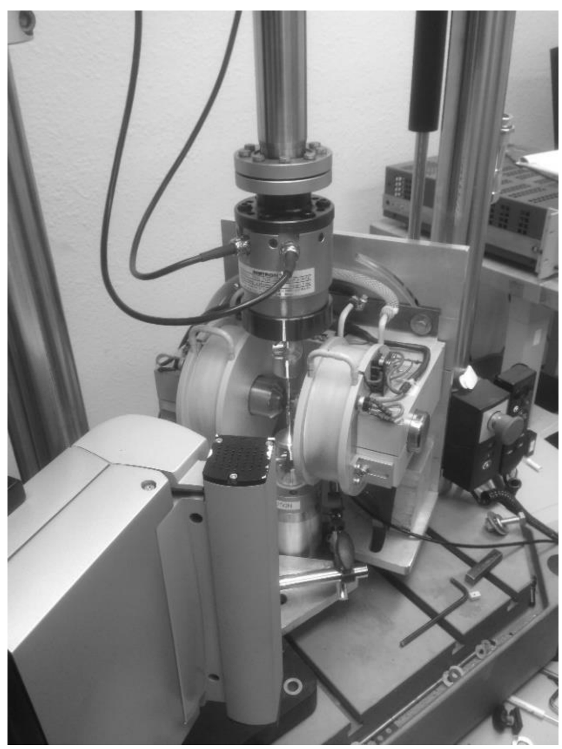

Figure 2: Full Instron machine

3.0 CONCEPT GENERATION

Due to the small space within the testing environment, it was decided that there was only one basic design that could be implemented. Within this basic design there were however two main variable components. This decision was reached as the design process began, it became evident that each design apparatus was too similar in their setup to deem separate designs. Therefore the designs for the overall concept generation were split into two main categories: sensing devices and actuating devices. These two categories are completely different in their functionality and allow for a large range of options to select from when selecting the final design. The overall design with the two variable devices can be seen in **Fig. 3** below. The basic design works by placing the actuator and sensor an undecided distance from the MSMA, allowing for more design and size options to solve this problem.

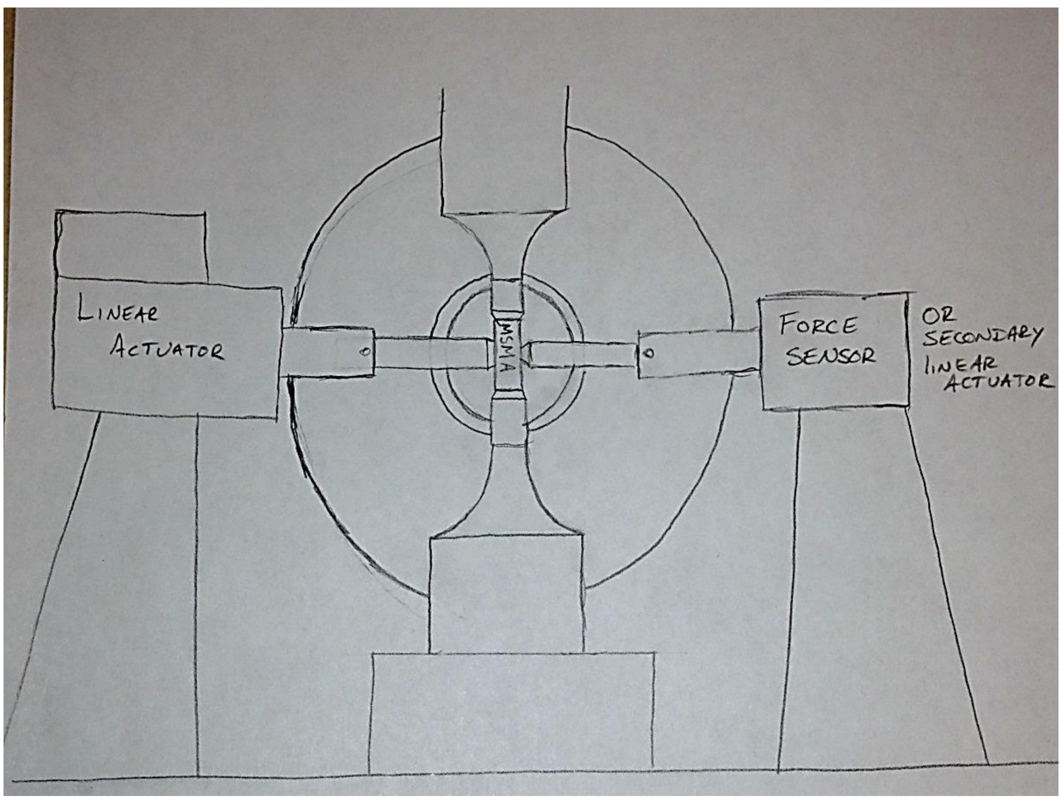

Figure 3: Overall design with two areas left for the sensor and actuator

3.1 SENSING DEVICE

For the force sensing device, three different designs can be chosen. These designs consist of piezoelectric, strain gage, and force sensing resistor (FSR) sensors. These three sensors are very diverse from one another, which allows for more options on the final design.

The first option is a piezoelectric (PZT) sensor. This PZT is mounted onto a piece of aluminum that will be flush with the MSMA and as the MSMA experiences a variant transformation and changes in width, the PZT will deflect and then output a voltage [1]. This voltage will then be transferred to the chosen actuating device to allow for a full feedback control system. The PZT is capable of high sensitivity, but does have some pitfalls since they are rather expensive and very fragile.

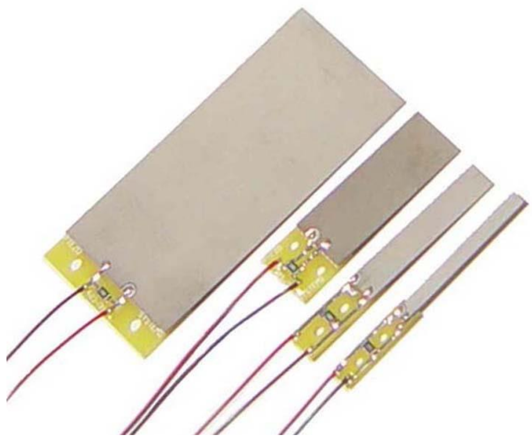

Figure 4: PZT sensor in various sizes [9]

The second option is a strain gage. In this design two strain gages would be implemented on the ends of the chosen actuator and positioned on both sides of the MSMA, where the force is being applied. Using a virtual instrument this design would measure the strain associated with a range of known applied forces [5]. During testing, the vertical force will cause increased forces in the lateral direction. The virtual instrument and strain gage will work together to read and adjust the lateral force being applied on each end on the MSMA. This two gage design enables equal forces to be applied on the respective sides of the MSMA.

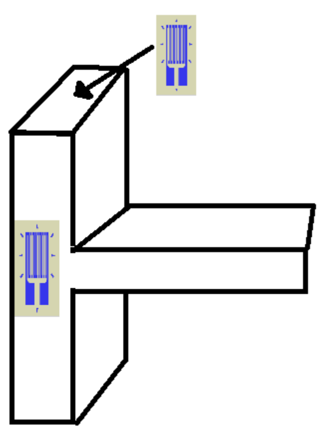

Figure 5: Basic Strain Gauge Design [5]

The third option is a force sensing resistor (FSR), seen below in **Fig. 6**. This force sensing device is a lot like a strain gage in principal, however instead of measuring lateral deformations, it measures electrical resistance created by direct compressive forces [7]. These devices can come in small sizes, and are inexpensive. Unfortunately they are not as precise as the other options.

Figure 6: General FSR used to sense forces [8]

3.2 ACTUATING DEVICE

From the actuation device, again, three different designs were selected to be chosen from. These types are electromechanical, pneumatic, and hydraulic. These three allow for a range of design opportunities within the final design layout.

The first option is an electromechanical actuation device, as seen in **Fig. 7**. An electromechanical actuator uses an electric motor which turns a screw. This screw moves in a linear motion. These types of linear actuators can have very fine resolution, and can even be fitted with force sensors that give feedback [6]. This could prove useful for this project, as there is a need to adjust the actuator force based on force feedback in order to maintain a constant force as the MSMA changes shape. However, to use this actuator there must be a constant power source and they are generally large in proportion to our required design.

Figure 7: Linear electromechanical actuator with its components [4]

The second option is a pneumatic actuator. This pneumatic actuator would have a piston and cylinder design scaled down to fit the required forces. The problem with this type of actuator is that it does not stop in the middle of its cycle. From this lack of flexibility in the design, the precision of force applied is low, whereas for this particular problem, the precision needs to be much higher. Along with this, the actuator must have a constant power and compressed air source.

Figure 8: General pneumatic actuator [3]

The third option is a hydraulic actuator. This would consist of a computerized servo controlling one piston attached to a small hose filled with hydraulic oil and an actuator on the other end. Since the fluid is incompressible, the actuation is directly linked to the motion of the piston, unlike the pneumatic option. Since a hose is used to transmit actuation, the actuation component will fit in the cramped space allowed. Ideally, the back pressure could also be measured, and would allow for feedback control of the actuation [2]. The question is whether this will work at the small-scale required. There also needs to be a reservoir of hydraulic fluid and a power source to successfully implement this actuator.

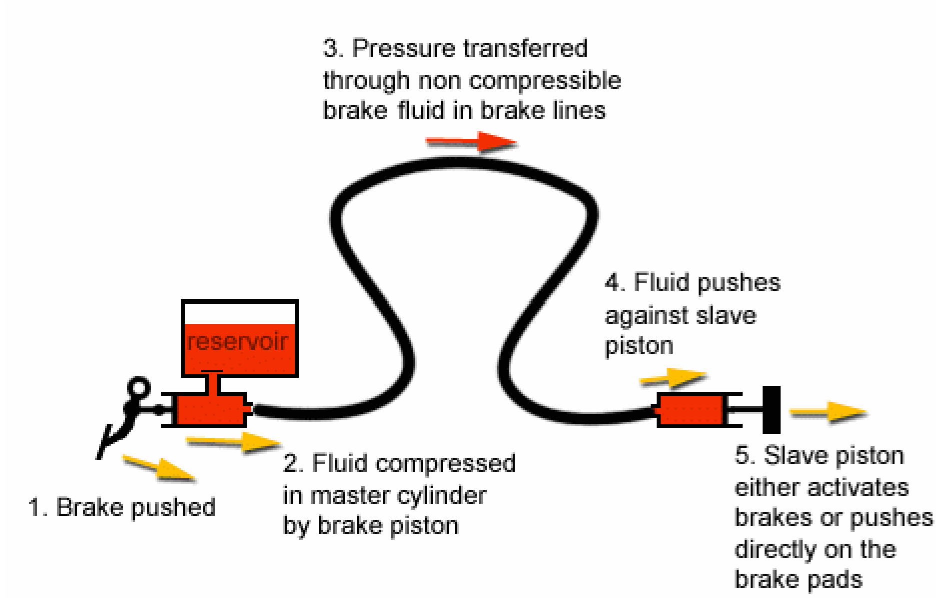

Figure 9: Schematic of a hydraulic actuator [2]

4.0 DECISION MATRICES

Since the properties of our design are so unique there is no clear best decision. Therefore the next step was to construct decision matrices to allow for an objective look at each design option.

The first devices compared are the sensing devices. Whilst looking at the design as a whole several requirements for the sensors were developed. These requirements, along with their given weights of importance (on a scale from 1-5) are as follows:

- **Sensitivity:** Defined as how fine of a measurement each of these sensors is able to take. This is rated as a 4 because while it is important to be able to sense minute changes and adjust for them there is a point at which the extra sensitivity is useless in this application.

- **Cost:** Defined as the cost of the sensors in relation to one another. It has a rating of 1 because the overall cost of these sensors is going to be relatively similar in scale. While the cost of the sensors will not be one of the major contributing to the overall cost of the project, it is important in design comparison.
- **Size:** Defined as the size of the sensor, and ability to be implemented within the system. This is important to the design because of the limited amount of space available to us; the sensor must be able to be applied in small areas. While size is important it received a weight of a 3 because it is not as important as sensitivity and other criteria.
- **Effectiveness in a magnetic field:** Defined as how precise the sensor will be under a magnetic field. This will be a relative measurement of how much a magnetic field will affect the readings and how feasible it will be to apply one of these sensors within the field. This is weighted as a 5 because most sensors will be operating within the magnetic field and they need to be able to provide accurate readings.
- **Durability:** Defined as how well the sensor will hold up under the testing conditions and the materials ability to not break. This is weighted as a 3 because the conditions are not extreme so the sensor should not have to be extremely durable but if the sensor breaks then the rest of the design will be ineffective.

Once the requirements were decided, the decision matrix was developed and can be seen in Table 1. The corresponding numbers were decided upon by researching the different types of sensors and their different capabilities and properties.

Table 1: Decision Matrix for the sensing devices

	Weight	**Piezoelectric**	**Strain Gage**	**Force Sensing Resistor**
Sensitivity	4	8	7	4
Cost	1	4	7	9
Size	3	9	5	5
Effectiveness in a magnetic field	5	6	7	7
Durability	3	4	6	7
Total	n/a	105	103	96

In the end, the piezoelectric sensor had a total of 105. Its high sensitivity and small size allowed it to overcome the high cost and low durability thanks to the weighting factors associated. The strain gauge was a close second with a total of 103. The strain gauge scored fairly consistent during evaluation in all criteria. In the end it lost because of the complications that could arise with the size restrictions. Finally the FSR ended with a total of 96. Although it is very cost effective and durable the low sensitivity made this option not viable for our design. Although the PZT scored higher than the strain gauge the difference between them is extremely close. To combat the subjective nature of decision matrices, it was decided that both the PZT and strain gauge are viable options. Therefore both sensors will be analyzed as options for the final design.

After the sensors were compared, the actuators could be compared. Looking at the design, several requirements were decided upon. These requirements along with their respective weights of importance (on a scale from 1-5) were found below:

- **Controllability:** Defined as the amount of control that each of these actuation methods allows in regards to the force applied. This is a sub-category for precision specifically looking at the precision of control during feedback. It is weighted at 5 because this criterion is crucial to the implementation of the design. Controllability was one of the major requirements for the project as a whole. Without good controllability the project could be considered ineffective.
- **Cost:** Defined as the total cost of the actuation device and associated fluids, or power sources. It is weighted at 1 because each of the different types is going to be fairly close in cost so the change in cost is going to be pretty miniscule. Still it is expected that we develop an inexpensive design.
- **Precision:** Defined as the ability of the actuation unit to provide consistent results for a specific actuation force. It is weighted at 5 because this criteria is crucial to the implementation of the design. The idea is to keep the accuracy of the already established testing procedure therefore any new component must provide accurate results.
- **Amount of applied force:** Defined as how much force each of these actuation types is able to apply. This is weighted as a 2 because each of these actuators are required to have an actuation force of at least 75 N otherwise the design would be unsuccessful. Normally this is not a large amount of force to apply but the small size required of these actuators could affect some designs.
- **Size:** Defined as the size of the actuator being used. This is important because of the limited space we have to work in. If the actuator is too large to be implemented then it is

useless. This is rated a 3 because there is some leeway on the area available depending on where the actuator is placed.

Once the requirements and their weights were decided upon, the decision matrix was formed, as seen in Table 2. After researching the three difference actuators, numbers were chosen for each requirement for the various design options.

Table 2: Decision Matrix for the actuation devices

	Weight	**Electromechanical**	**Hydraulic**	**Pneumatic**
Controllability	**5**	9	7	4
Cost	**1**	3	5	3
Precision	**5**	6	7	3
Amount of Applied Force	**2**	5	8	8
Size	**3**	4	8	6
Total	n/a	100	115	72

Once the numbers were then calculated, it was clear that the pneumatic actuator was a fairly poor choice for the design with a total of 72. The low level of controllability and precision eliminate it as a viable option for this application. The electromechanical actuator ended with a total of 100. This design had a very high controllability but its large size proved to be a problem for this application. The hydraulic actuator was the preferred design choice with a total of 115. The good controllability combined with the applicable size sealed the victory for this actuator in the given system.

5.0 FINAL DESIGN

Combining the chosen concepts from the decision matrices produced the following designs. A hydraulic actuator controlled by a dual strain gauge force sensor and a hydraulic actuator controlled by a PZT force sensor. Both designs allow for a small piston, driven by hydraulic actuation, to apply force to the MSMA test subject. In both designs there will be two pistons, applying equal and opposite forces in a lateral direction. From there either the strain of the actuator or PZT deformation will be measured and used to control the actuation force through a VI.

6.0 CONCLUSION

During the analysis of the current experimental apparatus it was determined that the project designs should focus on two specific design areas, actuation and force sensing. With this in mind three design options were selected for each area. Those options were evaluated for effectiveness based upon specific design criteria. These criteria each had a weighting factor based upon the project goals and constraints. After evaluation two final designs were constructed as viable options to solve the given problem. From here the two selected designs will be analyzed on a more specific level. With the data gathered during this analysis the project design can be finalized and optimized to complete the requested lateral loading.

7.0 CITATIONS

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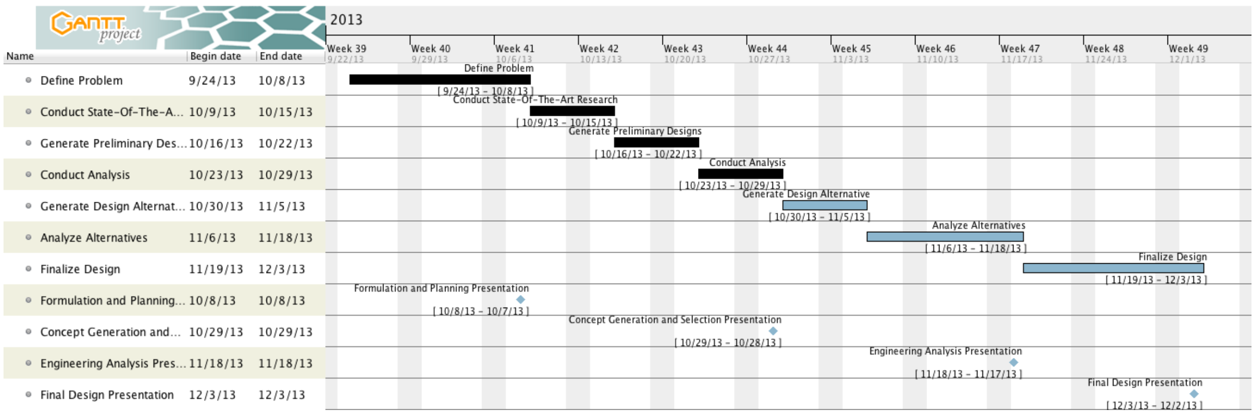
8.0 APPENDICES

Appendix A - PROJECT PLANNING UPDATE



Gantt chart displaying updated schedule for design completion through this semester. The black signifies tasks that have been completed.