Multidisciplinary Senior Design Conference
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ABSTRACT

The objective of the project was to design and develop a complete positioning system capable of measuring the position of a variety of forgings in a diversity of dies to better than 1cm accuracy which could be deployed to the customer. Furthermore, the system had to measure the deviation of the die position from the ideal position and display this deviation on a large easy-to-interpret display visible to an operator driving a forklift. Finally, positioning of the forging within the die when it is pressed had to be permanently recorded electronically for future reference.

INTRODUCTION

Hot forging of parts is a common method of producing complex high strength mechanical assemblies for aerospace, military, and/or automotive applications. In closed die forgings, material is pressed in a die under high pressure to create the desired part. The placement of the piece in the die plays a major role in the quality of the part. If not aligned properly inside the die, the piece may require forge rework due to under-fill in some areas. High precision forgings may require several sequential forging steps, requiring alignment of an incomplete forged part with the next set of forging dies. This alignment is currently performed at Wyman Gordon by hand using pry bars and forklift trucks, and alignment is performed by eye by an experienced operator. The company relies on operator judgment to locate the piece and there is no way to verify that the alignment of the piece is correct.

The team was requested to design, analyze and construct a system for locating the piece in the die to improve quality and reduce rework and scrap. The team decided that the use of sensors would be the best solution to the problem. A list of different sensor types was generated with the advantages and disadvantages of each option. After performing some analysis and discussions the team decided that a Time-Of-Flight sensor was the best option under the project constraints the team faced.

PROCESS

CUSTOMER NEEDS/SPECIFICATIONS

The customer needs and engineering specifications were initially given in the project readiness package in the start of Multidisciplinary Senior Design I. The team understood the importance of identifying and understanding the customer specifications and requirements. For this reason, the group had an initial site visit, meetings, and conversations in order to fully comprehend what the customer required.

The group started with the discussion of different approaches that could potentially fulfill the customer needs and engineering specifications. Table 1 shows the list of engineering specifications provided by the customer. After analyzing the specifications and requirements, the team was able to proceed with a detailed design that would be able to fulfill the needs of Wyman Gordon.

Wyman Gordon Engineering Specifcations						
Spec ID	Importance	Cust. ID	Specification Description	Unit of Measure	Value	Comments
1		C1,C3	Position Resolution	mm	<0.635	
2		C2,C8	Sensor Speed	sec	0.1	
3		C1,C2	Sensor Range	m	5	
4		C6,C10	Impact Resistance	tons	5	
5		C6,C7,C10	temperature resistance	F	600	
6		C11	sensor cost	Dollars	3000	
7		C4,C12	Display visability	m	5	
8			Power Requirement	W	<1650	
9		C6	Foreign Body Protection, Solid	Index	6	Based on IP ratings (Dustproof)
10		C6	Foreign Body Protection, Liquid	Index	5	Based on IP ratings (Hose Down, residential)
11		C6,C7,C12	Equipment Interaction	%	<10%	Setup time, adjustments
12		C5,C12	Data Storage	Logical	1	

Table 1. Wyman Gordon Engineering Specifications

CONCEPT GENERATION & EVALUATION

The team agreed that sensors seemed to be the right approach to pursue and with this in mind a list of different sensor options was created. A Pugh Analysis was performed in order to compare the benefits of the alternative solutions the team came up with. The option chosen had to be able to fit within budget, be safe for the operators, be able to resist a dirty manufacturing environment, not interfere with the operators during work and be a feasible option that would optimize the performance of the forging operation. After the analysis, the use of a laser sensor was concluded to be the best option to go with. After some research, a Time-Of-Flight laser sensor was chosen as the option that would best fit the customer's needs with the project constraints presented. Once the type of sensor was decided upon the team conducted a site visit to better understand the customer's constraints. After analyzing the collected information the team came up with a solution that would require at least six sensors. Following the preliminary system design a detailed design was developed using the understanding of the customer's specifications and constraints. CAD models were developed and the use of different engineering concepts was used to come up with a system design that would fulfill the requirements presented by Wyman Gordon.

MECHANICAL CONCEPTS

Section 1 – Sensor Bracket System

The team was assigned a specific forging operation to design a proof of concept for, but also had to take in consideration that the system would eventually be applied to different forging operations. The system needed to be flexible enough to adapt to different geometric scenarios. The solution was to develop an adjustable space frame that would allow the users to position the individual sensors to locations where they could reference particular points on the forging die and pre-form. In addition, the setup, spatial orientation, and operation of the Bracket System had to be minimally invasive on the forging process.

Given the time constraints surrounding the 22 week curriculum the team was referred to Minitec of Victor, NY for structural space frame solutions. Minitec is a manufacturer of modular t-slotted aluminum framing and accessories. Using the wide range of accessories that Minitec offered, the team was able to derive a vertically and horizontally adjustable solution using two linear guides connected orthogonally.

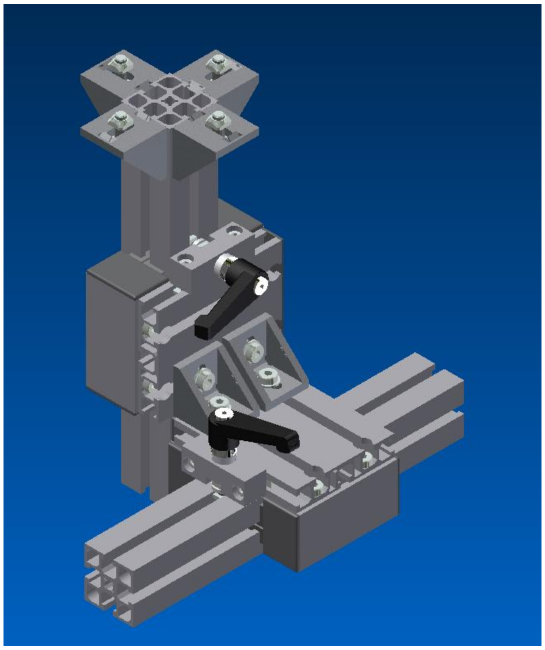

Figure M.1.1

Solid CAD models published on Minitec's website (minitecframing.com) allowed the team's designers to quickly formulate three-dimensional concepts.

Referenced in Figure M.1.1, the orthogonal linear guides allowed for the necessary two-degrees of freedom adjustability. The cantilever-handled pressure locks maintain positioning of the guides incase of accidental impact and in addition aid the vertical member in bearing the weight of the sensor and sensor enclosure.

Interference and risk of damaging the sensor on the east side of the die presented the team with the difficulty of offsetting the eastside sensor to the north side of the impression-die. To solve the issues of orthogonal sensor layout the team designed a cheap mirror reflector that would allow the sensor to maintain an orthogonal reference on the eastside. The concept is illustrated in Figure M.1.2.

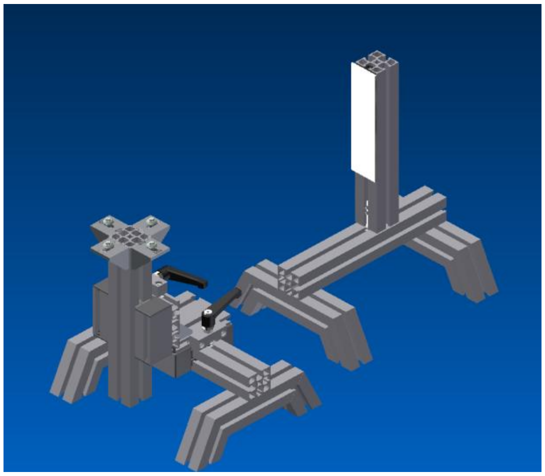

Figure M.1.2

Section II – Magnetic Anchoring System

The Sensor Bracket System is set atop the shoe of the forging press, which is the steel base upon which the impression die is set and locked. It is pertinent that the Bracket System is secured to the shoe, but there is a lack of mechanical fastening features that would properly accommodate the variable positioning of the system. To overcome the issue the team devised magnetic anchors that attached to the Bracket System through aluminum L-brackets. The design calls for magnets with 75-100 lb. capacity, enough normal force to resist accidental impact from the operators working on and around the shoe.

Figure M.2.1

The overall design concept is illustrated in Figure M.2.1.

Section III – Sensor Enclosure System

To ensure the Time-of-Flight lasers are protected from the harsh manufacturing environment, they are enclosed in a protective case. The key elements to be concerned with is impact damage from forklift and/or operators mistakenly striking the box as well as thermal considerations. The sensor was packaged within an aluminum enclosure lined with thermal insulation. The rear of the box contains the communication line to the laser and the front contains a viewport for the laser's optics. To prevent debris from entering the viewport of the enclosure, a manual shutter is added to be closed when lubrication/smoke/water/pressurized air is applied to the area.

Section IV – Insulation

To prevent the sensors from the high temperature environment produced from the 700-900°F die and 1700 - 2100°F Billet pieces, fire rated thermal insulation was used. Advanced Materials provided us with Super Firetemp M; an inorganic, noncombustible high temperature insulation for use in fireprotection systems. It can be used in systems operating up to 1800°F (982°C), well above the ambient temperatures seen within the working area.

Section V – Display Enclosure

A part of the customer needs was to develop a large easy-to-interpret display that communicated the necessary corrections to the pre-forms deviation. The mechanical design of the directional display is to enclose the electronic boards that light up the markers. An electronic enclosure was purchased and the enclosure was modified to fulfill those necessities. Utilizing RIT's Brinkman lab, proper sized relief panels were machined into the cover of the enclosure to allow the directional markers to shine through. In addition, proper holes were drilled in the container of the enclosure to accommodate standoffs that properly positioned the electronic PCB boards

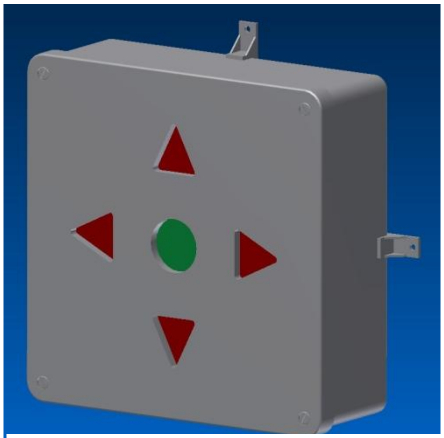

Figure M.1.1

that the directional markers were manufactured on, illustrated in Fig. M.5.1.

ELECTRICAL CONCEPTS

The locator system provides active feedback through the use of a display module. The module consists of four red arrows and a center green circle as shown in Figure E.1.1. The color of the elements is determined by the type of light emitting diode (LED) installed on the PCB during assembly. These LEDs are extremely bright and are very durable. The five display pieces are made up of five individual printed circuit boards (PCB) that are arranged inside the enclosure to give the final display appearance. By using only five elements and using basic shapes colors of red for a no-go condition and green for a go condition the display is simple to understand and fast the read. This is ideal for the manufacturing environment that the system will be deployed in.

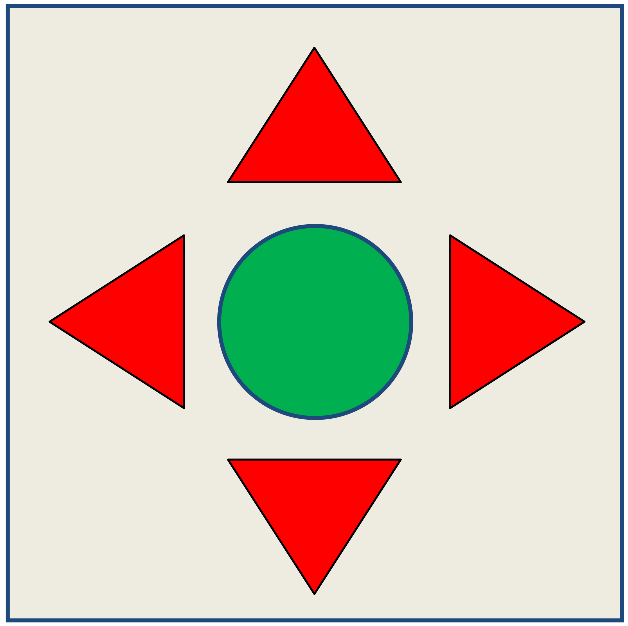

Figure E.1.1.- Display Module

For ease of assembly and cost of production, the PCB was designed in a manner that allowed both of the desired elements of the display to be assembled on the same board. The use of 0ohm jumpers allows the PCB to be configured based on the intended use.

The board consists of six main inputs which are the four alarm signals generated by the lasers, a 24V input and a 16V input. To reduce the number of components required for the boards and simplify the circuitry the board were built using the 16V to 24V differential that was available from the alarm signals and the laser power supply. The alarm signal functions by switching between 16V when the alarm condition is not met and 24V when the condition is met. The alarm condition is set based on whether the measured object is within a desired range.

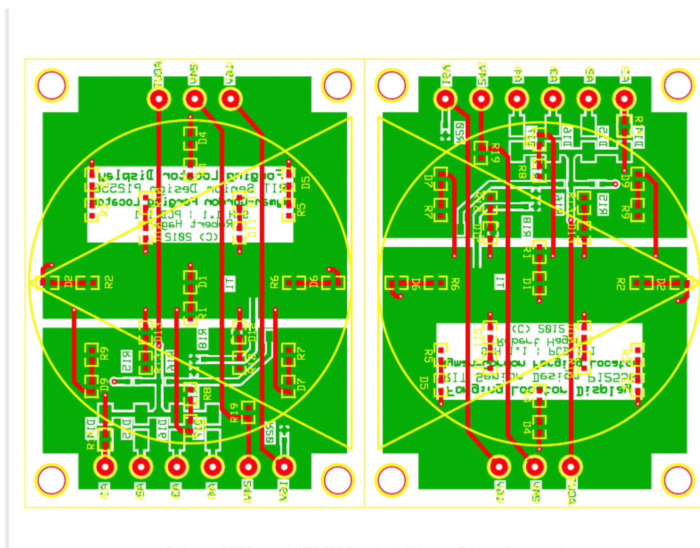

Figure E.1.2.- PCB layout

The logic that lights up the red arrow is only dependent on one laser and as a result the arrow circuitry is very simple. By supplying the board 24V and tying the alarm signal to the ground line the arrow will turn on when the alarm is in a low state and supplying 16V the ground circuit is completed and the arrow turns on. This indicates to the operators that the work piece must be moved in the direction the arrow is showing. There are a total of four arrows on the display which are each tied to the corresponding laser which makes up the four possible directions the piece could have to be moved on the die.

The second element of the display is the green circle which indicates that the piece is placed correctly. The logic for this board is the same as an AND gate. If any one of the alarm conditions are not met, creating a signal low state, then the circuit will remain off. When all four of the alarm conditions are met the green element will light. To reduce components and improve board simplicity the AND logic is implemented using four diodes, three resistors and a Darlington transistor. When any one of the four alarm signals is low it pulls the gat signal of the transistor below the threshold voltage which turns the transistor off. When all four lines are high the gate voltage exceeds the threshold voltage which turns the transistor on and lights the LEDs. A basic circuit diagram of this element is shown in Figure E.1.2 below.

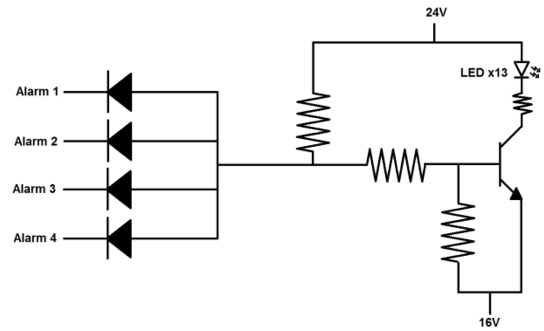

Figure E.1.3. – Control circuitry of center display element

Laser Distance Sensor

The Laser Distance sensor used in the design of the system is the Micro-Epsilon optoNCDT ILR 1181-30 time of flight sensor which was specked out by the team. In comparison to Triangulation sensors, Time of Flight sensors are much cheaper and able to fit the budget alotted to the team for this project The time of flight sensor offered the ability for repeatability of measurements below the .5mm range which is below the specification of 6.35mm required by the customer. All other options of time of flight sensors do not have the repeatability of this laser making it the only possible time of flight laser. The laser also has data acquisition software and programming ability to make it easy to retrieve measurements and work with. The response time of the laser ranged anywhere from 100ms up to 6s making it a slower choice depending upon the range of the measurements being performed and the reflectivity of the surface being measured. While this is shown to be quick enough for the application being utilized it would be ideal to have a faster response time. For future iterations an ideal case would have the ability to purchase tribagulation lasers for a much more precise measurements and faster response times.

Figure E.2.1.- Image of Micro-Epsilon optoNCDT 1181-30 Time of Flight Sensor

Computer Interface

An Acer netbook was specked out by the team in order to interface all of the lasers. RS422 to USB converters were needed as well as an eight port USB hub to allow all of the lasers to communicate to the netbook. The netbook needed very little computing power as the program takes very little in terms of computing resources. The computer was chosen for the quality brand as well as larger screen and lower cost.

Programming

Custom code needed to be written in order to perform all zeroing of the lasers at once. This allows all of the lasers to reference one another in order to set up the coordinate system for the piece about to be measured. Separate code was utilized in order to extract single point in time measurements from the laser and to present them in an excel spreadsheet. The current software which preforms data extraction only does so separately and presents the data over a range of time. The new software presents all of the data together and in a neat and concise manner at a single point in time. This makes it easy for operators to simply run the zero program before the piece is loaded into the billet. Then right before the press occurs run the next program to extract all of the data.

TESTING

In order to meet the engineering specifications provided to us by Wyman Gordon as well as specifications we deemed necessary for proper functionality, appropriate testing was conducted. To test impact resistance, a modified drop test derived from the MIL-STD 810G Procedure IV Transit Drop protocols was implemented. The enclosure (without laser or insulation) was dropped at a height of 48” on three sides likely to be struck in the work environment. Testing reveal no significant damage that would result in the failure of the enclosure. The damage recorded was the loosening of the shutter rivet and compression damage to a screw fastening the enclosure cover to the base.

Sensor testing was conducted and met the advertised specifications.

CONCLUSION AND RECOMMENDATIONS

In considering the process that we followed throughout the past twenty-two weeks we have several conclusions and recommendations to improve upon. The budget, nearly twenty thousand dollars, speaks to the size and scope of the project and is one of the largest budgets approved for the multidisciplinary senior design course. Managing such a large scale project on a twenty-two week schedule was difficult, especially when managing a full course load in addition to the project.

One of the first issues we initially encountered was defining the problem and understanding the needs of the customer. It was difficult to properly extract the customer’s needs via teleconferences. We eventually had to conduct a customer visit. The fact that the customer was located in North Grafton, MA (which meant an overnight trip) prolonged the visit until week four. In retrospect the visit should have occurred in weeks one or two. In addition, we did not acquire the necessary data package from the customer, detailing layouts, until week six.

In addition, we could have attempted to better understand the customer’s needs through asking more questions. Our initial approach was to observe the process and take-in voluntary information to build our customer needs, but as the design process progressed we found additional customer needs to be fulfilled. As a result, several weeks were wasted on trial and error type design discussions.

Another issue was encountered when we got the chance to sit down with the customer and speak during our visit. The initial understanding from the customer was that we were devoted to the project for a one full year. The customer did not realize that we were only given 22 weeks to research, design and develop the system. In hindsight we should have conducted a teleconference meeting with the customer prior to our visit, outlining our schedule and course requirements that we needed to meet so that the customer understood our own needs. We realized that this is synonymous with the proposal contract that a design consultant would draw up in the beginning of the customer affairs.

The initial design that the team developed required a vast quantity of customized parts that needed to be machined. We did not have much time for machining and therefore had to redesign several subassemblies of our initial design proposal in week fourteen so that the design would accommodate pre-assembled parts that we could purchase off the shelf. The amount of invested time into the design was grossly underestimated in the beginning, and we were reluctant to trade our money for time savings. We should have been more decisive in the first ten weeks to develop an off the shelf design. This would have allotted us more time to manage other aspects of the design such as our test plan.

There were many small points that we could have streamlined to save more time. We came into the project with the assumption that our customer understood our own needs and later on assumed that we understood our customer's needs. The conclusion is that we could have saved a lot of time by properly executing several phases with more attentive detail.

REFERENCES

Minitec Framing Systems, LLC – www.minitecframing.com
Micro-Epsilon – www.micro-epsilon.com
McMaster Carr – www.mcmastercarr.com

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