Spring 2018

MHT Assembly Line

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Honors Senior Design Project

MHT Assembly Line

The University of Akron and LuK USA

Sean Lundholm

Department of Mechanical Engineering
Class of 2018

Project Sponsor
Dr. Gopal Nadkarni

Company Mentors
Gabe Pyers and John Dunham

Spring 2018
Executive Summary

The purpose of this report is to record the process followed and steps taken to design and implement a new product assembly line. While the implementation of the line required more than what is in this report, the projects outlined are those I was personally involved in and responsible for. This report will outline why the project was required, the steps taken to complete the project, and the challenges faced. Throughout the progression of the project, many different parts and areas were considered. As each of these was brought into focus, new challenges presented themselves and were dealt with accordingly. Due to confidentiality of the project, many aspects could not be shared and were omitted or blacked out from this report. This project was a huge undertaking for all involved and it has been very rewarding to see it all unfold and culminate successfully.

Acknowledgements

I would like to thank my managers/mentors, Gabe Pyers and John Dunham, who have taught, guided, and supported me throughout this as well as many other projects. They have provided me with valuable opportunities and wisdom throughout my time under their supervision and leadership. I have no doubt they have made me a better engineer, co-worker, and employee.

I would also like to thank my parents and family for supporting me and providing me opportunities, not only now, but throughout my life. I would not be where I am now without them.

Finally, I would also like to thank my project sponsor, Dr. Gopal Nadkarni, for his support and guidance throughout this process. I am also thankful to the University of Akron and all of the faculty and staff for helping me reach the position which I am now in.
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Introduction

As time moves forward, technology advances. What was state-of-the-art 10 years ago is now rendered obsolete. In industry, the survival of a company is based on its ability to stay competitive, which requires development of cutting-edge technology. The automotive industry is no exception. Over the past decade, vehicle manufacturers have raced to improve fuel efficiency while also delivering the power, safety, options and capabilities consumers demand. Hybrid and electric drive technology have been one of the largest areas of focus for efficiency in the last decade. The concentration of most automakers is to either replace or complement the internal combustion engine with an electric motor. However, from a transmission company’s point of view, there is a different approach as to how this can be accomplished.

Called the ‘MHT’, the Modular Hybrid Transmission brings the traditional automotive transmission to the forefront of hybrid technology. While this new and innovative product helps our company enter a new market, it presents unique challenges on the manufacturing side. In the past, new products were adaptations and updates to existing ones. This allowed for the products to be built on existing assembly lines. However, the MHT is an entirely different concept and requires special accommodations. Therefore, a new assembly line had to be designed and built from the ground up. Through careful planning, extensive communication, international collaboration, and several revisions, the MHT assembly line was designed, built, and installed.
The Gantt chart in Figure 1 illustrates the project milestones and their beginning and ending dates in addition to duration of time to completion. The dates stated here were successfully met for the majority of the project.
Machine Descriptions and Specifications

While the MHT is an entirely new product, it is still akin to the conventional torque converter with slight modifications. Because of this, a smaller existing assembly line was overhauled for the production of the MHT torque converter (TC) subassembly. In addition, space was created for a new machining area as well. Both of these processes are considered out of scope of this project and were handled by other engineers.

The complete MHT assembly consists of three main subassemblies, effectively requiring an assembly line for each, totaling four (three subassemblies, one final assembly). To save on space and cost while still having the capacity to meet annual demand, all subassemblies and the final assembly could be manufactured on the same line. Each separate product run was referred to as a ‘Pass.’ The use of these passes, though, would necessitate the changeover of several of the stations (i.e. changing press tooling).

In order to produce the MHT assembly, 34 stations were essential on the assembly line. Descriptions of the stations were drafted to begin building the foundation of the plan. Knowing the machines required would help to determine cost, cycle time, manufacturability, operators, and so on. For brevity of the report and for confidentiality purposes, one sample station machine description follows.
Station: 150 – 2 Ton (20 kN) Press
Pass: 3 – KO Ball Plugs

Parts to be assembled: KO Subassembly – KO Ball Plugs (x2) –

Assembly Drawing: [Diagram]

Process Description: Operator load ball plugs (possible use of tool); press plugs into subassembly

Process Controls: Force/travel monitoring; part height check at station 160, NOK parts to be rejected by machine

Process Parameters: Press ball plugs at 2500 lbs (11 kN)

ALDS tracking: Scan DMC when subassembly enters line; no new DMC until pass is complete

Changeover: Easy change tooling; max changeover time of 10 minutes

Figure 2 – Sample Machine Description

2D Layouts and 3D Models

Once the machines were determined, the physical space for the line had to be allocated. The area designated for the MHT assembly line was a previously used bay, meaning there were existing size constraints that had to be considered. This presented a challenge right off the bat.
The MHT line was much longer than the line which previously occupied the bay. While considering the layout, one also had to consider the flow. Part carriers, the mobile build ‘platforms’ on which the part rides from station to station, must be able to return to the beginning of the line. Therefore, the end of the line must reconnect with the beginning. If the line were to resemble a straight line, this would be possible through a return beneath the work in progress (WIP) conveyor. Considering the size constraints mentioned earlier, however, the only way to fit the line within the bay dimensions was to create a ‘U’ shaped line. The return carriers could then travel back to the beginning via an elevator system. The close proximity of the beginning and end of the line due to the ‘U’ shape was of benefit through the reduction of required carriers on the line. The layout went through several revisions including the addition and removal of a few stations as machine sizes and locations changed.

Figure 3 – Initial line layout
As the 2D layout was finished, 3D models of the line were generated in order to project a more realistic depiction of the new line.
Part Work Flow

After establishing the 2D layout and determining the function of the line, the part flow around the line could be laid out. In order to allow the carrier on which the in-process parts travel to return to the first station, an elevator system was used to bridge over the open end of the ‘U’. Parts would enter through one end of the ‘U’. They would then travel down the line in a linear direction, stopping only at the stations required for its construction, dependent on the pass. Certain passes would not require the use of specific machines on the line. This part travel would be controlled by a computer system running the entire line, telling each station whether or not the part should be stopped for an operation. Parts would come around the bottom end of the ‘U’ and return toward the beginning down the second leg. Once reaching the end, the part would reach a pack station and be removed from the line and placed in packaging. The empty carrier would then return back to the beginning station for the next build cycle.
Material Work Flow

In order to assemble the parts, the material had to be delivered to the operator in a time effective and ergonomically sound way. The use of conveyors to bring material in through the back of the line was employed. Incoming material would be stored in a plant-wide supermarket, just as it is currently for other products. Operating on a lean ‘pull’ system, which reduces waste by allowing operations downstream to request parts as they are needed, tugger drivers would gather the necessary parts and deliver them to the line every two hours. The tugger, which operates like a train, transports the materials to the assembly line, where it can drive down aisle ways on either side of the ‘U’.

On the first leg, conveyors would run from the aisle to the operator under the assembly line. As the tugger passes by each station, the driver would drop off the materials on the corresponding conveyor. The material totes would then wait on the conveyors until the operator required another tote. The operator would then place the empty tote onto a return conveyor running over the assembly line back to the aisle and place the new tote onto the stand next to them. Empty totes would also be collected by the tugger driver and brought back to the supermarket.

On the second leg, the operators’ backs would be to the aisle (facing the same direction as the previous operators), so the incoming material would come in from behind. Evaluating pack density of the material totes, it was determined the material did not need to be fed directly to the operator. Rather, flow racks could be set up at two different points. These would hold the material until the operator walked over and grabbed a new tote. This was deemed acceptable as the highest frequency of this action would be every half hour for an operator.
MTM/Operator Usage

One of the most useful and powerful documents created was the Motion Time Management spreadsheet (MTM). At this stage, the flesh began to appear on the bones, so to speak. An assembly line and a product were envisioned, but now it was time to determine how the assembly was to be built. The MTM would lay out each and every motion taken in order to assemble the product, from beginning to end. This was extremely helpful as a basis going forward as it helped combine and determine operator steps, machine movements, time studies, part numbers, and operator usage. From this, cycle times could be determined, bottlenecks located, and labor could be focused. It was here that the assembly process took a huge step from idea to reality.

Through process studies, the order of assembly was determined for each station. Based off of the machine descriptions and the established line layout, the assembly by station was known. Therefore, the materials to be added at each station were determined. For example, if a riveting press was next on the line, the rivets and components to be riveted must be assembled at the station prior. The order to which the components and rivet were assembled was studied and timed here. The results of these studies were added to the MTM. Machine times were also estimated and added.

With the estimated cycle times for each station established, the times could be analyzed. Bottlenecks were identified and labor time was used to determine the required number of operators and the stations for which they would be responsible. Process improvements after this point were found and made using the MTM. For example, a process which was not required at a bottleneck station was moved to another station to both reduce cycle time and incoming material.
Figure 7 – MTM Graphical Overview of Assembly Line
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Figure 8 – MTM Overview
Figure 9 – Single Pass Overview
CONFIDENTIAL STATION OPERATIONS

Figure 10 – Single Station Overview
Figure 11 – Operator Plan for a Single Pass
Operator Instructions

As with anything requiring assembly, instructions are vital to build parts in standardized manner. The same is true in a manufacturing environment. The planned assembly process must be documented and published as well as provided to the operators. This is critical to maintain accountability, efficiency, controllability, and quality throughout the assembly process.

Schaeffler has a standardized document template for such instructions. The instructions were written up based on a tested method of assembly, which was modeled in the company’s Methods Room. This same tested procedure is what was used as the time study basis of the MTM. Any and every move the operator must make has to be recorded. If it is not documented, it cannot be expected to be performed. Two examples of the operator instructions follow (Figures 12-16). Part numbers have been blacked out and images of parts have been removed for confidentiality reasons.

In the examples, both start with the scanning of incoming parts. Tracking and traceability of parts is kept in the company’s computer system, which monitors production. If a batch of incoming parts were found to have defects after they were built into assemblies, then the affected assemblies could be quickly identified. This is very important for quality control purposes. The instructions then show the step or steps which must be taken at each station. Finally, all manual stations require the operator to either release the part to the next station or run the machine at the current station by pressing a touch pad.
Station 130, Pass 4
Hex and Ball Plug Installation

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<th>Visual</th>
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<tr>
<td>Parts to be scanned:</td>
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</tr>
<tr>
<td>Hex plugs -</td>
<td></td>
</tr>
<tr>
<td>Ball Plugs -</td>
<td></td>
</tr>
<tr>
<td>Housing Dowels -</td>
<td></td>
</tr>
<tr>
<td>Stator Dowel pins -</td>
<td></td>
</tr>
<tr>
<td>(batch)</td>
<td>(batch)</td>
</tr>
<tr>
<td>(batch)</td>
<td>(batch)</td>
</tr>
<tr>
<td>2. Assemble 2 hex plugs in housing.</td>
<td></td>
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</tbody>
</table>
3. Tighten by hand.

4. Insert ball plugs into housing channels.

5. Place dowel pins in block on carrier. Stator dowels go on the left, housing dowels on the right. Vision to check.
6. Press palm button to release.
Station 150, Pass 3
K0 Ball Plugs

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<tr>
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<td>2. Place 2 ball plugs in the 2 holes at the</td>
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<td>end of the K0 shaft.</td>
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Figure 15 – Second Sample Operator Instruction (page 1)
3. Run press.
Lift Assists/Ergonomic Accommodations

Lift Assists

Schaeffler’s ergonomics policy states that no one is to lift a load of more than 35 pounds without the use of a lift assist. This policy is in place to reduce the risk of operator injury, especially of the back, due to heavy lifting or twisting motion. The weight of several components, as well as completed assembly, exceeded 35 pounds and required the design and implementation of lift assists. As with other lift systems throughout the plant, a pneumatic system would be used. These systems have many advanced safety features to prevent misuse and injury. For example, the lift will not allow the operator to release the part if it does not sense the part is supported, as it would be when it is placed on the assembly line. Thus, an operator could not lift a part and release it over their foot, for example.

For the application of the MHT assembly line, special custom gripper tooing was required to grab the parts. In many cases, the design was complex due to the limited area of possible mounting surfaces on the parts. Gripper and pad materials were also specially chosen to ensure they would not damage the surfaces of the part which they came in contact with. In total, four different lift assists with unique tooling were developed. These assists, however, were designed in conjunction with the company producing the systems, and therefore the designs, drawings, and pictures of the products are confidential and cannot be shared.

Ergonomic Material Stands

To increase operator morale and efficiency, the ergonomics of the assembly process must be carefully considered. Repeated motions, outside of optimal working areas from the operator, can cause excessive fatigue and eventually chronic pain. Given that every person is different, optimal working areas vary. Because of this, the placement of the totes from which the operators will pick the material must be able to accommodate a variety of people.
Conveniently, the physical assembly line had a two t-slots available for mounting. These could be used for fastening the stand. A quick test was conducted to ensure this mounting method could hold the weight required without damaging the line. A fixture was made (Figure 17) and attached to the t-slot in two locations, positioning an eye-bolt a distance of 9 inches from the line, approximately where the center of mass of the stand and material was expected to be. A load of 70 pounds was then applied at this location, inducing a moment of 630 lb.-in. The line showed no signs of bending or yielding. This proved a moment of 630 lb.-in was acceptable.

![Custom fixture made to test torque applied to line](image)

Initially, visions for the stands were along the lines of two arm link, much like a monitor or TV stand (Figure 18). This stand would have two pivoting points and gas piston on one arm for height adjustments, allowing the stand to be placed anywhere in an x, y, z coordinate system. The limitations of systems like these are weight as well as durability, both of which are important in a manufacturing setting.
Concerned about the aforementioned drawbacks of weight capacity and durability, alternative models were explored. In order to consider other designs, the optimal working area required for the operator and the effective area of the stand were established and compared. It was decided the most important variable movements would be the height and distance (z and x axis, respectively). Figure 19 shows the coordinate system referenced.
The stand would be fixed during use but could be adjusted easily by the operator. Adjustments along the x-axis, laterally on line, could be made by loosening the screw on the side. Height changes could be made by pulling a spring plunger on the side and sliding the vertical bar. This design was much more robust and compact while still meeting the requirements (Figures 20-22).
Figure 21 – Side view of stand

Figure 22 – View of back of stand
Custom Production Tooling

Having the proper tool makes all the difference in efficiently and effectively completing a job. Improving the ease and speed of the operators’ jobs benefits the company in many areas, including increased production, quality, and morale. In the following cases, issues were identified and solutions were brainstormed, designed, prototyped, tested, and produced. These examples follow the true spirit of a design process. Due to confidentiality, the tooling cannot be shown on the part as it will be used in production.

Dowel Pin Locator

During the building of a subassembly, referred to as a housing, there are two dowels which are press fit into corresponding holes in the housing. Because they require a press fit, it is not possible for the operator to pre-position the dowels into the holes before pressing. This required the implementation of tooling to position these dowels for the press. Brainstorming took place and an initial design was modeled. The model was tested for fit and interference in the modeling software and then the design was 3D printed. The tool consisted of two separate pieces, each locating on the unique footprint of the area surrounding the dowel hole (Figures 23 & 24).

Figure 23 – Top view of first concept, 3D print
This design, however, utilized an as-cast mounting surface, which did not allow for tight tolerances to be held. Consequently, the project went back to the drawing board and a new concept was generated. After reconsidering options, a design was created utilizing two pin style features to prevent tool movement in a translational as well as rotational manner. Slip fits would be used to allow the operator to easily position the tooling. A revision of this design was made to ensure the tool was poka-yoked, meaning it was made to only work in one orientation so as not to allow the operator to use it incorrectly. The design was again prototyped through the use of a 3D printer (Figures 25-27). An additional piece, referred to as a ‘spacer’, was also created to allow for the tooling to be used for both variants of our product.
After the full-size prototype was tested and approved, the drawings were sent out to be machined out of Delrin (a type of resin). This material was chosen for its durability, impact and chemical resistance and machineability, as well as for its low risk of damaging the part. The tooling also featured two press fit hardened steel bushings for contact with the dowels. This material would prevent wear from repeated use. The machined part was tested and functioned as designed (Figure 28 & 29).
Figures 30 & 31 are copies of the prints sent out to the manufacturer. Confidential dimensions have been blacked out from the prints.
Press fit dowel and bushings
Top of dowel/bushing should be flush with surface

Figure 30 – Drawing of Dowel Locator Assembly
Figure 31 – Dimensioned drawing of main component
Housing Blocks

A second tool was also designed for use on the housing subassembly. During the placement of another component via a lift assist, there were concerns that contact between the parts or with the lift assist during installation could damage the housing. Therefore, a tool was requested for the protection of the part. Locating features were analyzed and possibilities were considered. It was decided the tool could actually consist of three individual pieces. This would benefit the operator by reducing weight and increasing the ease of handling and positioning as opposed to a single, larger tool. The tooling would still be effective if three strategic locations were chosen around the part. This design went through several iterations before being produced, varying locating features and size of tooling. For the last concept, only holes held to tight tolerances denoted as ‘significant characteristics (SC)’ on the print were used. Tests were conducted to ensure the tooling would not damage the part itself. The final design was poka-yoked to ensure the tool could only be used one way. Figure 32 shows the 3D generated model and figure 33 shows the finished CNC result.

Figure 32 – CAD model of Housing Blocks
Figures 34 & 35 are copies of the drawings generated for the blocks. Confidential dimensions have been blacked out.
Figure 34 – Drawing of a Housing Block Assembly

Press fit dowels into block
Dowel should be flush with top of block.
Figure 35 – Dimensioned drawing of a Housing Block
The final tooling was improved by adding a taper to help guide the installed part into the housing, again making the operator’s job easier. The material chosen was a hardened steel for resistance to repeated impact and scraping which was expected to occur. A tool holder was also designed and fabricated out of stainless steel by a laser cutter and metal bending brake (Figure 36 & 37). Slots on either side of the tooling allowed for easy access for the operator. This holder implements the lean manufacturing principle of 5S (2\textsuperscript{nd} S; straighten).

![Figure 36 – CAD model of tooling and holder](image1)

![Figure 37 – Finished tooling and holder](image2)
**Changeover Instructions**

Similar to the operator instructions, the changeover instructions were used to make sure the changing of machine tooling followed a standardized process. With the assembly line being used for multiple subassemblies, as well as the final assembly, machine tooling would differ depending on the part being produced. The changeover instructions are a detailed, illustrated, step-by-step procedure for how one is to prepare each station for production. Much like the operator instructions, these instructions help to maintain accountability, efficiency, and controllability. The following is an example of the written instructions (Figure 38 & 39). Pictures of confidential tooling as well as the tooling numbers was required to be blacked out.
1. **Purpose**
   This Work Instruction is to ensure that all qualified personnel use a standard changeover procedure.

2. **Scope**
   This Work Instruction applies to Station 150 for all passes of the MHT Final Assembly Line.

3. **Definitions and Terms**

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4. **Procedure**
   Passes 3, 4, & 5 require Station 150. Press tooling must be changed over dependent upon the product pass.

   4.1 Pass 3

   Pass 3 requires tooling to press ball plugs into the KO shaft.

   4.1.1 Pass 3 tooling

   4.1.2 Remove existing tooling in top by pulling the silver knob out and swinging the blue arm from right to left. Hold the current tooling while doing so as it will drop when released.

---

*Figure 38 – Example of Changeover Instructions*
Install bottom tooling by positioning tooling into place and rotating locks over tooling.

4.2 Pass 4
   - Pass 4 requires tooling to press the bearing and snap ring into the housing.

Figure 39 – Continued example of Changeover Instructions
**Machine Prove Outs**

As machines began to arrive on site and were installed, testing had to be conducted to ensure the machines operated as specified and were capable of producing good parts. Some requirements of the prove outs included changeover time, manual and machine cycle time, nominal machine forces and travel, creating process tolerances, as well as possible failure modes and results.

Changeover and cycle times were recorded by actually performing the task. Both times related back to the MTM, Operator Instructions, and Changeover Instructions. The estimates laid out in the MTM for the individual steps of assembly could now be confirmed. The Operator and Changeover Instructions were also verified and updated to match the final assembly process as these documents would be used in production.

In a first of its kind for our location, new presses monitored the force (in kN) and travel (in mm) of the machine as it went through the operation. With this monitoring ability, one could plot these values and perform statistical analysis to determine the bounds of the process. Measurements, such as nominal force, were calculated in multiple ways. Initially, force was calculated theoretically through part design and FEAs (finite element analysis). Once known, the machine could be specified for the required capacity (i.e. 25 kN, 100 kN). These force values were used in the machine and process descriptions created at the beginning of the project.

As the parts were manufactured in the prototype department using non-production methods, a hydraulic press was used. By calculating the cylinder area from the diameter, the force applied on each component could be found by monitoring the pressure (F=PA). This allowed expected production force to be determined and was subsequently the starting value used in machine prove outs. By monitoring the force at the machine during the operation, one could see the point at which the press bottomed out through the part by monitoring for when the slope of the travel-force curve went nearly vertical.
Figure 40 – Force vs. Travel curve of a set of parts

If this slope were never reached, it was most likely due to the fact that the part was not completely pressed and the force must be increased. In Figure 40 above, it can be seen the part bottoms out at a little under 304 mm of travel and requires roughly 4.5 kN of force to get there. The vertical slope at the far right of the graph shows the point where the machine is applying force against itself. All test parts were numbered according its recorded press data and print callout dimensions were measured to ensure parts were in specification.

Tolerances could also be created from this data. With these tolerances, abnormalities in the machine process would be able to be detected and those parts would then be red flagged. This process helps to track possible bad parts or failure modes. The data in Figure 41 below shows process tolerances and parameters applied to the experimental data. The tolerances are the red upper and lower bounds. These tolerances were based on standard deviations.
People make mistakes, but one must ensure these mistakes do not reach the customer or result in damage to the machine or injury to the operator. For instance, one part requires the pressing of two identical plugs in a single motion. In the event an operator was to forget one, or even both, would the machine be capable of detecting this? Both of these conditions were tested and our system was able to detect this possibility by recognizing the travel-force curve was not in specification. The data in Figure 42 shows the results of these trials. The red ‘tolerance’ lines were determined from the experimental data and applied to the graph. Part 300, the green line, is a good part with both ball plugs present. Parts 636 and 637 (orange and blue), had only a single ball plug. The force detected by the machine was roughly 55% of what we would be expected. The force with no plugs, part 638 (purple), was approximately 0 until the press
botted out. With the tolerances determined from the experimental data, both of these failure modes fell outside of our created tolerances and would be rejected in production.

Figure 42 – Detection of failure modes

Another process required the operator to flip the part for that specific operation. The part geometry differs on each side. However, if the operator were to fail to flip the part, the component being pressed would not incur a force until it bottomed out on another component. It would never find the press fit feature as it is intended to be assembled on. In this case, the machine would detect that it had not registered a force by the travel distance at which it expected to see a force, similar to the failure modes graphed above. This would fault the press and the part would be rejected. The opposite situation was also tested. If the operator were to flip a part which did not require the part to be flipped, the machine would crash with the part as it was still in motion to its press window (expected distance) because the part geometry is much higher than in the correct orientation. To prevent damage to the part or press, if the machine sees a force before it expects the load, the machine will again fault and reject the part.
**Capability**

After determining tolerances and verifying failure modes, the machine and process capability had to be calculated and approved. Capability was quantified by Cp and Cpk, which are statistical values determined experimentally and based heavily on the standard deviation. The equations for Cp and Cpk are as follows, where the USL is the Upper Specification Limit, the LSL is the Lower Specification Limit, μ is the mean, and σ is the standard deviation.

\[
Cp = \frac{USL - LSL}{6\sigma}
\]

\[
Cpk = \min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)
\]

The target value of an existing capable process should be 1.33, however with this being a new process the target should be set to a value of 1.67. Six sigma requires this number to be 2.00, resulting in only 3.4 defective parts in one million produced. Utilizing Excel to manage and organize the experimental data collected, Cp and Cpk were calculated and resulted in 2.59 and 2.16 respectively. Both values exceed the six-sigma target, proving the process as capable.

**Conclusion**

In order to produce good parts, a company needs reliable and consistent processes. Throughout the undertaking of this project, everything was designed to create the best processes and ergonomics possible. The best practices currently in use were adopted while inferior methods were avoided. In a project such as this, the old adage “measure twice, cut once” is very important as mistakes in this stage will translate to major headaches in production.

This project allowed me to apply what I have learned throughout my coursework as well as what I have learned during my other co-op rotations. I was able to approach many aspects of this project in a similar fashion as I did with class design projects. As an engineer, it is very satisfying to see concepts on paper become a reality.