Measured Process Identification

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Abstract **—** This project is created to reduced scrap and redirect the actual process of the bending and fabrication of tubes and hoses expressly made for aerospace purpose at Eaton Aerospace. The bend process consists on the manipulation of a straight tube giving different direction, angles and rotations to achieve a different form or contour on the tube. Parts could get to have over 20 bend in the same tube and get to measure more than 3 ft. Everything will depend on the design and structure needed on the aircrafts.

Key terms **—** *bend, Clark fixture, MYLAR, orientation*

INTRODUCTION

This project was developed at a facility that manufactures hydraulic hoses and tubing for aerospace industries. Sometimes, as times passes, the vision or purpose is lost, the importance of what is done, the why and the how are forgotten. This phenomenon also happens in organizations, governments, institutions, companies and even civilizations. As time passes, these organizations start experiencing this "big problem," which results in loss of control. In regulated industries, loss of control could result in monetary loss and could cause a crippling situation. For example, what happened to this company was huge loss due to improper procedures and quality verification of the product. The bend process and the actual verification that is currently being done will be explained in the next section.

Before starting this explanation, we must acknowledge that all the tubes manufactured at this facility must comply with the AMS standard. This standard regulates the tubing's processing [1]. For example, the majority of the tubing is processed as metal sheets and then they are rolled into the diameter desired by the customer and then are welded, creating a seam on the tubes. For the bending process, a CNC machine (figure 1) is used.

Figure 1
CNC machine

This machine [2] has the capability of bending tubes from 0.250" to 4" in diameter. For completing this job, the machine utilizes several tools that are essential to the process [3], [4]. They are as follow:

- **Collet:** Closed on the back of the tube to prevent the tube from moving out of position or off the machine.
- **Rod:** Connected to the mandrel to help direct it on the inside of the tube.
- **Mandrel:** Placed inside the tube, for giving direction and support to the inside of the tube.
- **Wiper die:** Helps direct the tube during the bending process and helps prevent the tube from losing ovality.
- **Radius die:** Located on the stationary section of the machine, it is the die that will give shape to the bends.
- **Clamp die:** Maintains pressure between the tube and the radius die while the arm of the machine rotates to produce the angle desired on the bend.
- **Pressure die:** Applies pressure to the tube to help push the tube in a horizontal movement.

This machine is connected to a computer that has all the software to create different bending projects. Also, this machine could produce a maximum bend of 185 degrees and has different controllers to increase the speed or the height of the bending projects [5].

Figure 2 shows a visual example of the tool previously described, as well as illustrates how it is used.

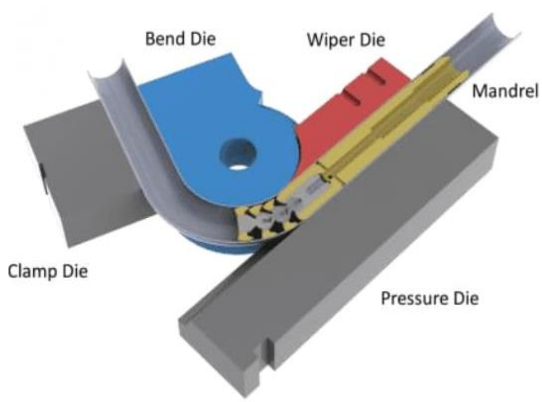


Figure 2
Tooling and illustration of bending process

One of the final steps of this process is the inspection and it involves the following steps:

- Verify the tubes for any scratches.
- Make sure that all the bends are in accordance to the ovality specification as per the bend regulations.
- The part must be tested on the Clark fixture to assure that the part fits all established dimensions by the print.

To finalize this process, the part must be placed on the fixture and the end targets of the fixture must be used to assure that the part has the correct dimensions and lengths. If the part passes this step, we need to double check all the measurements, rotation and bends by using the MYLAR table. After talking to employees and getting feedback on the major issues that were occurring on the process, a fishbone diagram was created showing the typical issues on the three CNC machines (figure 3).

These are the problems found:

- Inappropriate verification: After the investigation, it was determined that this part of the process is the one that generated more scrap. MYLAR is a basic system used to measure the contour of the parts. This process is simple: it starts with a plastic MYLAR sheet with a 2-D illustration of the part with the proper coordinates marked on it. This sheet is put on an aluminum calibrated table. Then, stanchions are placed on each coordinate point; on each stanchion there is an adapted channel that will be adjusted according to the angle and height established by the coordinate points. After all, the stanchions are placed on each point, the

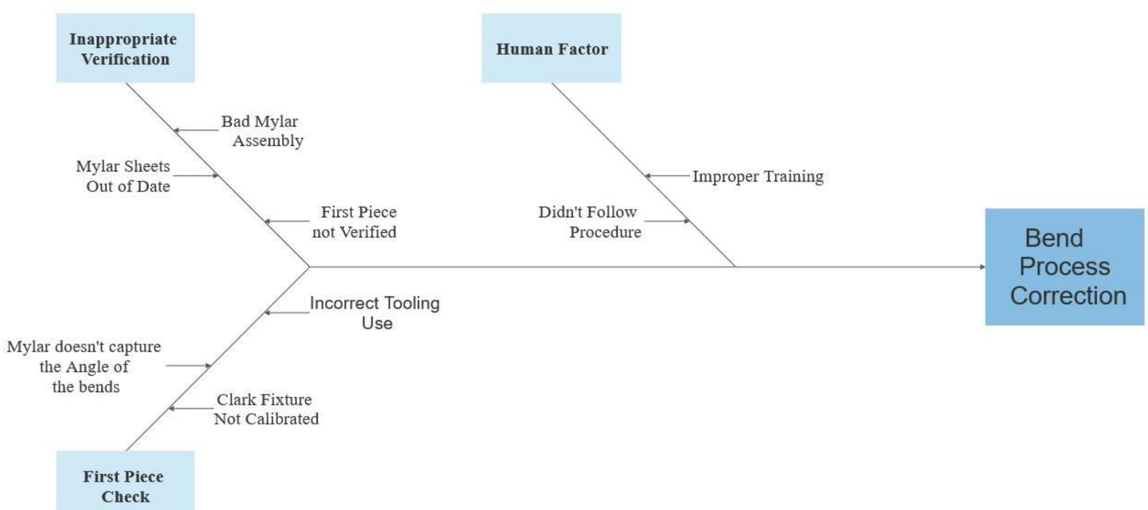


Figure 3
Fishbone diagram

MYLAR is ready to be used. If during the assembly of the tables the operator is not cautious with the points and the angles for the channels, the MYLAR will be assembled incorrectly. The other big issue is regarding the revisions of the MYLAR sheets; most of the times when the drawings are changed or revised, the MYLAR should be changed simultaneously to avoid conflicts. Normally this doesn't happen, and the MYLAR is built based on an older version.

- **Human factor:** A major issue occurred when new employees arrived to this area and weren't trained properly or the operator trusted the repetitive procedure to manufacture parts without reading the manufacturing instructions. Every part has a manufacturing instruction, referred to as a router. This router is simply like a step-by-step recipe to building the parts. Usually this document includes instructions on how to carry out each step. For example, the trim operation has comments on how to trim the part properly or, in other cases, the use of a trim fixture or just the proper tooling for completing the operation properly. For example, a trim operation should have the following comment: "CUT TO LENGTH, 59.00 INCHES AS PER PRINT AND AS PER ACES 35 MOVE TO NEXT OPERATION."
- First piece check: The current process established that every time the operator had a new order, they were required to do an inspection of the first part produced before they continued with the rest of the order. The mayor issues with this is that the part is normally checked, but if the MYLAR was incorrectly building the whole order, it will be defective. Moreover, sometimes the MYLAR doesn't capture the angles on the bends, just getting the straight section of the part instead.

METHOD

The method selected to demonstrate the improvement and the process in this project is DMAIC (figure 4). It was easier to illustrate through DMAIC because this project is attempting to improve an existing process.

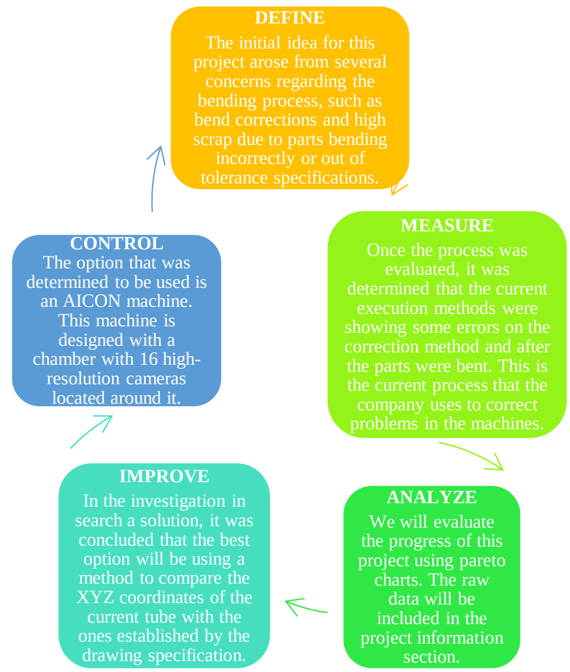


Figure 4
DMAIC

DMAIC provides structure because each phase of the process contains tasks and tools that will lead to finding an eventual solution.

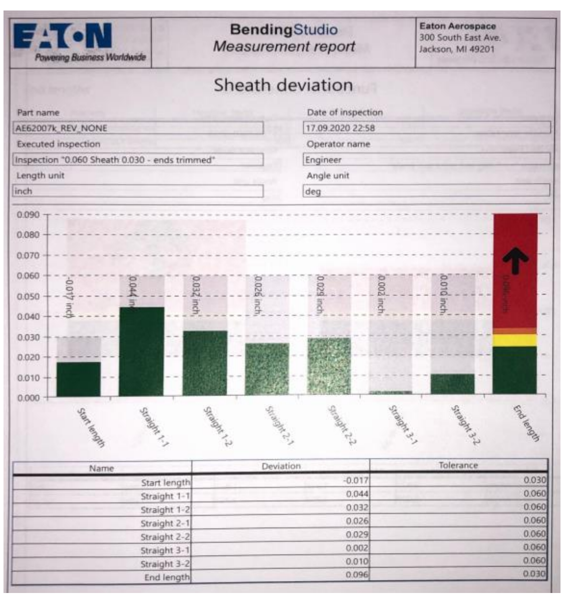
- **Define:** A normal day in the bending process at Eaton Aerospace starts with the requirement of certain design of tubing to be accommodated to the design of an airplane or helicopter. After being evaluated by the product engineers, the design is illustrated on a drawing that will have all the required coordinates for X, Y and Z. After all this is established, depending on the complexity of the part, the engineering team will determine if the part requires a MYLAR table or if the part could be bend to a 2-D template. Then, the operator proceeds to the CNC machine to generate a program based on the coordinates of the tubes. The bender should run the first piece check on this step. The bender will also compare the produced part to the 2-D template or MYLAR table. The initial idea for this project arose from several concerns regarding the bending process, such as bend corrections and high scrap due to parts bending incorrectly or out of tolerance specifications [6]. If the bend corrections are not implemented before bending all the parts on the router, the cost could surpass $6,000, depending on the type of material the tubes are made of. A high scrap cost generated by the bend process could surpass $11,000 if the parts are not corrected before they are bent. This cost could scale up and reach $32,000 if the parts reach the weld assembly router, due to higher cost of components and operations.

- **Measure:** Once the process was evaluated, it was determined that the current execution methods were showing some errors on the correction method and after the parts were bent. The current process used by the company for the problem's correction in the bending process was generating several critical points, which will be used to measure the progress of the project. These are the following: Part trim short or out of tolerance: The next process of this operation will be Welding if the tubes are trim under the established tolerance the final component will be short. If this happened it could be leaving a highly scrap cost from $10,000.00 to $30,000.00 per order, set up time on the CNC machines and after bending the first part the operator must verified the lengths required for each end of the tube, then trim the tube to the tolerance giving and the final step is to verify on the MYLAR or Clark fixture if the part has proper fit, he can continue bending the rest of the order. All this is believing that the first part bend is going to be fitting on the fixtures, if not he must make the desired adjustments.
- **Analyze:** We will evaluate the progress of this project using pareto charts. The raw data will be included in the project information section [7].
- **Improve:** In the investigation in search a solution, it was concluded that the best option will be using a method to compare the XYZ coordinates of the current tube with the ones established by the drawing specification [8]. The AICON machine will take pictures of the current tubes to read the patterns of the bends and, after that, will make a comparison of the drawing's coordinates and the current read coordinates of the tube. This project will be under evaluation for the first year to assure that the main goal is achieved to reduce the high cost in scrap.
- **Control:** The option that was determined to be used is an AICON machine (figure 5). This machine is designed with a chamber with 16 high-resolution cameras located around it. The operating system allows to read the different contours of the parts on the XYZ axis and compare them to the current drawing measurements [9]. After the comparison of both XYZ axis, the program offers corrections on the different points that need or require adjustments. After the first piece is produced, the operator must proceed to use AICON to get the measurements of the critical point in the part being evaluated. With the first reading completed, AICON will have the capability to connect via Ethernet to the CNC bending machine, in case that the bending program needs any adjustments on the angles, rotations, radius of the bends and straight lengths. This will provide a better and more robust system to avoid more deficit on the bending process. The software in AICON will require software updates to maintain optimal program function.

Figure 5
AICON machine

RESULTS

This project helps the company to heavily reduce scrap cost, overtime pay and buyer reduction and to help produce a quality product pursuant to the aerospace division's standards. The project will help the company minimize scrap in various departments due to the technology used to measure and control the manufacturing process in the facility. This project is visualized to reduce scrap cost by $100,000 yearly for the Fabrication department. The fishbone diagram in figure 3 shows the initial problems found during this project. To eliminate the majority of these issues, we evaluated the AICON because this machine will be elaborating a report measuring all the straight lengths, angles, radii and rotations of the part. As a final improvement, the AICON will be connected directly to the CNC benders, meaning that after the first piece is measured, it will send the corrections to the bending machine to make the needed corrections for the next part. As a final gadget, the AICON will generate and accept or reject a report pursuant to all the measurements obtained from the part. Figure 6 shows an example of a report for the initial and final angles of a part.



Name	Deviation	Tolerance
Start length	-0.017	0.030
Straight 1-1	0.044	0.060
Straight 1-2	0.032	0.060
Straight 2-1	0.026	0.060
Straight 2-2	0.029	0.060
Straight 3-1	0.002	0.060
Straight 3-2	0.010	0.060
End length	0.096	0.030

Figure 6
Rejection report

As we can see, both angles are supposed to appear in the green section of the graph. In the case of this part, tolerance should be one degree; the start angle is in tolerance and that is why we can see it in the green area, but the final angle of the part is showing a red section, meaning that the angle measure in this section of the part doesn't comply with the tolerances established in the drawing. The part is supposed to have a tolerance of one degree, but when it was manufactured, it was not produced under the needed program, producing a non-conformance part. When the part was measured, its end angle was off by two degrees, making it a good example of a rejection report. Figure 7 shows a good example of an acceptance report. This page of the report will be different. It is evident that all the straight lengths of the part starting front the front end to the back straight length. In this report, we can see that the whole straight length is in the green zone, except the back end straight, because the part was left longer on purpose to compensate for the weld shrinkage on the next operation.

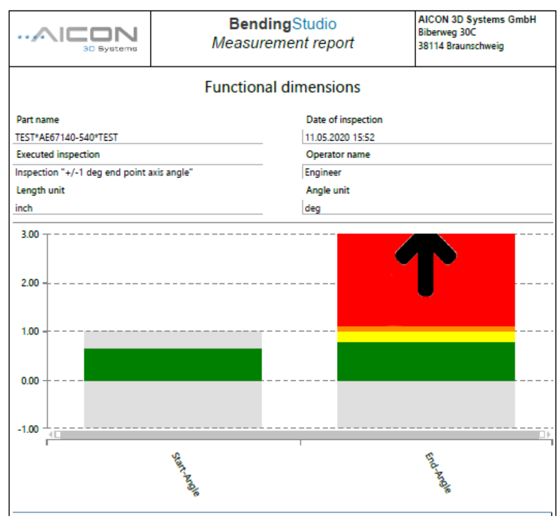


Figure 7
Acceptance report

DISCUSSION

After running this project for the last two months and a half, it could be determined that the time of setup on the CNC machines was reduced by 8%. This improvement was due to the program on the AICON machine, as its software allows us to transfer the corrections that were determined by the comparison of the XYZ coordinates between the drawing and the current tubes. The other big improvement was due to the proper way of verifying the lengths, angle and rotation of the bent parts. The expected goal of this project was $20,000 to $30,000 in scrap reduction. After evaluating the project, there was a savings of $64,473 only in scrap reduction and the GU can be increased to 8%, which allows for 14 additional orders delivered per month. If we translate the 14 extra orders to the time paid to employees getting this order ready with the old system, the result is 5 working days and $10,512. Therefore, the final achievement is $74,985 saved.

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