Wire-Drawing Machine Design & Analysis

Final Report

Senior Design & Analysis – MET 494

Professor Dupen

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Group members:

Mark Armstrong (armsml02@students.ipfw.edu)

Emily Bendix (bende01@students.ipfw.edu)

Joe Gallmeyer (galljc01@students.ipfw.edu)

James Harris (harrjl10@students.ipfw.edu)

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Abstract

Fort Wayne Metals is a manufacturer of medical wire for various medical components. Founded in 1946, Fort Wayne Metals has grown in their capabilities of producing various products and their reputation of being a world leader in manufacturing quality medical-grade wire. As Fort Wayne Metals has grown, many of their machines have become dated and are in need of modifications and improvements in order to keep up with advancing technology.

Our senior design group worked with Fort Wayne Metals to analyze and redesign a machine to upgrade it to expand its manufacturing capabilities. Their current machine set-up could not properly produce material at its largest incoming material size of 0.057 inches. In order for the machine to be able to produce wire at this size, the machine had to be set-up with the wire improperly wrapped on the machine's capstan and idler components, that would lead to surface defects on the finish product. With Fort Wayne Metals being an excellent medical wire producer, this machine required redesign in order to meet their quality standards.

The technical team at Fort Wayne Metals had a general idea of how they thought the machine could be upgraded. Our senior design group worked together with Fort Wayne Metals to gather all the details of the necessary capabilities the machine must possess. From there, our group begun designing upgrades to the machine including larger capstans, larger idlers, repositioning each idler, and redesigning the die boxes. The larger capstans will allow for more friction to be produced for a greater pull force, the larger idler will allow for better wire spacing, the repositioning of the idler will allow for ease of operator set up, and the redesigned die boxes will prevent further corrosion from processing aids.

Our group used calculations to ensure these changes did not compromise any of the machine's components. The team did an experiment to gather the maximum draw force needed pull the 0.057-inch diameter wire. Using the results, calculations were completed to find the maximum torque that will be put onto the gearbox and motor of the machine from the changed capstan size. These results were then compared to the published torque curve by the manufacturer for both the gearbox and motor.

With all changes implemented, the machine worked as planned and allowed the machine to produce the 0.057-inch diameter material without surface defects from improper setup.

Introduction

Fort Wayne Metals, a wire manufacturing company located in Indiana, is in need of improving one of their wire-drawing machines. The previous machine was not designed to process the desired size of product they would like: the wire encounters itself, which in turn breaks down the quality of the wire and causes surface deformation. Two progress reports have previously been submitted, outlining the progress our group has made since beginning this project. In this final report, we will outline the machine's previous state, and compare it to its current state with our newly designed components.

Background

The machine being evaluated for this project is a wire-drawing machine, which pulls intermediate sized wire through wire-drawing dies to reduce the cross-sectional area. Typically, the machine is capable of producing wire from incoming diameters of 0.0226 inches (smallest) to 0.057 inches (largest). The dies used for this process are usually made up of either polycrystalline diamond or carbide. When operating the machine, the wire is fed through a die box that contains a lubricant and a wire die. The lubricant is applied at the face of the die where the wire enters, which reduces the size of the wire. After the die, the wire is transferred onto a capstan, an idler, and a dancer pulley. The capstan is what drives the motion of the wire; they are large circular objects that are each attached to a gearbox and a motor that cause continual rotational speed. An idler is a slightly smaller circular object that controls the alignment of the wire around the capstan, and prevents it from encountering each other. The dancer pulley allows tension to be placed onto the wire before entering the next die. Each dancer pulley is attached to an air cylinder and a potentiometer, which helps to adjust and control motor speed. The machine is a four-die string up, meaning there are four sets of die boxes, capstans, idlers and dancer pulleys stationed on the machine. After the wire has been strung through the fourth die station (which does not have a dancer setup), the wire is then transferred onto a spool using a take-up, where it will then be transferred on to its next processing machine.

Problem Statement

Fort Wayne Metals has a process that wants to be able to run the machine and produce material with a larger incoming diameter of 0.057 inches. The machine's previous state could not pull wire this size without deteriorating the surface of the material. By improving the machine's present setup, we had hoped to eliminate wire contact when fed onto the capstans. By improving the machine, we established two main objectives to accomplish: redesign the capstan sizes, and relocate the position of the idlers on the machine. By increasing the size of the capstans, we will increase the capstan's surface area so that there is more room for the wire to wrap the capstan to generate the pull force needed to draw the wire with a proper set-up to prevent the wire from contacting itself. For our second objective, we will reposition the idler for each die station. Due to its previous position, the material only made contact with the capstan a quarter of a turn around the capstan before transferring onto the idler. Once we move the idler so that it is positioned above the capstan instead of below, the wire will make contact with the capstan three quarters of a turn around the capstan, which will create more friction. Our objectives will also include further analysis and detail during the design phase.

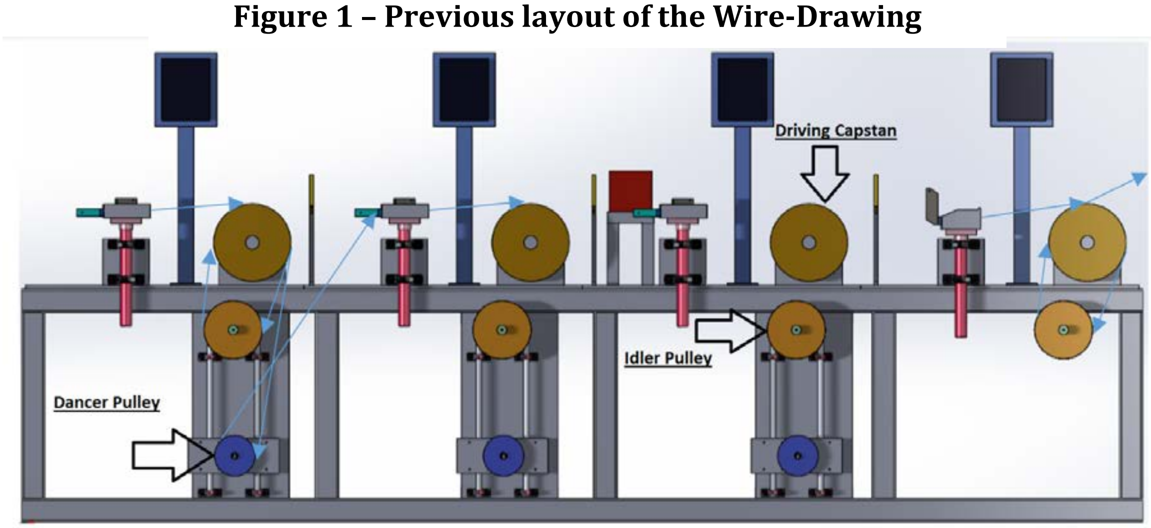
Due to these changes, we will perform a machine analysis to ensure we are not compromising any of the components reliability and functions. This machine analysis will include comparing torques on the shaft of the capstan, and sizing of the gearboxes and motors. The sizes of the air cylinders will also be evaluated, as well as the shaft sizes of the die boxes. As an additional requirement requested by Fort Wayne Metals, we also hope to accomplish redesigning the die boxes at each station. Corrosion keeps appearing on these boxes, which could cause lubricant contamination and eventually affect the wire quality. By switching out the boxes with a different material, we hope to eliminate this issue.

Design & Research Process

Machine's Previous State

Figure 1 on the following page illustrates what the wire-drawing machine previously looked like before modification; wire is processed from the left to the right, and is illustrated by this through the blue arrows. As mentioned, this machine is a four-die string up, meaning there are four sets of capstans, idlers, dancer pulleys and die boxes. Each capstan is made out of Phenolic, which is a hard, dense material made by applying pressure and heat to different layers of paper or glass cloth. The combination of heat and pressure transforms the material in a thermosetting industrial laminated plastic. Each idler and dancer pulley is also made out of Phenolic. The frame of the machine is made out of 0.25 inches thick square tube steel. The die boxes are currently made from plain carbon steel, which we will replace with stainless steel. Performance specifications for the wire were also mentioned before: incoming size wire ranges from 0.0226 inches to 0.057 inches with proper machine set-up. Though outer dimensions will not change, the length of the machine itself is 16 feet, and approximately 3.5 feet wide.

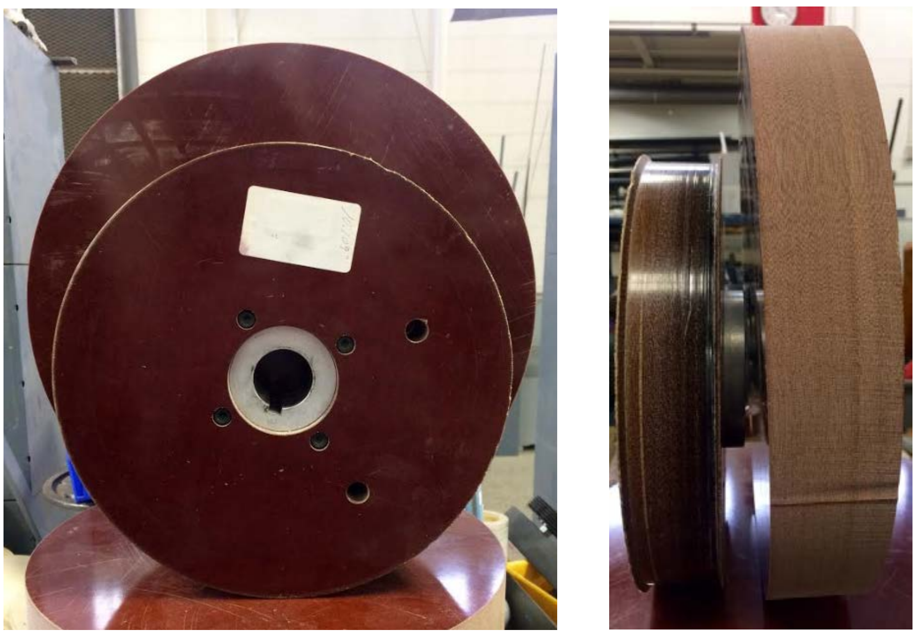
Figure 1 – Previous layout of the Wire-Drawing



Machine's Proposed State

The previous diameter sizing for the capstans ranges from 9.125 inches to 10.5 inches; the proposed diameter our group agreed on is 13 inches. The width of each capstan will also be increased, from 1.5 inches to 2 inches. Not only will all capstans be consistent in size, but they will also draw wire at the largest diameter possible whilst complying with safety standards of the machine and the product. A comparison in size of these two capstans can be referenced below in Figure 2.

Figure 2 – Size Comparison of the Previous Capstan vs. Proposed Capstan (Front vs. Side Views)



Due to the previous size of the machine, increasing the diameter size beyond 13 inches would cause too much clustering amongst components on the machine, which could pose as a potential safety hazard. As well, increasing the diameter will cause almost a 25% increase in machine output since the speed of the machine will also be increased. The size of the idlers are also different size diameters, and range from 5.25 inches to 7.25 inches; a photograph of these components in their previous state, along with the dancer pulleys, can be referenced to in Figures 3 & 4. The size of these will also be increased to not only keep consistency, but that is what Fort Wayne Metals has requested for this machine. Thus, we will abide to their request and increase the size of each idler diameter to 7.5 inches.

Figure 3 – Idler Pulley

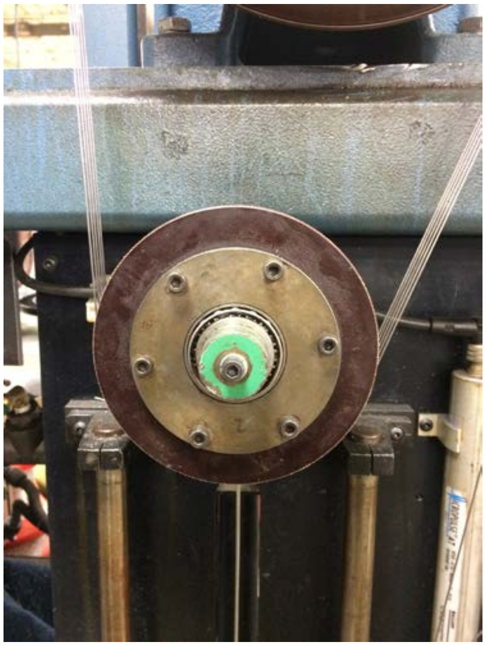


Figure 4 – Dancer Pulley

With the proposed changes made, Figure 5 below illustrates what the wire-drawing machine will look like. In order to relocate the idler pulleys, an additional support system needed to be created; thus, we fashioned a bracket for each station of the machine to support the idler, and avoid contact with the capstan. Fort Wayne Metals maintenance department fabricated these brackets for us, and can be referenced to in Figure 6. By positioning the idlers above the capstans instead of below, more friction will be generated. Increasing the size of the capstans will prevent the wires from contacting each other (A.K.A. "rubbing"), and allow Fort Wayne Metals to run the desired range of wire diameter sizing (0.0226 inches to 0.057 inches).

Figure 5 – Proposed layout of the Wire-Drawing Machine

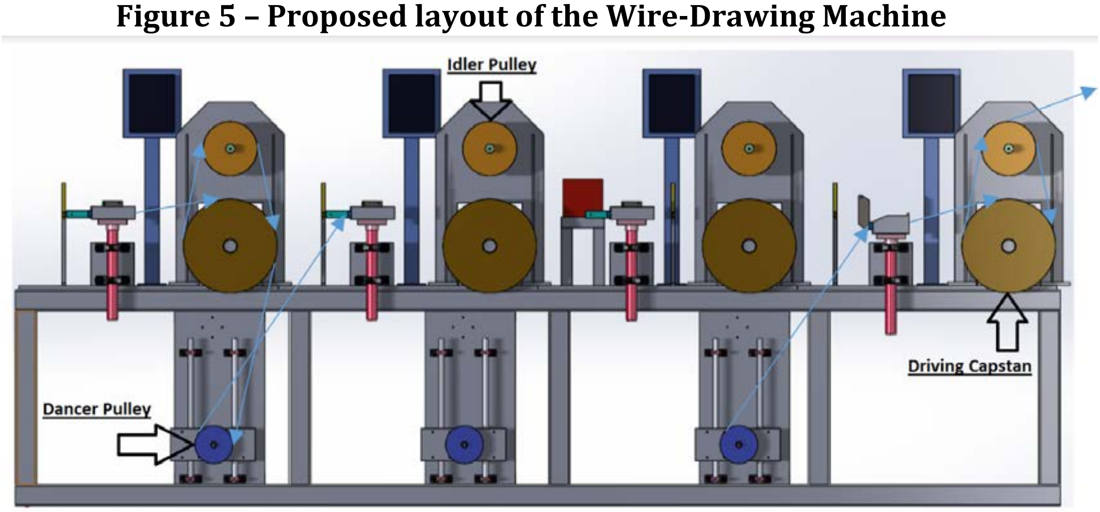
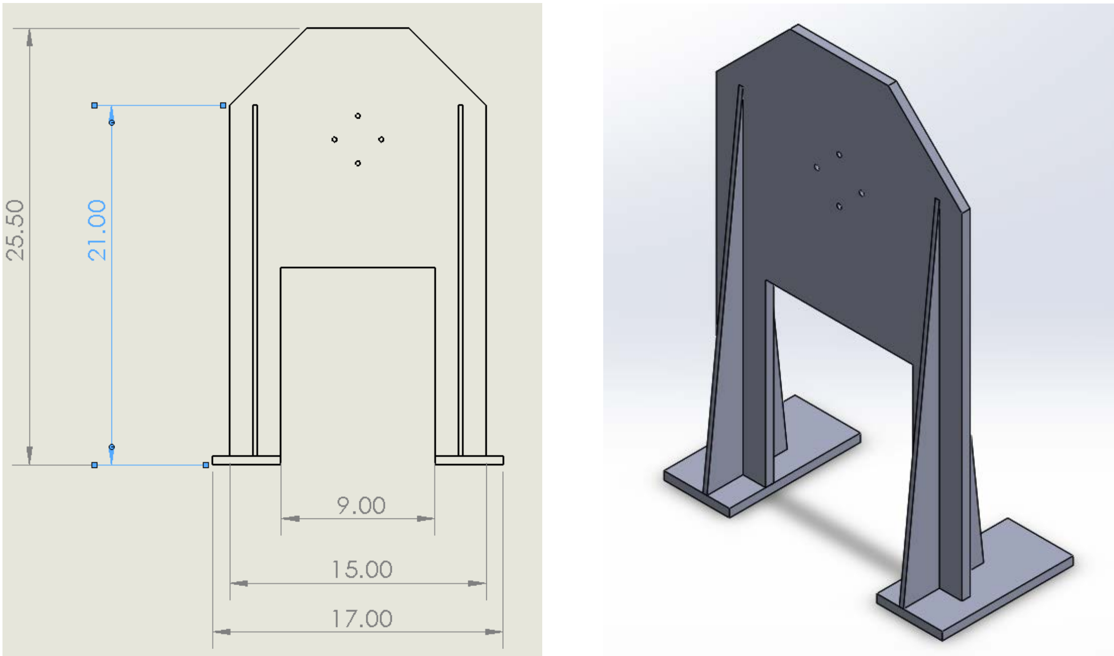


Figure 6 – Newly Designed Bracket



Performance Specifications
Information regarding the sizing of the gearboxes, motors, and air cylinders have been obtained, and can be referenced to in Appendix I. Analysis on these three machine components are critical; by collecting this information, we are demonstrating that none of these need to be modified or replaced by our redesign of the machine. The machine's air cylinder is a double acting pneumatic cable cylinder (A.K.A. "CC10") manufactured by Tolomatic. We were able to obtain information regarding this cylinder from their website, which can all be referenced to in Appendix I. The purpose of the air cylinder is to use compressed gas to produce a force, which drives the motion of the wire-drawing machine. On average, the machine's cylinder is run at 30 pounds per square inch (psi). Using this information, we can calculate the acting area of the cylinder, as well as the average force applied.

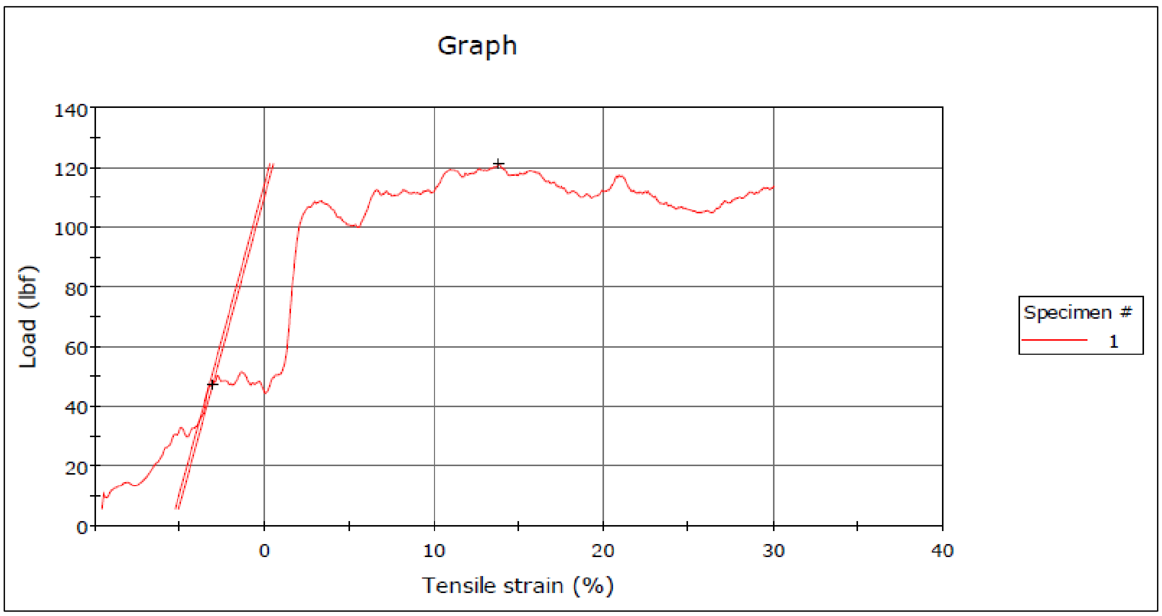
Based on the information and calculations, we can expect an average force from the cylinder to be 23.5 pounds. As for motors and gearboxes, we obtained their specifications from the manufacturers to be able to calculate maximum allowable torque; this was easily accessible through their websites, along with being listed on the gear reducer data plate. Figure 8 compares the current capstans torque values with the proposed capstans values; equations used to obtain these values can be referenced in Appendix II. Based off the calculation values, the larger size capstan will produce a greater torque by 24%, which is only 17% of the maximum allowable torque of the motor. Thus, increasing capstan diameter size will not affect motor performance of the machine.

In addition to these values, pull-force was also obtained using an Instron tensile tester (as seen in Figure 7). In order to obtain the maximum pull-force for the machine, we tested the largest diameter wire that is run on the machine (0.057 inches). Data collected from this tester can be referenced to on the following page in Figure 8. Based on the results, the maximum force required to pull this sized wire is 121.29 pounds. Thus, to prevent any machine damaging, we will conclude that the maximum pull force for the machine is 130 pounds.

Figure 7 – Instron Tensile Tester

Figure 8 – Pull-Force Tensile Testing Results

	Serial Number	Diameter (in.)	Breakload (lb.ft)	Tensile Strength (psi)	Elongation (%)	Yield Load (lb.ft)	Yield Strength (psi)	Modulus (Mpsi)
Sample 1	0.057 - S/0.0508	0.05840	121.288	45280	30	47.625	17780	0.7691
Mean		0.05840	121.288	45280	30	47.625	17780	0.7691
Standard Deviation		-----	-----	-----	-----	-----	-----	-----
Mean (+ 3 SD)		-----	-----	-----	-----	-----	-----	-----
Mean (- 3 SD)		-----	-----	-----	-----	-----	-----	-----
Minimum		0.05840	121.288	45280	30	47.625	17780	0.7691
Maximum		0.05840	121.288	45280	30	47.625	17780	0.7691



Testing Analysis

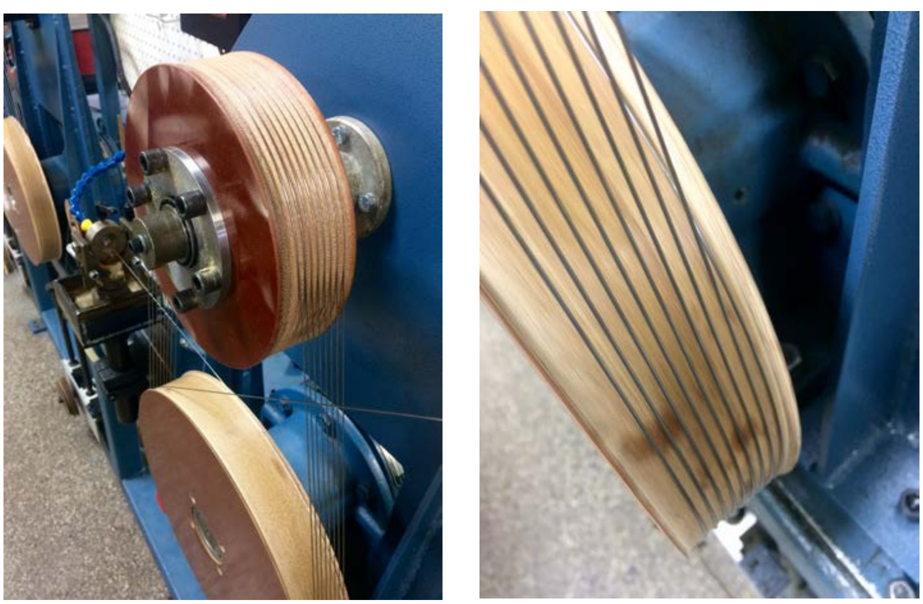
Once the newly designed components were implemented onto the machine, testing analysis was executed. Our testing analysis encompassed the objectives that the newly designed machine components can be properly installed onto the machine, and be able to process wire normally/as expected per Fort Wayne Metals process. For further investigative purposes, we processed the largest diameter wire through to ensure no wire contact took place.

Discussion of Results

As expected, testing analysis proved to be successful. Wire was able to string up as expected, and the machine performed as expected with no wire contact detected. Figures 9 & 10 below shows the final product of the machine with the complete modifications.

Figure 9 – Current State of the Wire-Drawing Machine

Figure 10 – Current State of the Wire-Drawing Machine



Issues
Despite being able to draw wire successfully, our group ran into a few minor issues along the way. One problem we faced when implementing the newly designed components on the machine was the size of the capstan. Although the size is a perfect fit, the spacing between it and the machine frame is extremely small; which in turn produces a pinch point, and poses as a possible safety threat. In order to correct this issue, a 0.5-inch plate will be placed underneath each of the four stations on the machine to raise each station. The new mounting plate will allow for all components of each station to be offset from the frame by 1.0 inch.

Another problem we encountered was the sizing of the die holder for each drawing die. After receiving these fabricated components from an external manufacturer, Diversified Metals, it was found that the die holders were made to the exact size of the die casing, which caused issues with the die fitting. Thus, the die holders were re-bored to a size of 1.01 inches in order to have them properly fit to the casing.

Project Costs & Timeline

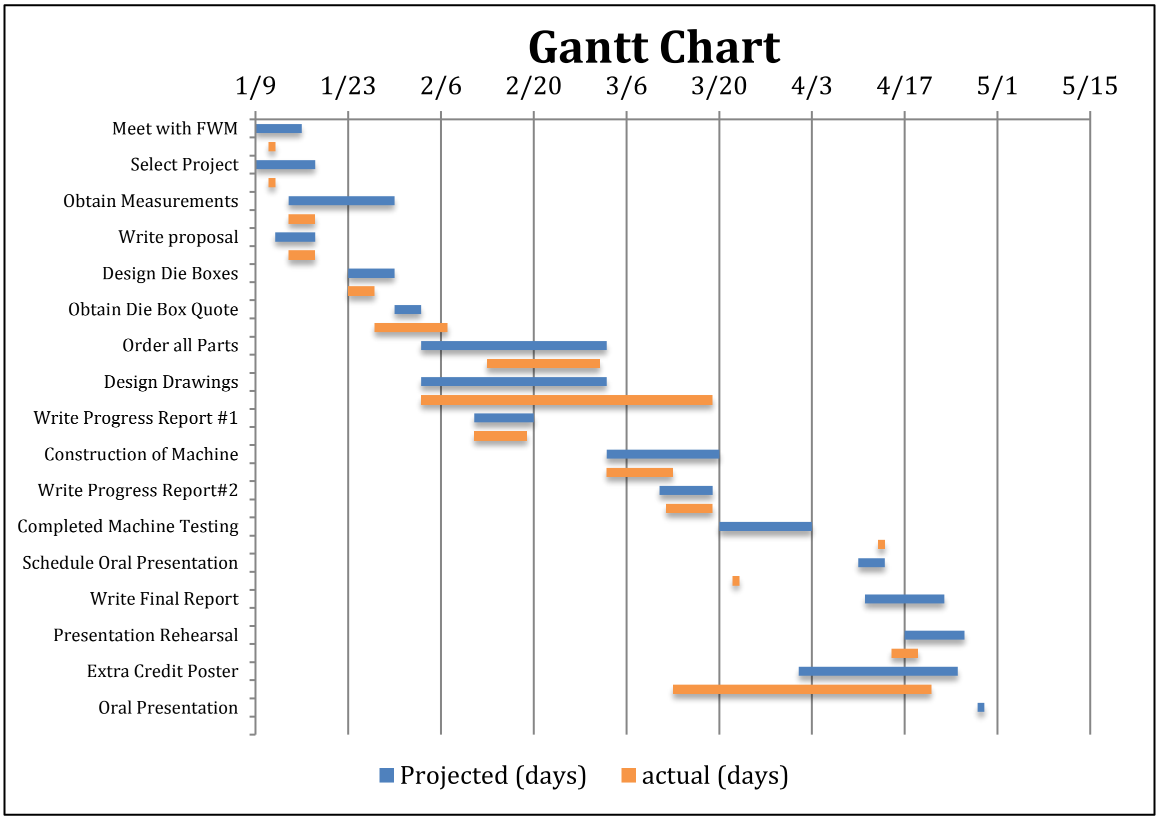
Our group did not originally start with a projected cost for this project. Fort Wayne Metals originally targeted a total projected budget of $10,000; however, after their additional requirement to redesign the die boxes, they agreed to increase this value to whatever our group needed in order to complete the project. Details regarding machine component costs, along with the die boxing costs, can be referenced to in Figure 11 on the following page. Besides the die boxes, which were fabricated by Diversified Metals, all of the machine components were made and assembled by Fort Wayne Metals maintenance department. In total, this project cost roughly $14,774; this also included labor costs for Fort Wayne Metals maintenance department, but not our group's extra credit poster that we designed. The members of this group were financially responsible for this project's poster.

Figure 11 – Total Project Costing

Project Component	Component Details	Cost ($)	Quantity	Line Cost ($)
Die Boxing	Standard Die Box	1,000	3	3,000
	Die Box Shaft	110	4	440
	Shaft Mount	75	4	300
	Pulley Arm	65	3	195
	Finish Pulley Mount	75	1	75
	Finish Die Box	2,000	1	2,000
	Die Housing	500	3	1,500
	Finish Die Holder	2,940	1	2,940
	Standard Housing Plate	50	3	150
	Lube Mount	55	3	165
	Pulley Bracket	110	4	440
	Pulleys	38	16	608
Phenolic Parts	Phenolic Sheet	1,063	1	1,063
	Labor Costs	550	N/A	550
Miscellaneous	Bracket Materials	8	4	348
	Powder Coating	200	1	200
	Manual Labor	40/hr	20	800
			Total	***14,774***

In addition, a Gantt chart has been created to illustrate our progress throughout the entire project, and can be referenced to on the following page in Figure 12. Referencing to the chart, we were able to keep a consistent pace in order to successfully complete this project by the scheduled due date of April 28th, 2017.

Figure 12 – Gantt Chart



Conclusion

In conclusion, this project produced successful results. The proposed modifications to the machine, including the capstan sizing and idler repositioning, solved the issue of the wire encountering itself throughout each wrap. By offering these improvements and features, we feel confident that these proposed fabrications have met the expectations of Fort Wayne Metals, and will increase the performance of the machine for future use. As mentioned, the only issues that were run into with this project were the spacing of the new capstans from the machine frame, and the holder sizing of the die boxes. Both of these issues were recognized, and quickly resolved. The only proposed recommendation we have for any future projects is to execute fabrication of the components earlier; that way, we would be able to execute testing earlier and obtain results earlier. However, based on our timeline, we were still able to meet the expectations of the project beforehand, and deliver results on time.

Appendix I – Design Analysis Information

Our group has collected information for the machine's air cylinders, motors, and gearboxes, and have put forth this information into useful data calculations. Analysis on these three machine components are critical; by collecting this information, we are demonstrating that none of these need to be modified or replaced by our redesign of the machine.

The machine's air cylinder is a double acting pneumatic cable cylinder (A.K.A. "CC10") manufactured by Tolomatic. We were able to obtain information regarding this air cylinder from their website, which can be referenced to in Figures 14 and 15. The purpose of the air cylinder is to use compressed gas to produce a force, which drives the speed rate of the wire-drawing machine. On average, the machine's cylinder is set to 30 pounds per square inch (psi). Using this information, we can calculate the acting area of the cylinder, as well as the average force applied; these calculations can be referenced to in Appendix II.

Figure 14 – Force vs. Pressure (Air Cylinder)

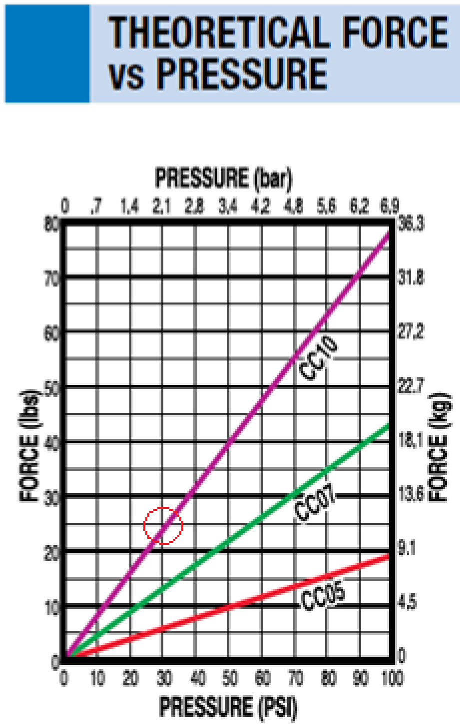


Figure 15 – Cylinder Specifications (CC10)

OVERALL UNIT SPECIFICATIONS			CC05	CC07	CC10
BORE SIZE		in	0.50	0.75	1.00
MAX STROKE		in	54	138	282
		mm	1372	3505	7163
BASE WEIGHT	Alum.	lb	1.38	1.38	1.38
		kg	0.63	0.63	0.63
	Steel	lb	NA	NA	1.49
		kg	NA	NA	0.68
WEIGHT PER UNIT OF STROKE	Alum.	lb per in	0.011	0.034	0.043
		g per mm	0.197	0.606	0.768
	Steel	lb per in	NA	NA	0.125
		g per mm	NA	NA	2.244
MAX PRESSURE		PSI	100	100	100
		bar	6.9	6.9	6.9
MAX TEMP		°F	140	140	140
		°C	60	60	60
MAX FORCE OUTPUT		lb	19.4	43.5	77.9
		N	86.3	193.5	346.5

TUBING SPECIFICATIONS			CC05	CC07	CC10
DEAD LENGTH*		in	1.11	1.18	1.31
		mm	28.2	30	33.3
WALL THICKNESS		in	0.0937	0.125	0.125
		mm	2.38	3.175	3.175
MATERIAL			Alum.	Alum.	Alum or Steel
TUBE SUPPORT SPAN	Alum.	in	60	60	72
		mm	1524	1524	1829
	Steel	in	NA	NA	78
		mm	NA	NA	1981

*Add to stroke length to determine overall length

CABLE SPECIFICATIONS		CC05	CC07	CC10
WIRE DIA	in	0.0468	0.0468	0.0468
	mm	1.189	1.189	1.189

Appendix II – Calculations

Figure 13 – Cylinder Calculations

$$Acting\ area = Bore\ area - Cable\ area$$
$$= \left[\frac{\pi}{4} * D^2\right] - \left[\frac{\pi}{4} * D^2\right]$$
$$= \left[\frac{\pi}{4} * (1\ inch)^2\right] - \left[\frac{\pi}{4} * (0.0468\ inch)^2\right]$$
$$= [0.78539\ in^2] - [0.0017202\ in^2]$$
$$= 0.7836698\ in^2$$

$$Force = Pressure * Area$$

$$= \frac{30\ pounds}{in^2} * 0.78836698\ in^2$$

$$Force = 23.5\ pounds$$

Actual Foot per Minute (FPM) (Tachometer): *69.6 FPM*

Current Capstan Diameter (Largest): *10.332 inches*

New Capstan Diameter: *13.000 inches*

Current RPM = *25.7*

$$Torque = Moment * Force$$
$$Torque = Pull\ Force * Distance\ to\ center\ of\ Capstan$$
$$\boldsymbol{Torque} = F\ *\ \frac{D}{2} * \frac{1}{12}\ [ft.lb.]$$

$$\boldsymbol{Speed} = \frac{(\pi * D) * RPM}{12} = [FPM]$$

$$\mathbf{RPM} = \frac{FPM * 12}{(\pi * D)} = \frac{69.6\ * 12in}{(\pi * 10.47in)\ (1ft)}\ = 25.4\ RPM$$

$$\mathbf{New\ Speed\ [FPM]} = \frac{(\pi * D) * RPM}{12} = \frac{(\pi * 13.000in)(1ft) * 25.4}{12in} = 86.45\ FPM$$

$$\mathbf{Percentage\ Efficiency} = \frac{Final - Initial}{Initial} * 100\%$$

$$= \frac{86.5 - 69.6}{69.6} * 100\% = \boldsymbol{24.28\%\ efficiency\ increase}$$

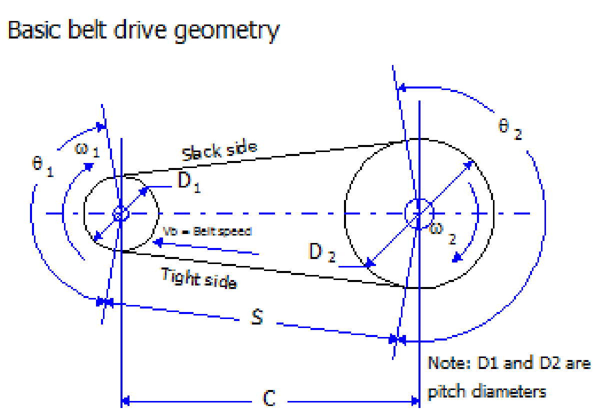
Arc Length Calculations:

Figure 16 – Arc Length Comparison (Current vs. Proposed)

Capstan / Wire Surface Contact					
	Capstan 1	**Capstan 2**	**Capstan 3**	**Capstan 4**	**New Capstans**
D1 (in.)	7.125	7.25	5.25	6.875	7.5
D2 (in.)	9.125	10.25	10.3	10.47	13
C (in)	11.5	11.5	11.5	11.5	14.25
θD_1(degrees)	170.02	165.01	154.63	162.02	157.75
θD_2(degrees)	189.98	194.99	205.37	197.98	202.25
Arc Length D_1 (in)	10.57	10.44	7.08	9.72	10.32
Arc Length D_2 (in)	15.13	17.44	18.46	18.09	22.94
Initial Arc Length θD_2 (in.)	7.56	8.72	9.23	9.04	31.89
Total Arc Length θD_2 (in)	83.20	95.93	101.53	99.49	246.66

D_1= Idler Diameter
D_2 = Capstan Diameter
C = Center Distance
Theta $D_1 = \theta_{D1}$
Theta $D_2 = \theta_{D2}$

Figure 17 – Basic Belt Drive Geometry & Equations (extracted from MDesign – Arc Length Angles)

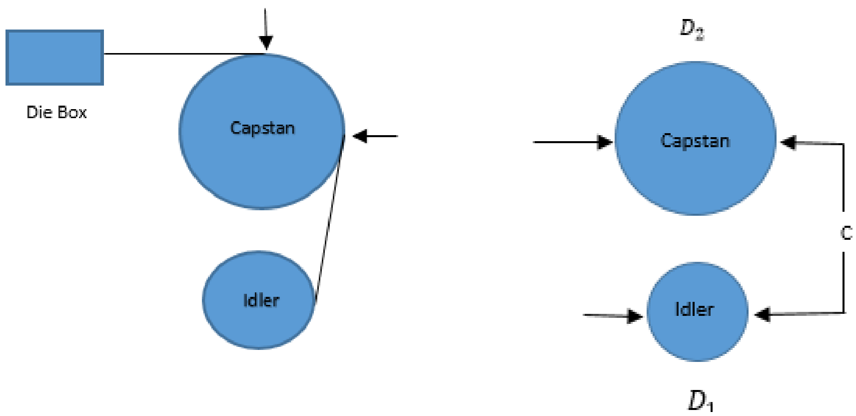


$$\theta_{D1} = 180° - 2sin^{-1}\left(\frac{D_2 - D_1}{2 * C}\right)$$

$$\theta_{D2} = 180° + 2sin^{-1}\left(\frac{D_2 - D_1}{2 * C}\right)$$

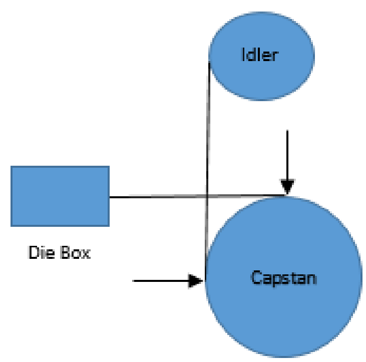
Arc Length $D_1 = \frac{\theta_{D1}}{360} * \frac{D_1}{2} * \pi$
Arc Length $D_2 = \frac{\theta_{D2}}{360} * \frac{D_2}{2} * \pi$
These equations were used to determine Arc Length of the idler and capstan.
Total wrap length of old capstans = $\frac{D_2 \; arc \; Length}{2} + \; Arc \; Length \; D_2 * 5$
Total wrap length of new capstans = $(D_2 * \pi * .5) + (Arc \; Length \; D_2 \; * 10)$

Figure 18 – Initial Arc Length



Initial Arc Length D2 = $\frac{Arc \; Length \; D_2}{2}$

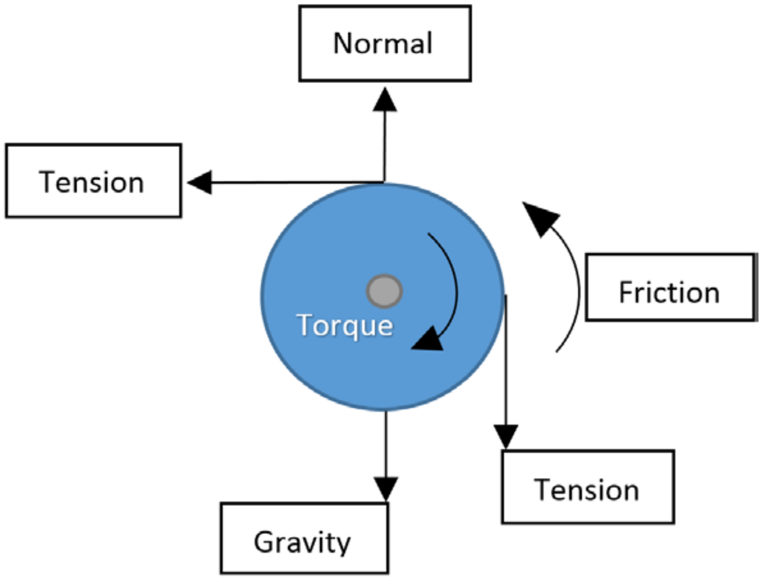
Figure 19 – Final Arc Length



New capstan initial Arc Length = $(\pi D_2 * .5) + (\frac{Arc \; Length \; D_2}{2})$

Note: Although arc length isn't crucial on the idler pulley, the main focus is on the driving capstans. D_1 is important because it is used to determine the arc length of D_2.

Figure 20 – Capstan Free Body Diagram



Torque Calculations:

Torque = $Force * Capstan\ Radius$

% Torque increase = $\frac{New\ Capstan\ Torque - Capstan\ 4\ Torque}{Capstan\ 4\ Torque} \approx$ 20%

% Torque max machine capability = $\frac{New\ Capstan\ Torque}{Max\ allowable\ Torque} \approx$ 17%

Figure 21 – Torque Comparison for Current Capstans vs. Proposed Capstans

Torque Comparison			
	Current Capstan	New Capstan	Max Allowable
Torque (lb.in)	680.55	845	4980
Capstan Radius (in)	5.235	6.5	-
Force (lb)	130	130	-

Appendix III – Reference Drawings

Figure 22 – Previous Capstan

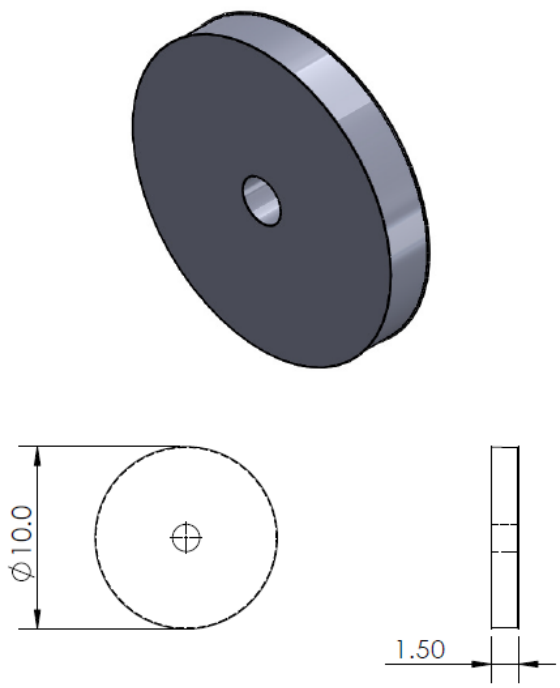


Figure 23 – Proposed Capstan

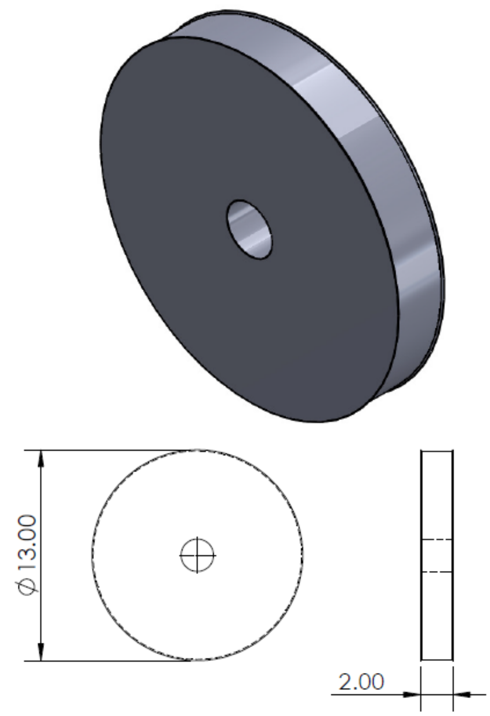
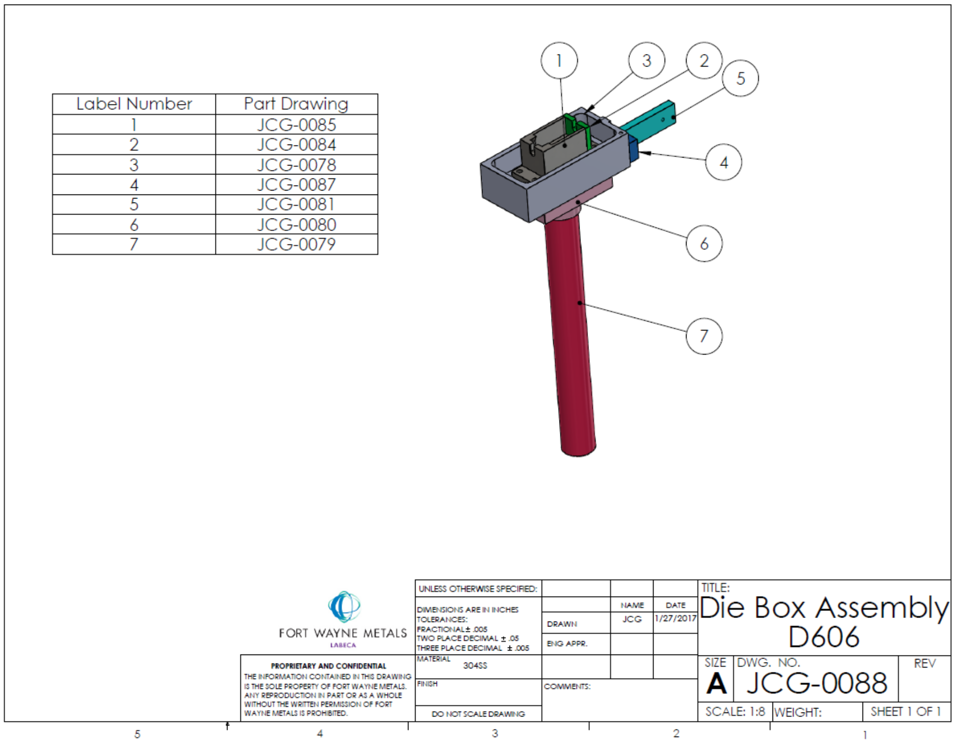
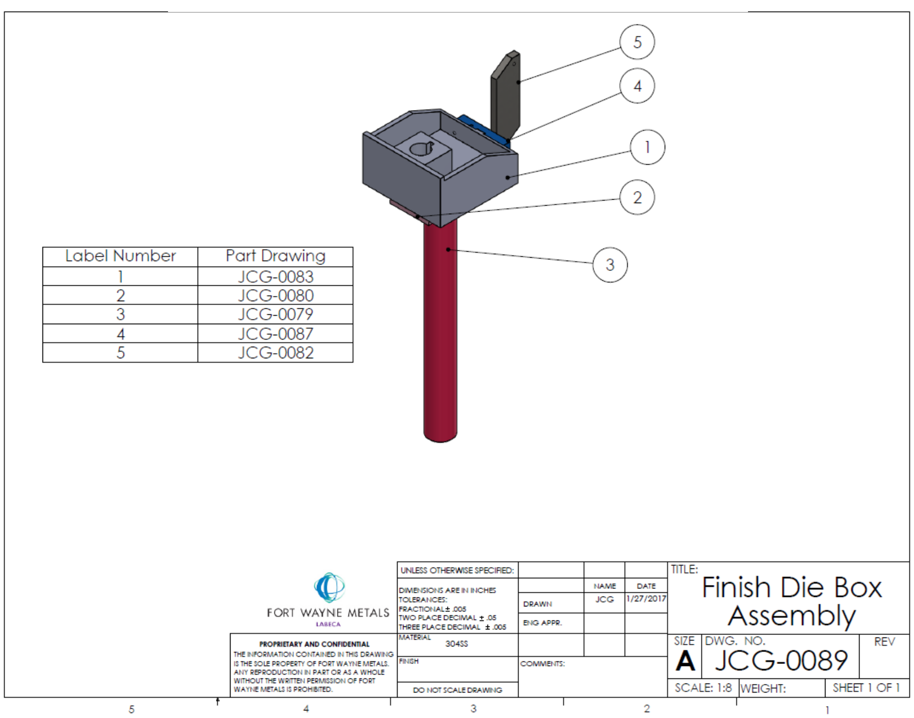


Figure 24 – Die Box Assembly



Label Number	Part Drawing
1	JCG-0085
2	JCG-0084
3	JCG-0078
4	JCG-0087
5	JCG-0081
6	JCG-0080
7	JCG-0079

Figure 25 – Finish Die Box Assembly



Label Number	Part Drawing
1	JCG-0083
2	JCG-0080
3	JCG-0079
4	JCG-0087
5	JCG-0082

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