Spring 2023

Nidec Automated Winder

Michael Pugh
mrp118@uakron.edu

Ben A. Swartz
The University of Akron

Andrew Leonard
The University of Akron, apl31@uakron.edu

Garrett Dostal
gd43@uakron.edu

Nidec Automated Winder

SENIOR DESIGN

MECE 471

HONORS PROJECT

MECE 497

By

1. Garrett Dostall ---------------------- Garrett Dostall
2. Andrew Leonard -----------------Andrew Leonard
3. Michael Pugh --------------------------- Michael Pugh
4. Benjamin Swartz----------------- Benjamin Swartz

UA Advisor: David Peters   Nidec Advisor: Justin Bracey

Dept. of Mechanical
Engineering College of
Engineering University of
Akron

April 2023

*Adapted from ECE445 guidelines, Univ. of Illinois

Abstract

This report is a comprehensive report covering the design, building, testing/validation, and the implementation of an automatic winder. The scope of this project is to take Nidec's manual winder and automate it. At this point in time, the automatic winder has been assembled, tested, validated, and implemented into Nidec's production. Further testing and validation will be completed as time permits to ensure all errors are worked out and to ensure a smooth operation to keep the winder going.

As stated above, this term our team focused on acquiring materials, building, testing/validation, and the implementation of the Nidec automated winder. In addition to several engineering principles learned/practiced, our team really seemed to enhance our skills with our hands when it came to the fabrication of the winder. Another area that our team seemed to excel was in the testing/validation area. Sometimes it can be difficult to evaluate your own progress, but this is where setting metrics for success really came in handy. Before even building the winder, our team spent countless hours evaluating and testing the current Nidec manual winder setups to ensure what our automatic winder had to hold up to and even surpass in some areas. I am happy to say that our winder has passed its benchmarks set by our team and continues to operate in a reliable fashion. In the future we plan to program more "recipes" which will allow for more armature combinations and further automation for the Nidec company.

Contents

1. Introduction

What is a winder? A winder is a machine that winds copper coils to the core or the armature of the electric motor. We want to redesign the winder because the current winding process is a fully manual process with the operator needing high skill to use efficiently. There are safety concerns with dangerous pinch points, inconsistencies with cycle time completion, and heavy amounts of operator waste. We wanted to design a winder that would be more automated, develop a better operator process to be more efficient in production turnaround time, and to keep operator safety as the highest priority. The world turns more and more to electric powered utilities and tools every day, and by applying our technical Engineering skills and principles we can help companies like Nidec to stay on the forefront of the technical advancement in the world.

2. Outline of Subject Matter

2.1 Introduction

Nidec Drive Systems is a leading electric motor manufacturing company for industrial cleaning equipment around the world. They are a multi-billion-dollar company with several facilities in the US and across the world. However, as of recent, Nidec has started to see some signs of old and outdated production machines as the demand for motors is steady, but their production numbers are declining. Upon further research it was concluded that some of the production machines are run down and outdated, which is causing production to be down for extensive amounts of time due to frequent breakdowns and repairs. In an attempt to repair some of these issues, Nidec reached out to the University of Akron to look for senior design groups to help design and standardize better production machines. We were tasked with redesigning a new winder, which is a machine that winds the copper coils to the core of the motor. Currently the winding process requires an operator and is a fully manual process. This machine revolves around an outdated winding process that requires precise skill to use efficiently. Some operators can take more than 4 months of training to be able to wind fast enough to keep up with demand. This is not a good way to produce parts. Our task was to design a new winder that can be more easily learned and understood, and make the machine have a more automated process to help with operator confusion and production numbers to stay up. With some restrictions like production floor space, minimal Maintenance time, and automated winding, we took on this challenging project. Starting with redesigning the loading racks for lighter weight, cost reduction and better standardization from machine to machine, this design was able to help build our shape for the rest of the machine. We then designed the fixture, which is the connection for the loading racks to sit on and the armatures to be loading in. Standardizing the fixture and cutting cost with a simplistic, yet highly functional design. We then designed the shell of the machine, after calculating stress points we were able to cut cost and weight by making all side panels out of

plexiglass as they are not loading bearing walls. We then decided on a pneumatic lift system with a programable PLC to automate the process of the machine. Having operator safety as our top priority, we have incorporated a way to keep both hands busy to ensure no operation without the right conditions met.

2.2 Design

2.2.1 Design procedure

In terms of design, our team has several approaches to the way we could tackle this. There are several different categories of design such as the shell, the internals, the operator's station, and finally safety. In terms of the shell, we were originally assigned to reuse the old cast iron shell. However, after diving into this project, the scope of work changed and we then were asked to redesign the shell which will hold the all of the internals that make the winder function. For the shell we used an internal frame of extrusion framing. This would allow us to securely bolt the outside panels to the frame. The frame is also nice because it can support a good deal of load while also being a cost-effective solution. The second area of design is the internals that make the winder work. The winder needs to have functions such as the ability to move up and down, move side to side, and clamp onto the armature. For the up/down and clamping movements, our team decided to go the pneumatic route. This was based on a cost perspective as well as our experience as a team from previous co-op rotations. For the side-to-side motions, we elected to use a servo approach. This was due to the ability to reuse a servo that was already in house. In addition to this, the side-to-side motions need to be extremely precise due to the way the armatures are wound. Finally, we had to design around the operator's station. Despite this winder being automated, it does need to be operated by an operator. This includes the operation of a joystick, and the pushing of buttons. We needed to design the setup to be as user

friendly as possible, making it easy and clear what the operators need to do and how to do it. Finally, our main concern in terms of design was safety. In any application, safety should be the highest priority, this automated winder is no exception. We designed our winder with high safety factors and worked to ensure that there are no pinch points, and that all of the moving parts are concealed with no way to get a finger or body part stuck in the operation. We want to ensure that every person who came to work went home exactly as they came to work.

2.2.2 Embodiment Design

Embodiment Design Table				
Motion Up/Down	Servo	Linear Screw	Hydraulic	Pneumatic
Motion Left/Right	Servo	Linear Screw	Hydraulic	Pneumatic
Method of Control	Computer	Manual	PLC	
Operator Controls	All Button Control	Lever Controls	Combination of Buttons & Lever	
Shell Design	Thick Steel Framing	Extrusion Framing	No Internal Frame	Misc Support Members
Central Shaft Design	Square 2"x2"	Circular 2" Dia	Circular 1.5" Dia	Custom Keyed Shaft

Figure 2.1: Embodiment Design Table

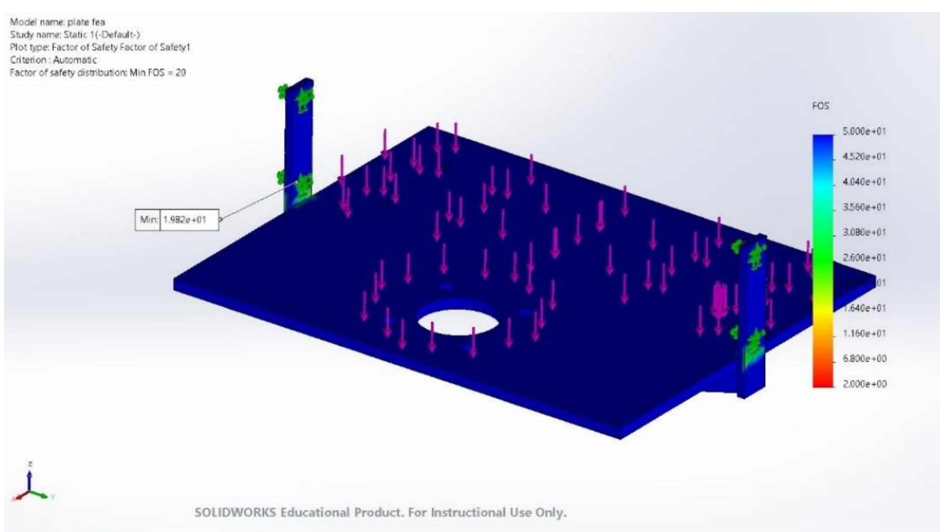


Figure 2.2: FEA Study on Top Plate

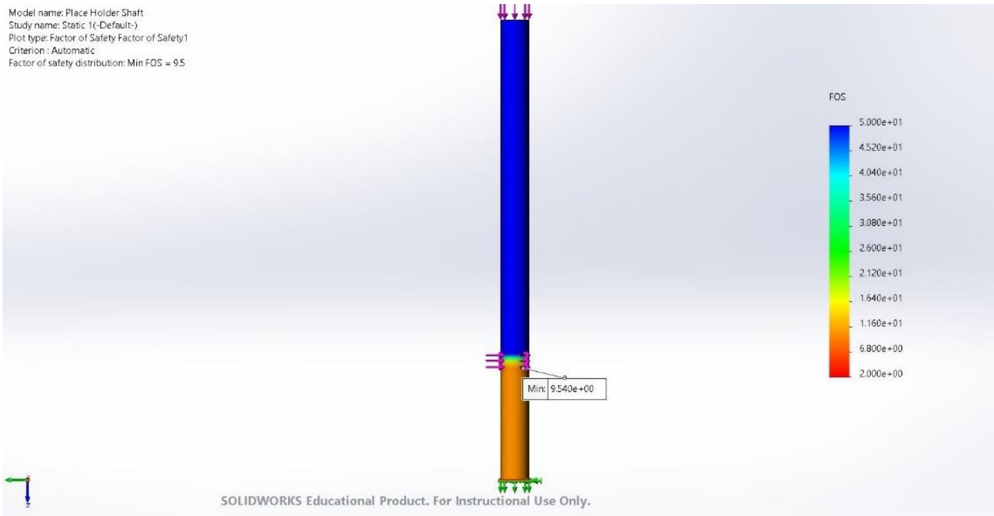


Figure 2.3: FEA Study for Center Shaft

Factor of Safety calculations for Air Cylinders			
Servo Motor Weight	18	Minimum Factor of Safety	1.55
Gearbox Weight	18		
Plate Weight	20	Maximum Force of Cylinder	248 lb
Shaft Weight	13		
Pulley	5	Force Available Using Minimum FOS	192.2
Bushing	5		
Armature Weight	15	Available Force	68.2
Wire Pulling Force	30		
Total	124	FOS	1.8181818

Table 2.1 : FOS Calculations for Pneumatic Cylinder Selection

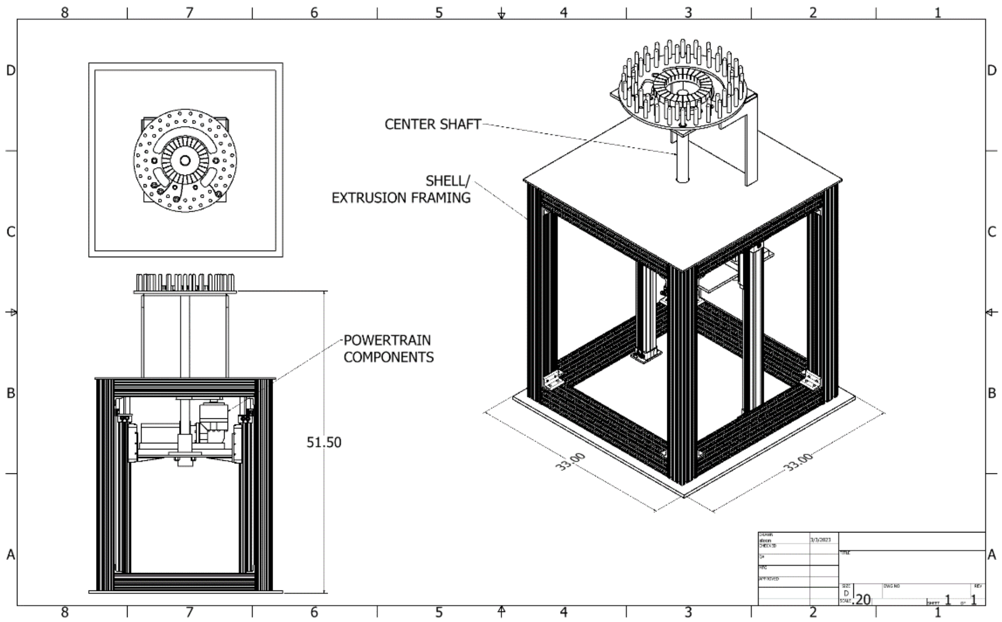


Figure 2.4 : Drawing of Winder Footprint

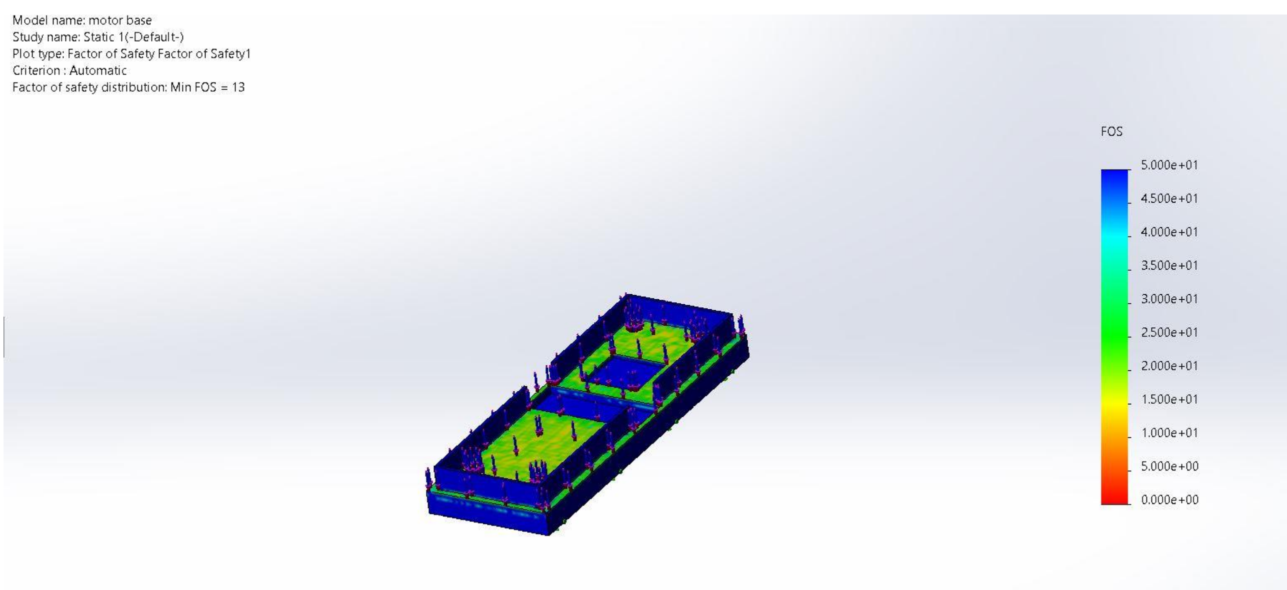


Figure 2.5 : Motor Mount Study

2.2.3 Design details

For our design, we consulted several different options indicated by our Embodiment Design Table. Starting from the top, we needed to construct a new loading rack and clamp assembly. We analyzed what was used for the current process of winding the armatures. This gave us a good starting point to make improvements and construct better versions of the loading racks. There are currently three different configurations of loading racks, a 66 pin, 56 pin and a 14 pin configuration. You can see the current winding set up with a 55 pin configuration loading rack in Figure B.11. Therefore, three different versions of loading racks would need to be constructed. Our first approach was that we wanted to standardize the three different loading racks where we could so they would be easier to handle for operators as they were completely different sizes, materials, and thicknesses. The first change was in our materials design phase. The loading rack, pins and wire guides needed to be analyzed to find the best material fits for our application. After extensive research, we found that switching the loading rack and pins to aluminum would be best. This would help cut down on weight, making it easier for operators to handle. For the wire guide, the current material was a solid block of nylon. After careful analysis we discovered that we could 3D print the wire guides out of nylon filament with 100% accuracy, cutting the cost to produce from $630.85 a part to $15 a part. We then looked at part design changes to continue the standardizing process as shown in Figure B.12. We changed the overall size of the loading rack for all three to the same size. We changed hole positions on the rack to make for concentric dimensioning. We then added guiding pins to the rack to help operators place the rack properly onto the fixture, and to stabilize the rack while the operators are loading the copper coils onto the loading rack. We also added hole liners to the two spots where the clamp locks in to help cut down on wear since we want the clamp to be tightly secured while the machine is in operation. After carful consideration, we decided to increase the thickness of the

loading rack from 1/4” to 3/8” to accommodate the change in material. We then made the center hole of the loading rack larger to allow the average person’s finger to fit in between the part and the wire guide as there was a safety concern on pinching/losing fingertips when the machine was in operation. For the clamp design, we first looked at material design. We switched from cast iron aluminum to a standard 4140 aluminum. This allowed for lighter weight, as operators are constantly putting the clamp on and off the machine and was a lot cheaper to manufacture. For the overall part design, we first changed the lengths of the hole positions to match the new loading rack as you can see in Figure B.13. We then decided to change the fillet angle dimensions around the part which helped cut down the cost for manufacturing and helped the overall look of the clamp to be more professional. You can see our new loading rack and clamp assembly in Figure B.14. We then moved on to the design of the fixture. We came up with several mock designs for possible fixtures. Our first design looked great, as shown in Figure B.15 but due to some parts needing to be bent, the venders on our list we unable to cut parts as we needed. In the end, we decided on a simplistic idea involving square and rectangular plates to be welded together as you can see in Figure B.16. We also went with 6061 steels, which is the same material as our top plate, so we were able to weld the fixture together and then weld the fixture to the top plate. This idea was very welcomed by Nidec sponsors as they have had problems in the past with over engineering and making movable components. Since we are welding our fixture to the top plate, this ensures there won’t be any chance of movement on the top of the winder. Being a very standard design, we were also able to cut most of the steel ourselves, furthering the positives of the more simplistic design.

We considered what was best for the motion up/down for the winder. We decided that pneumatics was the best option for this case. While servo would have been nice, it was expensive and would have set our team far over budget. A linear screw was the runner up for the

pneumatic option but due to the customizations needed for this application, the linear screw became expensive very fast. Hydraulics are what Nidec currently uses on their winders and want to get away from. Their hydraulic winders seem to leak an excessive amount and always seem to need attention, so we really wanted to avoid hydraulic if possible. Finally, we are left with pneumatic (air). Pneumatics time and time again have proven their reliability and have shown themselves to be very successful so that is why we chose pneumatics to move our winder up/down. For the left/right motion that the winder must perform we decided to go with a servo option due to Nidec having one in house and donating it to our project. This would also allow us to have extreme precision when moving left/right, which is important when winding the armatures. Linear screws would be unusual for this application and would take excessive engineering to make work. Hydraulics are in the same boat as linear screws is that it would be excessive and not really typical for this application. Pneumatics were the backup for this but would be expensive. The method of control we ended up going with is a Programmable Logic Controller (PLC). This again was donated by Nidec and saved us thousands of dollars. A PLC is essentially a super smart computer that is used in industry to help automate their processes. Our PLC can control 6 different processes at the same time, which is just right for our application. In terms of operator control, we did some preliminary testing to figure out what is the easiest for people to operate and how to keep the process as safe and as efficient as possible. A combination of buttons and a lever allows the operator to easily start, stop, reset, and emergency stop the process if anything happens. A lever is there to move the winder up/down and left/right. For the shell design we had several different options we could use to tackle this problem. Our team decided on extrusion framing based on a Finite Element Analysis (FEA). This study showed us that the lightweight aluminum framing would be plenty strong enough for the loads that this winder would experience. Another huge advantage that the extrusion framing is

modular, and easy to put together. Finally, the extrusion framing is relatively inexpensive especially when compared to a steel frame, or a combination of steel beams to support the structure. Finally, and arguably the hardest part about the project was all around the steel shaft. Nidec currently uses a expensive solid steel shaft that is keyed in a particular way for this application. Originally our team planned to try and reuse this shaft but when the quote came in, it proved more expensive than we planned for. Through FEA testing we proved that we can use a circular shaft or a square shaft. A square shaft was initially considered because it is stronger but when considering how it would rotate, it proved very costly to get a solution for it. In the end, a 1.5’’ circular shaft was chosen to be our center shaft.

Three FEAs were run to facilitate the design of the lifting assembly. The first of the two FEAS were on the main lifting plate which will hold the powertrain components and the shaft assembly. The second FEA was run specifically for the shaft assembly. For the lifting plate FEA two forces were applied. The first force was within the perimeter of the powertrain system and was equivalent to the weight of the system. The second force is the weight of the shaft assembly applied within the perimeter of the base. Fixed supports were then applied where the plate would be bolted to the pneumatic slides. The simulation provided a factor of safety of 20. The FEA on the shaft itself is structured with a fixed supported on the bottom where is it connected to the hub. Then a 20 lb. load was applied to the top of the shaft to simulate a fully loaded armature. Last, a 160.8 lb*ft torque load was applied to the area that the belt gear is located. This load was chosen because it would simulate a max torque spike. The shaft has a factor of safety of 9.5 at its most extreme situation. The group deemed these results as more than satisfactory and would match the cycle life of the cylinders which is 3 million cycles. The third and final was ran on the motor base. This component will hold the servo motor and the gearbox that are responsible for the rotational winding motion of the machine. Incorporated into this

FEA is the combined weight of the motor and gearbox along with a temperature component that would simulate the worst case scenario of the motor overheating. Both of these loads were applied to the top face of the base where they would be sitting. After running this FEA was run it was determined that the minimum factor of safety was 13. This far surpasses our requirements because the motor would never run that long in that state.

2.2.4 Building & Construction

During this second phase of the project, our team has worked countless hours building this automated winder. Aside from the two parts we had sent out to get built (loading rack and fixture), everything on the winder we machined ourselves. To better organize our time and efforts, machining the necessary parts was broken down further by two criteria: ease of which to machine and function of the part. The steps that we were able to accomplish during our senior design project are as follows; machining all the steel plates used to mount the cylinders, the extrusion framing etc., constructing the shell by erecting the extrusion framing and mounting the steel plates, and the implementation of our pneumatic tubes and cylinders into the shell.

As stated above, the first construction phase was the machining of all the individual plates needed for the winder. First, we ensured that each plate was the correct size and cut or trimmed as necessary using a gravity saw. Next, by referencing the corresponding drawings, our team used machinery such as a drill and tap, drill press, and acetylene torch to machine these plates. Once finished, they were then rechecked against the drawings, which are also located in the appendix for reference, to ensure a reasonable degree of tolerance. Some examples of parts machined during this step include, mounting plates for our pneumatic cylinders, the top and base plates for the shell of the winder, and a baseplate that will hold the interior servo and shaft to allow for vertical movement with the cylinders.

Figure 2.6 Cylinder Mount Plate

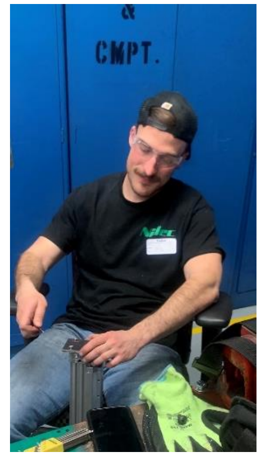


Figure 2.7 Installing Mount Plate

The next phase our team tackled was the shell. The shell consists of the extrusion framing "cage", the plastic material that goes around it in addition to the top and bottom mounting plates. The extrusion framing "cage" was chosen because of its lightweight yet very strong construction. We started by drilling the holes in the bottom plate which would allow us to align the extrusion framing columns. Next, we then worked on drilling and tapping the extrusion framing so that we can put a bolt in under the bottom plate and thread it into the extrusion framing columns. From there we installed the extrusion framing to make it a "cage", which involved laying out all the pieces in a loose fashion and adding in the gussets to support the vertical beams. Then we moved onto the top plate and drilling the holes in a similar fashion to the bottom plate to mount the other end of the extrusion framing columns. Once both the top and bottom plates were attached, we then affixed three of the plastic side plates by drilling into the side of the extrusion framing and putting a bolt at each corner. One side was left open so that we can still access and work on the interior of our winder.

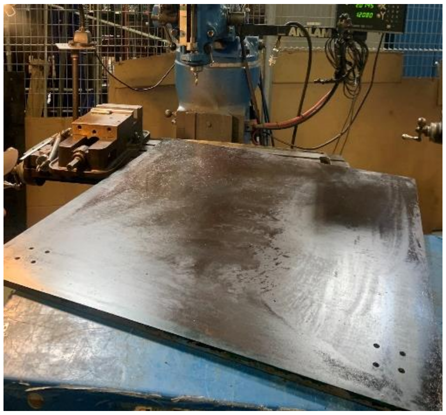


Figure 2.8 Top Plate Drilling

Figure 2.9 Cage Construction

Figure 2.10 Side Panels Installed

The last stage of our building revolved around the pneumatics of our device. This section covers all the air components such as the cylinders in addition to the air preparation equipment. We started with installing our designed cylinder mounting plates allowing us to rough fit the cylinders into position. Once we confirmed the fit of our parts, we measured the center of the top plate and used a torch to cut a 1.75’’ hole for our center shaft. Next, we moved onto drilling and tapping the carriage car mounts. This allowed us to use our designed mounting plate adapters to connect the mounting plate that lifts the assembly to the lifting cylinders. Once all the assembly process was finished, we put the completed assembly into the winder and drilled the appropriate holes to mount everything together. The images below represent our progress with the pneumatic installation, as well as appropriate labels needed for maintenance and 3Q6S continuous improvement.

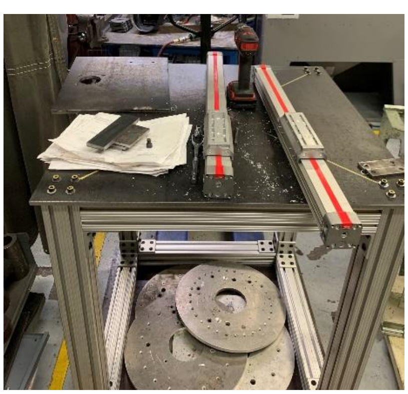


Figure 2.11 Cylinders Tapped

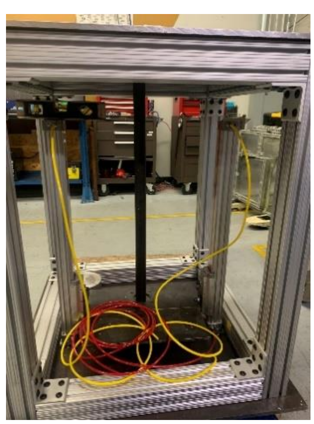


Figure 2.12 Cylinders Installed

Figure 2.13 Air Lines Ran

2.3 Verification

At the start of the project Nidec outlined production numbers for their six top selling models. In the table below those models and production rates are shown.

Model Number	Production
P565x001	24pcs/hr.
P56AN227	27pcs/hr.
P56AN239	30pcs/hr.
P565x043	24pcs/hr.
P565x103	24pcs/hr.
P565x163	10pcs/hr.

Table 2.2 Nidec Current Production

To achieve these production rates, the winder needed to reach certain performance metrics. These metrics are a rotational speed of 120 rpm while having a vertical speed on 2 in/s. These metrics were experimentally found while working with Nidec's production team and engineering department. After assuring that our winder would meet these criteria, we ran some simulations to determine what the theoretical production numbers would be with our new model. These new numbers are shown below and are based on the metrics above in addition to efficiency changes resulting from the design change.

Model Number	Improved Production
P565x001	36pcs/hr.
P56AN227	40pcs/hr.
P56AN239	45pcs/hr.
P565x043	36pcs/hr.
P565x103	36pcs/hr.
P565x163	15pcs/hr.

Table 2.3 Nidec Predicted Production

2.4 Costs

Due to the complex nature of a automated winder, it requires several components and a lengthy bill of materials (BOM). The total cost of materials was $13,000. When the project started, we were given a preliminary budget of $10,000. However, the project scope changed dramatically, increasing our workload and because of this, our budget for the winder increased to $15,000. I am happy to say that we are below budget and left the Nidec team with $2,000 left over for spare parts or whatever they see fit. Looking at the bill of materials does help paint a picture for how much the project cost, but it does not tell the whole story. Our team personally spent on average 6 hours a week on this project which incorporates the research, design, build, testing/validation, and implementation phases. Taking the average salary of a Mechanical Engineer in Ohio which comes out to $70,000, working approximately 28 weeks, with four group members comes out to approximately $15,000. This equation used is the ideal salary in hours (in our case this was the average salary of $70,000 divided into an hourly rate of $35) multiplied by actual hours spent (in our case this was 6 hours), multiplied by the number of group members (we have four members in our team), finally multiplying this by 2.5 will result in an answer of $14,700 or approximately $15,000. When you add this to our BOM stated above, this yields a total cost of $28,000 for the automated winder.

While some may think this is relatively high, it is important to first keep in mind that in fact our group was under budget for the BOM and secondly, we need to look at the payback that this winder will yield or Return on Investment (ROI). Nidec's original winders have been operating relatively smoothly since the mid-1900s, we expect around the same life expectancy for our winder with the most susceptible component in the winder expected to fail around 1,000,000 cycles. Due to the detailed maintenance schedules our team has proved Nidec with, this will lead to overall less

downtime and more time that they can spend making money. Finally, it is important to realize that this automated winder is going to be used hard and is expected to perform time and time again so it was unacceptable to cut corners. This winder we foresee holding up based on all of the engineering our team has put in.

Rodless Cylinder		59675K242	Mcmaster
Linear Postion Sensor		6863K3	Mcmaster
1/4" NPT Connector		5779K109	Mcmaster
1/4" Air Hose	Retract air house RED RETRACT 25'	5648K31	Mcmaster
1/4" Air Hose	Extend Air house YELLOW EXTEND 25'	5648K31	Mcmaster
Circular Tubing	3ft x 1.5'' Dia Circular Tubing	6628K44	McMaster
Trailer Hub	Hub Adapter for shaft rotation	1-4884	Surplus Center
Door Hinges	4 Door Hinges for the two doors on shell	1586A31	Mcmaster
Control Box	Control Box	7758K41	McMaster
E Stop	Emergency Stop Button	9235K2	McMaster
Start	Start Button (Up)	9235K17	McMaster
Stop	Stop Button (Down)	9235K17	McMaster
Reset	Reset Button	9235K17	McMaster
Joystick	Joystick Operator	2EL59	Grainger
Extrusion Framing	Interior Extrusion Framing (24in)	47065T502	McMaster
Extrusion Framing	Interior Extrusion Framing (36in)	47065T502	McMaster
Extrusion Framing Supports	Gussets for Extrusion framing	47065T254	McMaster
Swing Arm	Wall-Mount Flat-Panel Monitor Positioning Arm	1133A4	Mcmaster
Saftey Switch	Door Saftey Switches	65745K53	McMaster
Soleniod Bank	SMC Valve Bank SS5Y5-10SFA-05B-N7	71871642	Allied
Festo Filter and PPC	Festo Air Controller	70993916	Allied
Soleniod Valve	SMC Corporation SY5200-5U1	70403052	Allied
Blanking Plate	SMC Corporation SY50M-26-1A	70403044	Allied
Metal Material	Shell Material		Alro
Plastic Material	Shell Material		Alro
PLC	Programmable Logic Controller		Nidec
Door Latch	Latch for Winder	1820A32	Mcmaster
Festo Fittings	Fittings for Festo air prep	70991261	Allied
Hose for Festo Prep	Hose for Festo Prep 25' (GREEN) (SUPPLY AIR)	50315K25	Mcmaster
Nidec to Festo Hose Adapter	Nidec to Festo Hose Adapter	44555K116	Mcmaster
Gearbelt pully	Rotational pully system	6ffv9	Grainger
Quick Detachable Bushing	Main Shaft bushing	5uhz3	Grainger
Quick Detachable Bushing	Servo Bushing	qt22mm	Amazon
24" Belt	Drive Belt	1DHK9	Grainger
Loading Rack	Loading Rack		Outsourced
Nidec Gearbox	Nidec Gearbox		Nidec
1/4 hose barb	1/4 hose barb	5357K32	McMaster
8 mm hose barb	8 mm hose barb	5357K151	McMaster
1/4 pipe adapter	1/4 pipe adapter	3867T61	McMaster
Collet Closer	Air operated collet closer 5C	5317A13	McMaster

Table 2.4 Bill of Materials

2.5 Nidec Punch List

Throughout our design project we have run into multiple roadblocks and due to these roadblocks, we have been unable to complete the winder. In order to assist Nidec with completing winder once we leave, we have created a punch list for them. The following is a to-do list for Nidec to follow to complete the winder.

The first item on the to-do list is to write ladder logic which is the key to any automation for

the winder. Ladder logic is a programming language used to program a programmable logic controller (PLC) and is used to control the various components of the winder, such as the motor, gearbox, and pneumatic controls. After that we will install the PLC onto the winder which will include running power to it and connecting it to the systems it will need to control. After that, the ladder logic will need to go through a trouble shooting phase to ensure everything is firing at the correct time and nothing was overlooked during the creation of the ladder. As stated above the PLC will need power ran to it and so will the other devices in the winder, such as the servo and pneumatic control. After the electronics are installed, the pneumatic controls need to be installed on the winder as well. These controls are the Festo air pressure regulator and SMC solenoid bank assembly. After that pneumatic lines will need to run throughout the winder to such components as the cylinders and collet, which will need installed as well. Also, air and electrical mains will need to be run on the shop floor for testing and eventual implementation. With all the electronics and pneumatics installed the pneumatics will need to be manually fired separate from the PLC. This will ensure they are working correctly, and hoses are in the proper location that matches the ladder logic.

Once all of the control systems are in there a few small pieces that need fabricated to ensure that the winder will work as designed. The first items are the mounting plates that fasten on top of the winder. These connect the cylinders to the top plate of the winder via the support rods that will need installed as well. The purpose of the plate and rods is to prevent the cylinders from flexing during use. Holes will need to be drilled into both the top and bottom plates of the winder shell to accommodate this. Once the cylinders are secured, the components on the plate between them need to be installed. These components are the servo motor, gearbox, hub, and shaft. The hub needs bolted to the plate and the shaft needs inserted then cut the length. In regard to the shaft, the hole in the top of the plate will need to be cleaned up to allow for the installation of a bushing that

will prevent operators from being able to access the internals of the winder. Another step, to prevent operators from being able to access the internals is to add sealant around the top of the plastic of the shell. Also, the fixture needs redesigned, 3D printed, and installed to hold the servo and gearbox. 3D printing will be utilized to save cost and time. After the shaft and gearbox are installed the gears that go on them can be installed along with the belt. The belt will couple them and allow for the servo to power the shaft which is part of the automation process.

With the connecting plate taken of the rest of list focuses on the external of the winder. First is to install the control box with its corresponding wires and the mounting arm which it will be connected to. The control box holds most of the safety systems for the winder and is vital to its operation. An additional part of the winder are the doors. These will need cut out and installed on the winder. Part of this installation will include putting in the safety switches and ensuring that if they are activated it will cease all motion on the winder.

Nidec Punch List	
Order	Item
1.	Write ladder logic
2.	Install PLC
3.	Trouble shooting ladder logic
4.	Run electric lines throughout the winder
5.	Add air drops on shop floor
6.	Install pneumatic controls
7.	Run air lines
8.	Manually test pneumatics
9.	Finish fabricating mounting plates for top of cylinders
10.	Install plates and support rods
11.	Drill holes in top and bottom plate for cylinder mounting plates
12.	Redesign servo motor and gearbox mounting fixture
13.	Print motor and gearbox mounting fixture
14.	Install fixture
15.	Add sealant around the top of winder to seal it
16.	Clean shaft hole and add bushing
17.	Install control box and mounting arm
18.	Run wires for control box
19.	Cut out doors
20.	Install safety switches for doors
21.	Install doors
22.	Put gears onto gearbox and shaft
23.	Install belt on gears
24.	Install collet
25.	Run appropriate lines for collet

Table 2.5 Nidec Punch List

2.6 Conclusions

While our group did not get the winder completely done as we would have hoped, we did make significant progress despite countless setbacks. Our winder construction is primarily complete. All that is essentially left is the mounting of the motor and the implementation of the PLC and controls. For a complete list of items that need done, visit the Nidec Punch List that is above. While the winder is not complete at this stage, our team is leaving Nidec a project that is ready to be taken over to be complete by the next team. Nidec has all of the Engineered Drawings, the materials, and anything else they should need.

2.7 References

Below are some images that our team used to reference while we worked on the automated winder.

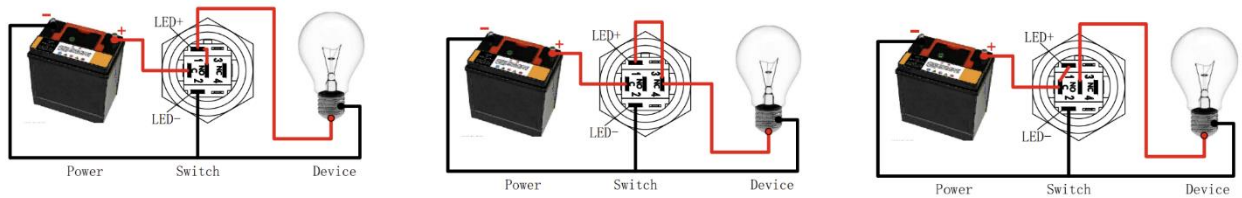


Figure 2.14 Button Wiring

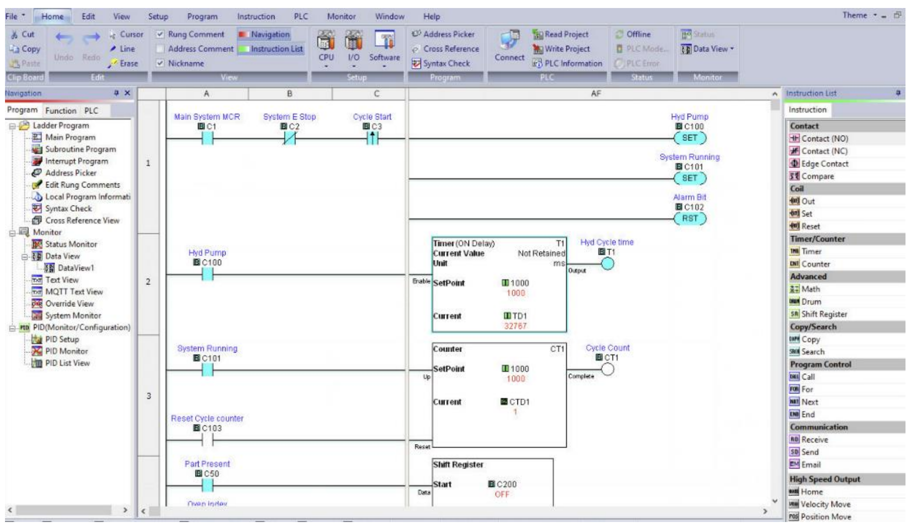


Figure 2.15 PLC Ladder Logic

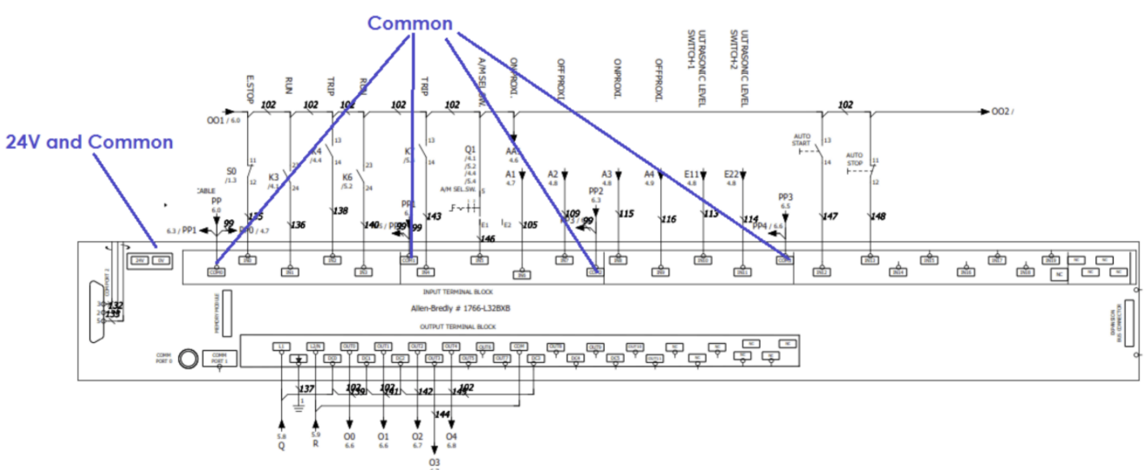


Figure 2.16 PLC Wiring

3. Codes and Standards

Throughout our entire project of automating the winder machine, we as a team emphasized and practiced safety measures throughout in accordance with the ASTM standards. Automating the winding process is complex and it is crucial safety remains the number one concern. In addition to improving the efficiency and reliability of the winder, we also wanted to make this winder upheld the same safety standards that are currently available to the Nidec employees. In this automated winder we have incorporated several different safety features in order to keep the operator safe. These safety features include Emergency stop button(s), door sensors, and PLC programming.

Since this winder is going to be moving at relatively quick speeds, it only takes a second for something to happen and for injury to take place. This is why our team incorporated a Emergency Stop button into the winder operation. If the operator sees something unsettling or is not sure about, they can simply press the Emergency Stop button in which will cut power to the whole winder, freezing everything in that moment. This will give time to the appropriate team to come in and address the issue at hand.

Our second safety feature involves door sensors. Our winder has two doors, which in turn means two separate door sensors. These door sensors are tied directly into the PLC and sense if the doors are open or closed. If the doors are closed (normal operation), the winder will function as normal, allowing the operator to move and rotate the shaft. However, if the doors or even one door is open, the PLC will not allow the winder to operate either the move or rotate the shaft unless a manual override is performed which needs to be done by a certified engineer. This will prevent anyone from entering a hand or foreign object into the inner workings of the winder where all the movement is taking place. Triggering any of the door sensors will act as an Emergency Stop button when the door is open.

Finally, our third safety feature we have incorporated into the automated winder involves coding in the PLC. In our winder machine we have sensors that tell the PLC exactly where everything is and how it is performing. It communicates with our PPC to monitor pressure and make sure everything is working as tended. If things reach a certain threshold, (too far off of design specification), the PLC will trigger a stop depending on the severity of the problem. The winder will not be allowed to run until the issue is fixed and the winder is reset.

In addition to these safety measures incorporated into the winder, we would like to mention that we have consulted the ASTM Codes and Standards when working on this automated winder machine. Specifically, our team has referenced ASTM A1047/A1047M-05. This work discusses the standard test method for pneumatic leak testing of tubing. As mentioned above, our winder will raise and lower the shaft using pneumatic cylinders. These cylinders are pressurized up to 100psi and need to be able to hold that pressure consistently. It is important for us as a team to verify there is no leaks because that could lead to injury if a line were to pop off or something similar. This work from ASTM goes over the procedures for the leak testing of tubing using pneumatic pressure and this is the procedure we followed when setting up the automated winder.

Overall, when doing any sort of design, safety should always be the number one concern. We want anyone who operates this winder to come home exactly as they came to work. This in turn involves us as the engineers responsible for the project to constantly make sure that corners are not cut and we are using appropriate calculations i.e. using the appropriate FOS (Factor of Safety). All of these factors combined allowed our team to create a functional, and most importantly, safe winder machine.

4. Conclusion and Further Resources

The last two semesters of senior design have been some of the most challenging times of our entire college tenure. Since it is such a different experience than every other class we had taken up to this point, we were forced to make quick adjustments in our daily cadence to compensate. Things such as reports, exams, and homework did not really exist in this environment, and it was up to us as a group to keep ourselves on task and make sure we were learning what we needed to. Even things as simple as scheduling became difficult now that there was no set assigned class time to work on our project and each member had their own schedule and priority. Another thing that proved challenging was the solution or lack thereof. This may seem confusing, but as engineers and STEM students we are very logical and detail-oriented people. Every question for the duration of our college career has been an application of steps to a problem with the outcome being one defined solution. One solution that is defined by the professor, and if we do not come to that solution then we are just wrong. For the first time we are faced with a problem that has no "correct solution". These are problems that haven't been solved before or that may even have multiple solutions; solutions that's validity is completely dependent on us. This plethora of choices can often lead to paralysis by indecision; made famous by a donkey and two bales of hay.

All these challenges, however, allowed for some very rewarding moments the past few semesters as well. By forcing us to adapt, I strongly believe that we learned more in senior design then we have in any other class. Things that you cannot teach in a classroom like maintaining a schedule, setting meetings, group discussions and workplace politics came easily even to those with little or no previous work in an industrial setting. Even the smallest decisions forced complex thought and discussion from each member in our group and taught a level of collaboration that is almost impossible to achieve in a class setting. This new knowledge and skillset will prove invaluable as we graduate from school and move on to our jobs afterward.

Furthermore, over the duration of our senior design project, we have gained more knowledge on each other than we ever would have previously. Learning more about each other on everything from music taste to workstyle created a supportive and stimulating environment that made the long work hours substantially easier. Playing to each other's strengths, and avoiding our weaknesses, made us a more effective team overall as we were able to pivot duties as needed. These relationships are ones that we will carry for the remainder of our college careers and hopefully further on into the greater world as well.

In addition to this, our team has learned/strengthened several skills primarily when it comes to machining. Most of our group members have not had an opportunity to work in a machine shop and operate machinery such as a drill press, band saw, welder, etc. These are just some of the pieces of equipment we have had an opportunity to work with these past two semesters. In addition to machining skills, we have also learned a lot more about project management and the importance of weekly meetings. With a project this large, it is crucial to stay on topic and stay focused on the task at hand. As mentioned before, our group members each specialized in a specific area(s) and if you do not have the proper communication, things can get overlooked or even forgotten. Going off this, we learned the importance of staying on top of people. Often, we found it hard to get items purchased from the proper people and this led to constant follow ups to get what we needed. This was a similar story with the vendors we worked with. They promised us a lead time of a few weeks, this then turned into months and could have still never been done if we did not continuously follow up with them.

References

[1] *https://electrical-engineering-portal.com/download-center/books-and-guides/siemens-basics-of-energy/basics-of-plcs*

[2] https://www.automate.org/tech-papers/understanding-the-basics-of-plcs

[3] https://conceptsystemsinc.com/the-basics-of-programmable-logic-controllers-plc/

[4] https://www.engineeringtoolbox.com/

[5] https://www.astm.org/products-services/standards-and-publications/standards.html

[6] https://www.engineersedge.com/class_i.htm

[7] https://www.engineersedge.com/iso_tolerance.htm

[8] https://www.indicatorlight.com/faq/how-to-wire-a-push-button-switch/

[9] https://www.automationdirect.com/clickplcs/free-software/free-click-software

[10] https://theautomization.com/plc-wiring/

Appendix A Nomenclature

Unit or Term	Symbol or Abbreviation
alternating current	ac
American wire gauge	AWG
ampere	A
ampere-hour	Ah
amplitude modulation	AM
angstrom	Å
antilogarithm	antilog
atomic mass unit (unified)	u
audio frequency	AF
automatic frequency control	AFC
automatic gain control	AGC
automatic volume control	AVC
average	avg
backward-wave oscillator	BWO
bar	bar
barn	b
beat-frequency oscillator	BFO
bel	B
billion electronvolts*	BeV
binary coded decimal	BCD
bit	b
British thermal unit	Btu
byte	B
calorie	cal
candela	cd
candela per square foot	cd/ft^2
candela per square meter	cd/m^2
cathode-ray oscilloscope	CRO
cathode-ray tube	CRT
centimeter	cm
centimeter-gram-second	CGS
circular mil	cmil
continuous wave	CW
coulomb	C
cubic centimeter	cm^3
cubic foot per minute	ft^3/min
cubic meter	m^3
cubic meter per second	m^3/s
curie	Ci
cycle per second	Hz
decibel	dB
decibel referred to one milliwatt	dBm
degree Celsius	°C
degree Fahrenheit	°F
degree Kelvin**	K
degree (plane angle)	...°
degree Rankine	°R
degree (temperature interval or difference)	deg
diameter	diam
direct current	dc
double sideband	DSB
dyne	dyn
electrocardiograph	EKG
electroencephalograph	EEG
electromagnetic compatibility	EMC
electromagnetic unit	EMU

*Deprecated: use gigaelectronvolt (GeV).
**Preferably called simply *kelvin.*

Unit or Term	Symbol or Abbreviation
electromotive force	EMF
electronvolt	eV
electrostatic unit	ESU
erg	erg
extra-high voltage	EHV
extremely high frequency	EHF
extremely low frequency	ELF
farad	F
field-effect transistor	FET
foot	ft
footlambert	FL
foot per minute	ft/min
foot per second	ft/s
foot-poundal	ft-pdl
foot pound-force	ft•lbf
frequency modulation	FM
frequency-shift keying	FSK
gallon	gal
gallon per minute	gal/min
gauss	G
gigacycle per second	Gc/s
gigaelectronvolt	GeV
gigahertz	GHz
gilbert	Gb
gram	g
henry	H
hertz	Hz
high frequency	HF
high voltage	HV
horsepower	hp
hour	h
inch	in
inch per second	in/s
inductance-capacitance	LC
infrared	IR
inside diameter	ID
intermediate frequency	IF
joule	J
joule per degree	J/deg
joule per kelvin	J/K
kilobit per second	kb/s
kilobyte	kB
kilocycle per second	kHz/s
kiloelectronvolt	keV
kilogauss	kG
kilogram	kg
kilogram-force	kgf
kilohertz	kHz
kilohm	kΩ
kilojoule	kJ
kilometer	km
kilometer per hour	km/h
kilovar	kvar
kilovolt	kV
kilovoltampere	kVA
kilowatt	kW

Unit or Term	Symbol or Abbreviation
kilowatthour	kWh
lambert	L
liter	l
liter per second	l/s
logarithm	log
logarithm, natural	ln
low frequency	LF
lumen	lm
lumen per square foot	lm/ft^2
lumen per square meter	lm/m^2
lumen per watt	lm/W
lumen-second	lm•s
lux	lx
magnetohydrodynamics	MHD
magnetomotive force	MMF
maxwell	Mx
medium frequency	MF
megacycle per second	MHz/s
megaelectronvolt	MeV
megahertz	MHz
megavolt	MV
megohm	MΩ
metal-oxide semiconductor	MOS
meter	m
microampere	μA
microfarad	μF
microgram	μg
microhenry	μH
micrometer	μm
micron†	μ
microsecond	μs
microsiemens	μS
microwatt	μW
mil	mil
mile per hour	mi/h
mile (statute)	mi
milliampere	mA
milligram	mg
millihenry	mH
milliliter	ml
millimeter	mm
millimeter of mercury, conventional	mmHg
millimicron‡	nm
millisecond	ms
millisiemens	mS
millivolt	mV
milliwatt	mW
minute (plane angle)	...'
minute (time)	min
nanoampere	nA
nanofarad	nF
nanometer	nm
nanosecond	ns
nanowatt	nW
nautical mile	nmi

†The name *micrometer* (μm) is preferred.
‡The name *nanometer* is preferred.

Unit or Term	Symbol or Abbreviation
neper	Np
newton	N
newton meter	N•m
newton per square meter	N/m^2
oersted	Oe
ohm	Ω
ounce (avoirdupois)	oz
outside diameter	OD
phase modulation	PM
picoampere	pA
picofarad	pF
picosecond	ps
picowatt	pW
pound	lb
poundal	pdl
pound-force	lbf
pound-force foot	lbf-ft
pound-force per square inch	lbf/in^2
pound per square inch§	psi
power factor	PF
private branch exchange	PBX
pulse-amplitude modulation	PAM
pulse code modulation	PCM
pulse count modulation	PCM
pulse duration modulation	PDM
pulse position modulation	PPM
pulse repetition frequency	PRF
pulse-repetition rate	PRR
pulse-time modulation	PTM
pulse-width modulation	PWM
radian	rad
radio frequency	RF
radio-frequency interference	RFI
resistance-capacitance	RC
resistance-inductance-capacitance	RLC
revolution per minute	r/min
revolution per second	r/s
roentgen	R
root-mean-square	rms
second (plane angle)	..."
second (time)	s
short wave	SW
siemens	S
signal-to-noise ratio	SNR
silicon controlled rectifier	SCR
single sideband	SSB
square foot	ft^2
square inch	in^2
square meter	m^2
square yard	yd^2
standing-wave ratio	SWR
steradian	sr
superhigh frequency	SHF
television	TV
television interference	TVI

§Although the use of the abbreviation psi is common, it is not recommended. See pound-force per square inch.

Unit or Term	Symbol or Abbreviation
tesla	T
thin-film transistor	TFT
transverse electric	TE
transverse electromagnetic	TEM
transverse magnetic	TM
traveling-wave tube	TWT
ultrahigh frequency	UHF
ultraviolet	UV
vacuum-tube voltmeter	VTVM
var	var
variable-frequency oscillator	VFO
very-high frequency	VHF
very-low frequency	VLF

Unit or Term	Symbol or Abbreviation
vestigial sideband	VSB
volt	V
voltage controlled oscillator	VCO
voltage standing-wave ratio	VSWR
voltampere	VA
volume unit	vu
watt	W
watthour	Wh
watt per steradian	W/sr
watt per steradian square meter	$W/(sr \cdot m^2)$
weber	Wb
yard	yd

Appendix B Engineered Drawings

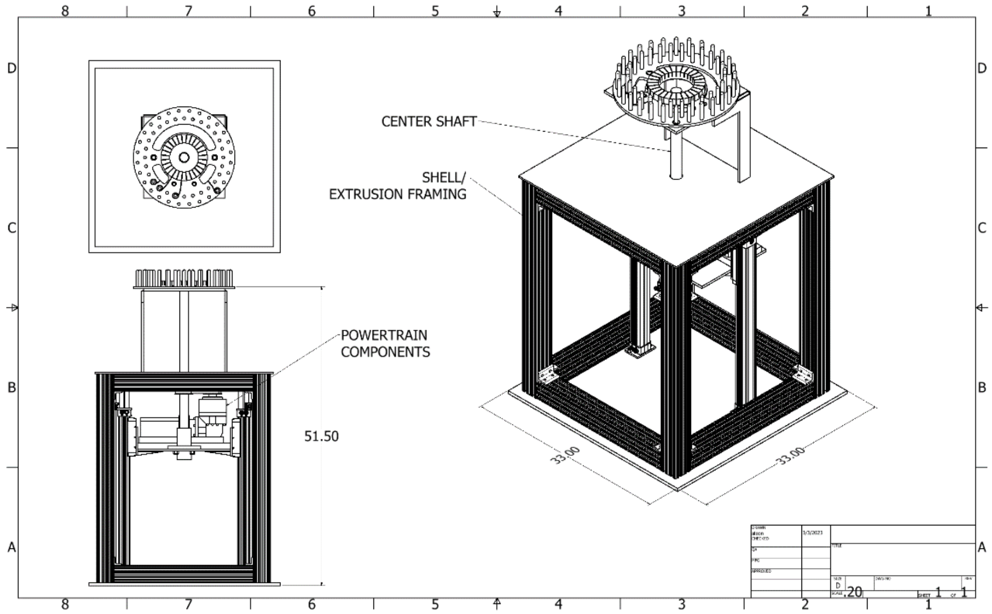


Figure B.1 Winder Master Assembly

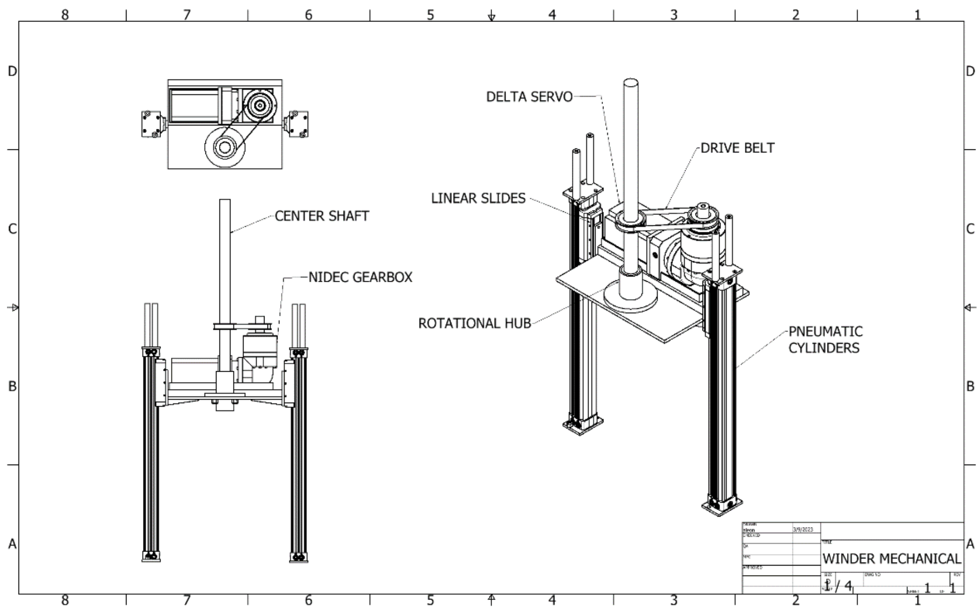


Figure 8.2 Winder Mechanical

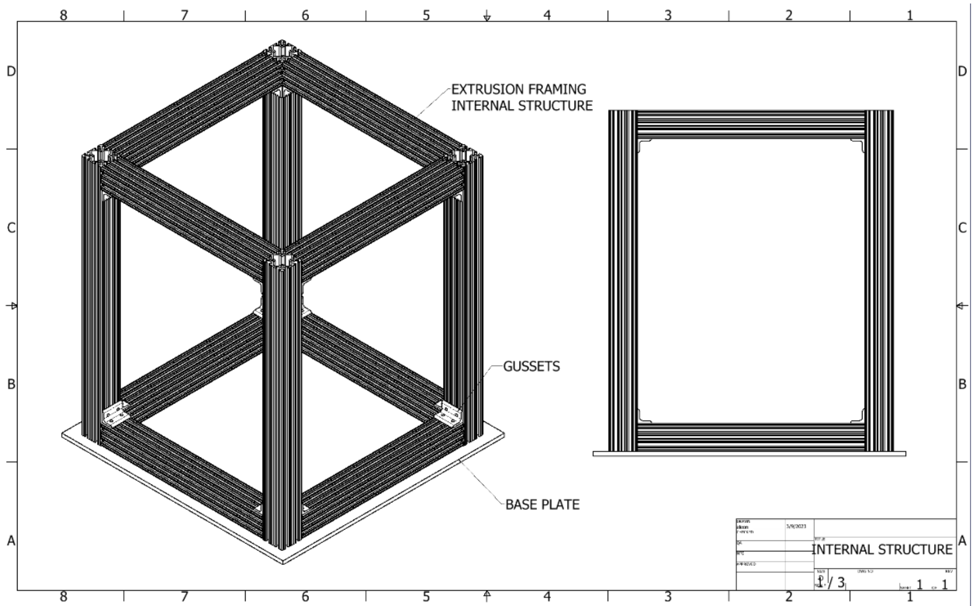


Figure B.3 Internal Structure

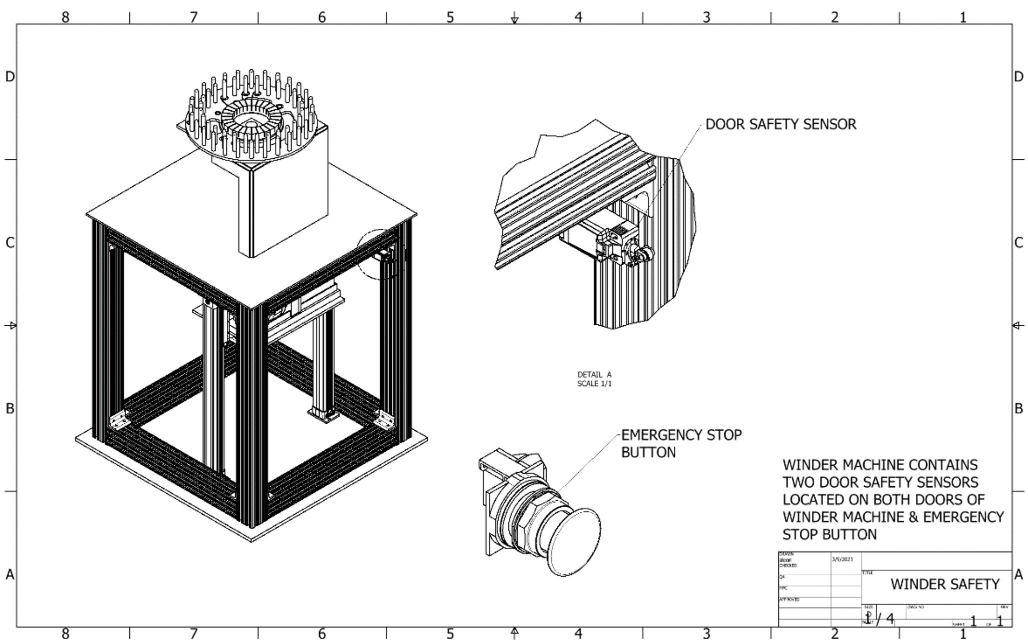


Figure B.4 Winder Safety

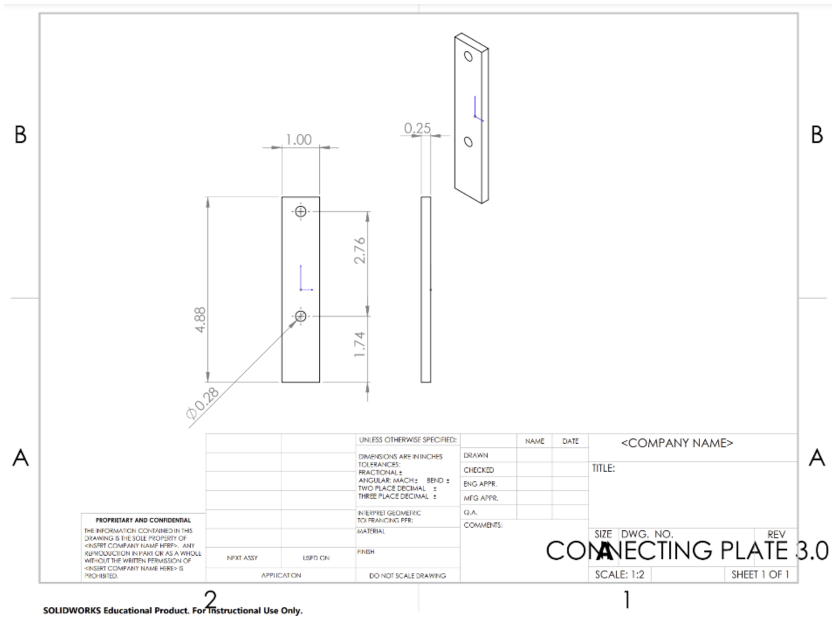


Figure B.5 Connecting Plate

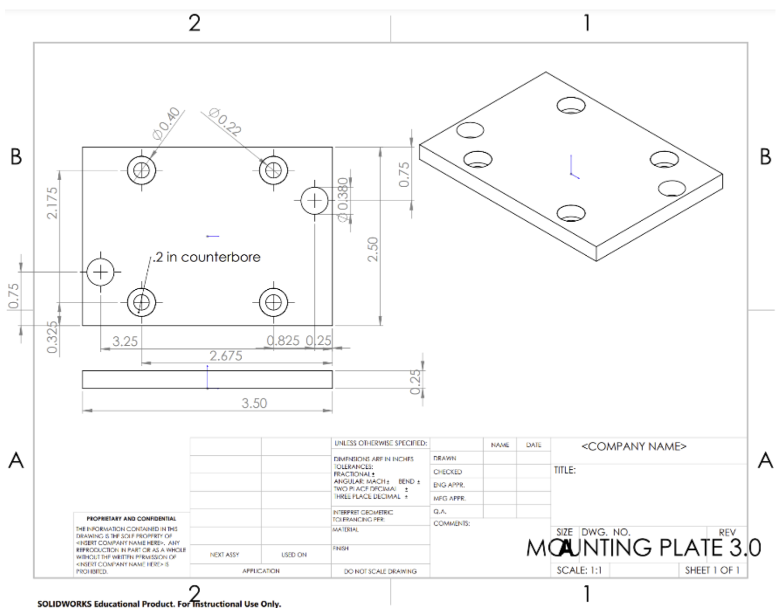


Figure B.6 Mounting Plate

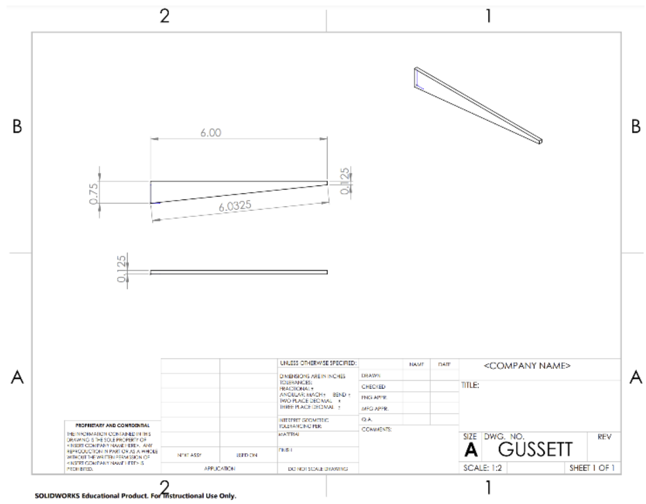


Figure B.7 Gusset

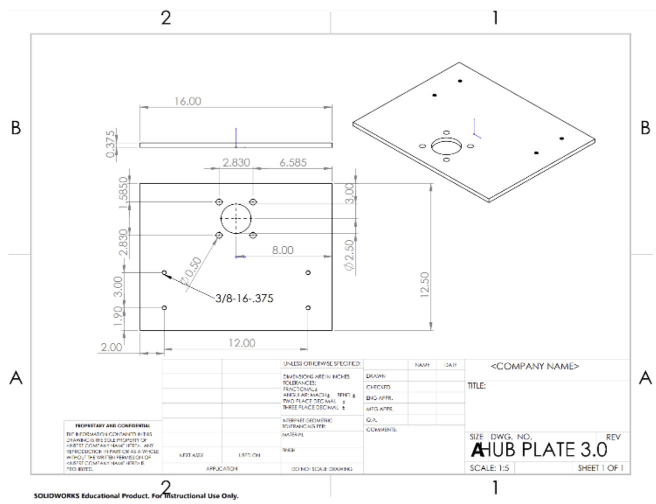


Figure B.8 Hub Plate

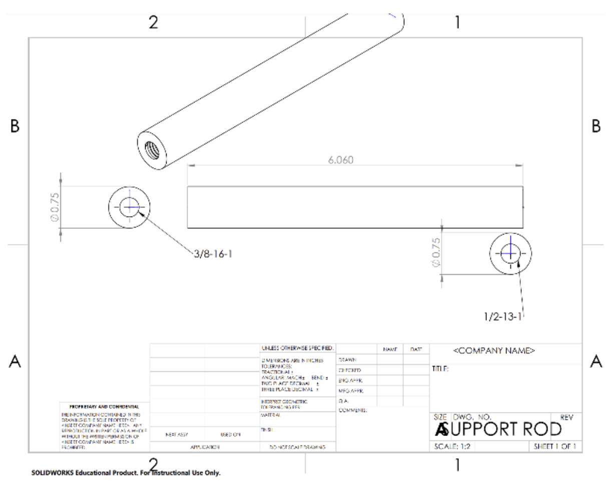


Figure B.9 Support Rod

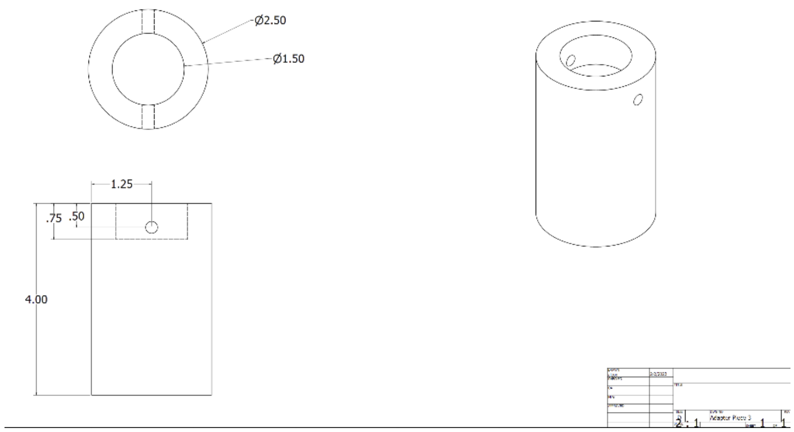


Figure B.10 Adapter Piece

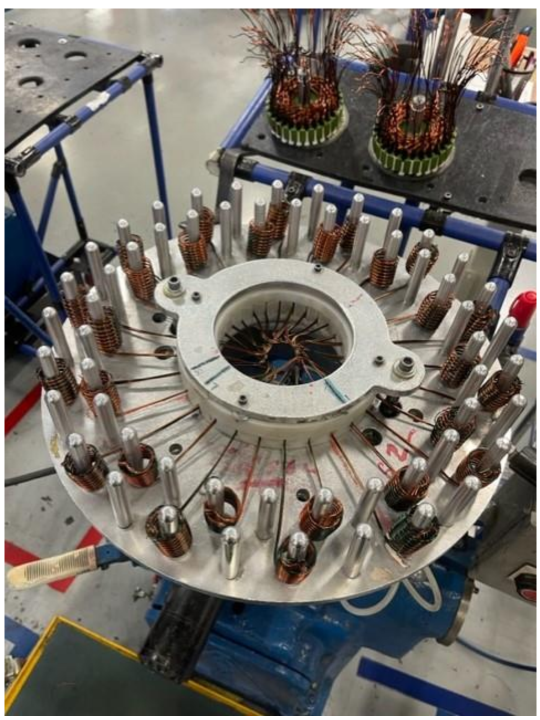
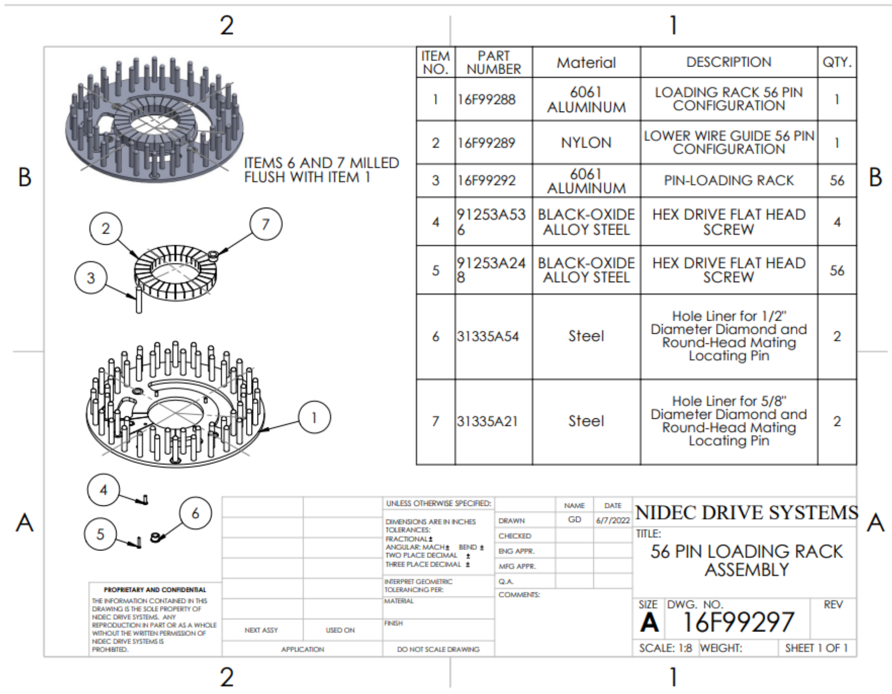
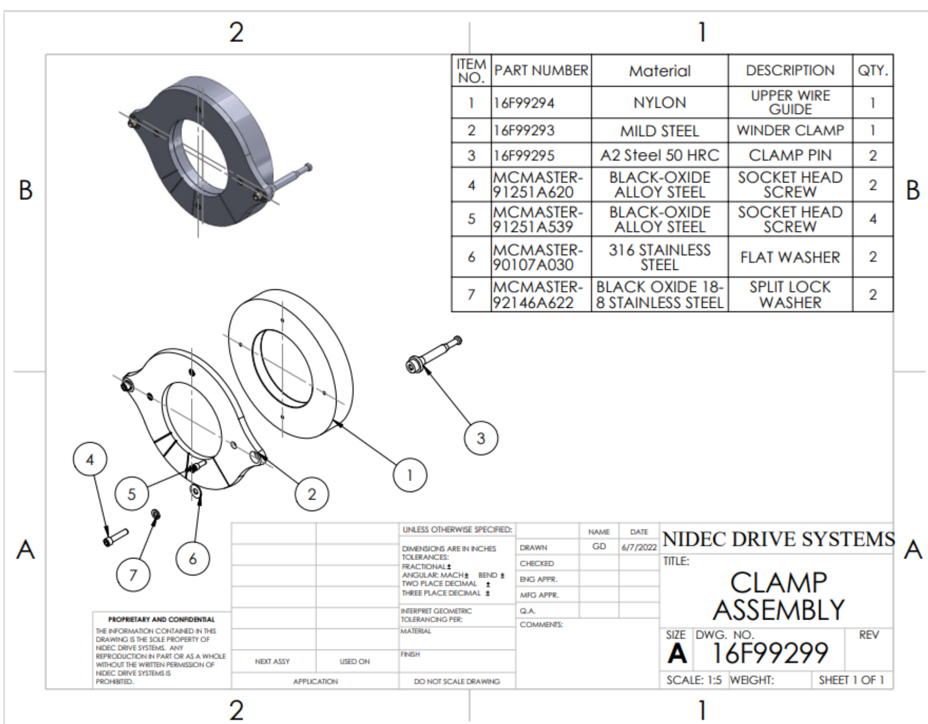


Figure B.11 Old Winder Loading Rack & Clamp Assembly



ITEM NO.	PART NUMBER	Material	DESCRIPTION	QTY.
1	16F99288	6061 ALUMINUM	LOADING RACK 56 PIN CONFIGURATION	1
2	16F99289	NYLON	LOWER WIRE GUIDE 56 PIN CONFIGURATION	1
3	16F99292	6061 ALUMINUM	PIN-LOADING RACK	56
4	91253A536	BLACK-OXIDE ALLOY STEEL	HEX DRIVE FLAT HEAD SCREW	4
5	91253A248	BLACK-OXIDE ALLOY STEEL	HEX DRIVE FLAT HEAD SCREW	56
6	31335A54	Steel	Hole Liner for 1/2" Diameter Diamond and Round-Head Mating Locating Pin	2
7	31335A21	Steel	Hole Liner for 5/8" Diameter Diamond and Round-Head Mating Locating Pin	2

Figure B.12 New Loading rack & Wire Guide



ITEM NO.	PART NUMBER	Material	DESCRIPTION	QTY.
1	16F99294	NYLON	UPPER WIRE GUIDE	1
2	16F99293	MILD STEEL	WINDER CLAMP	1
3	16F99295	A2 Steel 50 HRC	CLAMP PIN	2
4	MCMASTER-91251A620	BLACK-OXIDE ALLOY STEEL	SOCKET HEAD SCREW	2
5	MCMASTER-91251A539	BLACK-OXIDE ALLOY STEEL	SOCKET HEAD SCREW	4
6	MCMASTER-90107A030	316 STAINLESS STEEL	FLAT WASHER	2
7	MCMASTER-92146A622	BLACK OXIDE 18-8 STAINLESS STEEL	SPLIT LOCK WASHER	2

Figure B.13 New Clamp

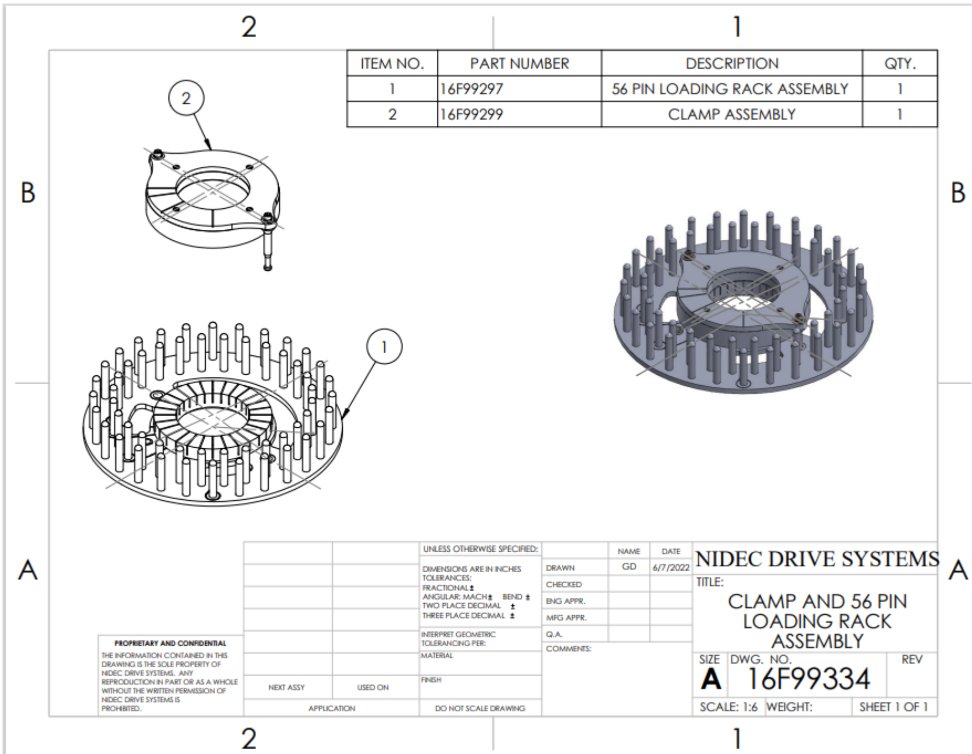


Figure B.13 New Loading Rack & Clamp Assembly

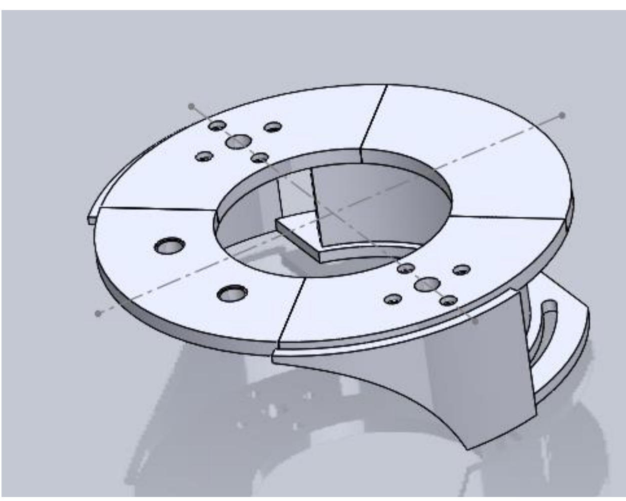


Figure B.15 First Fixture Design

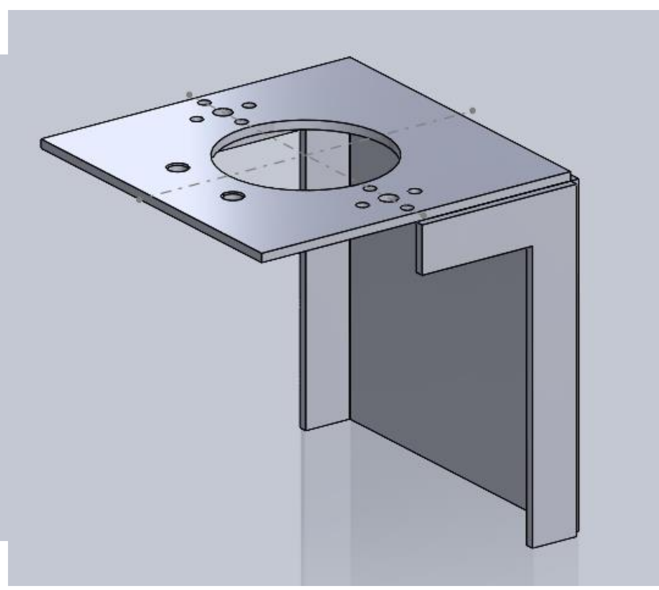


Figure B.16 Final Fixture design

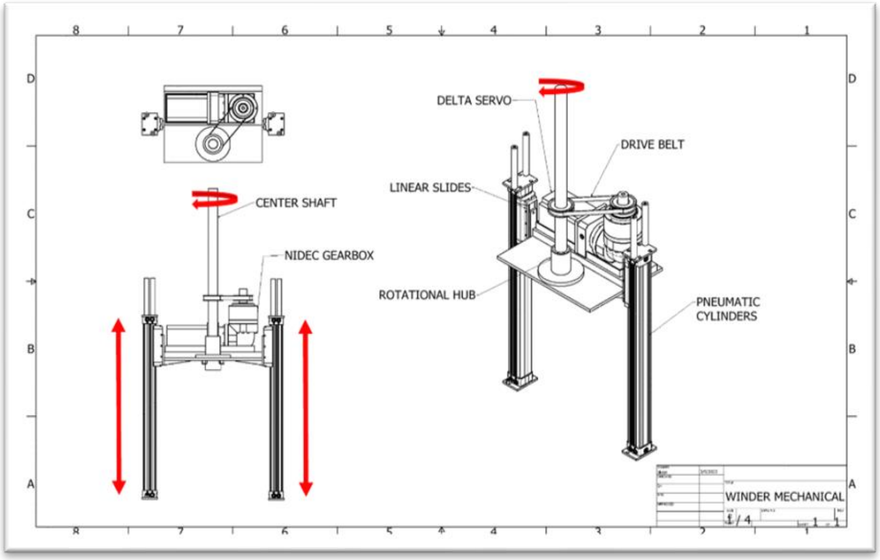


Figure B.17 Winder Explanation

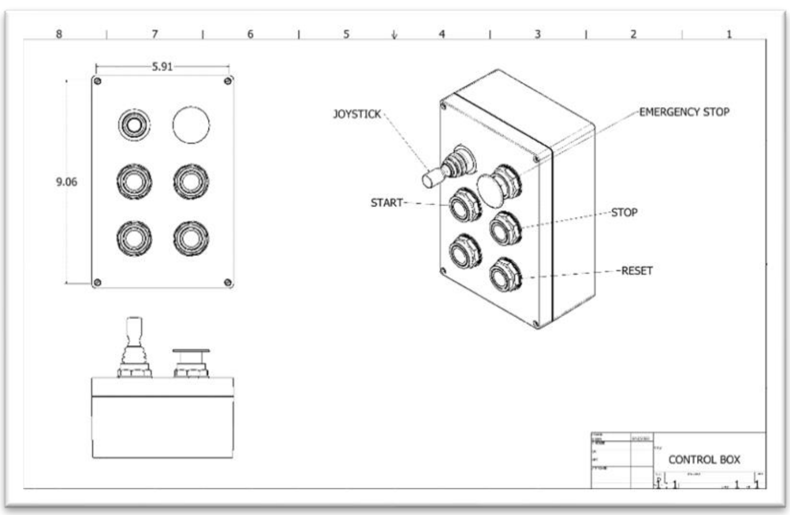


Figure B.18 Control Box

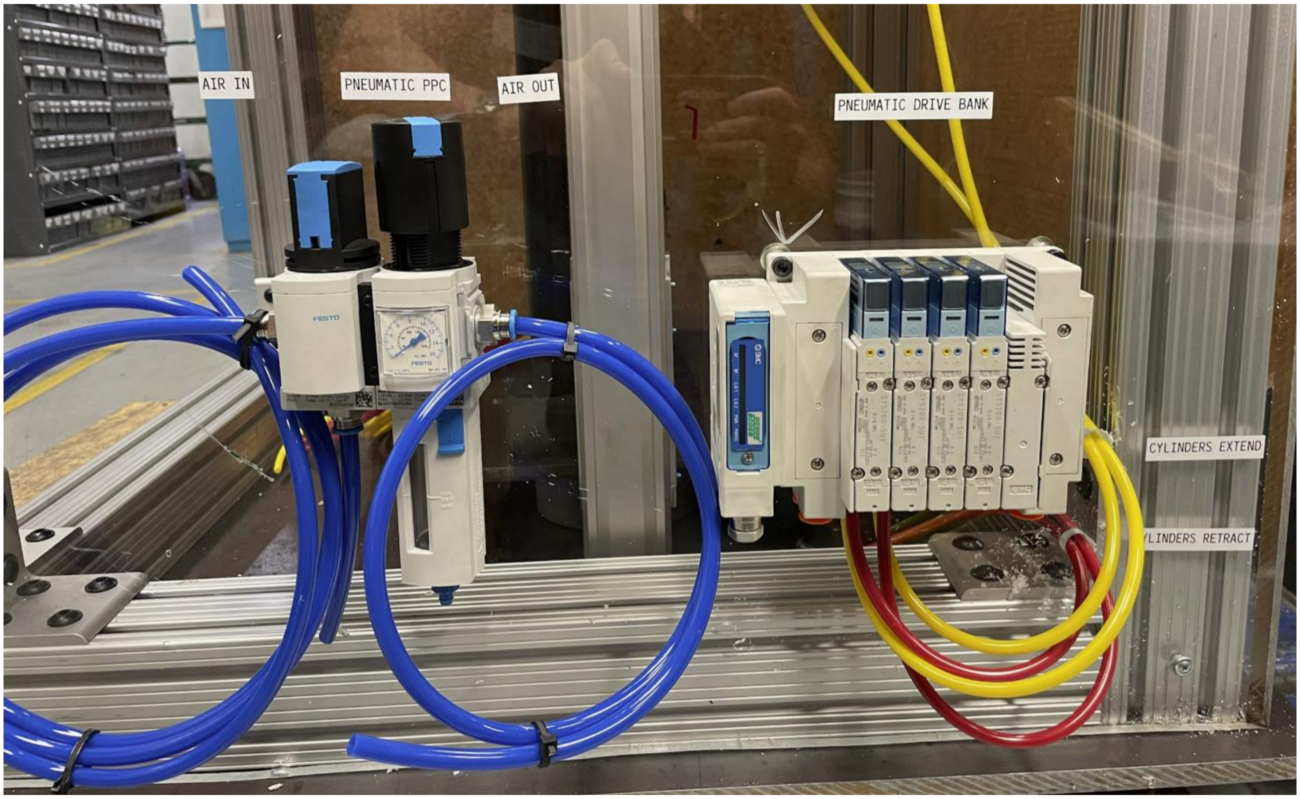


Figure B.19 Pneumatic Air Preparation & Bank

Figure B.20 Pneumatic Bank Wiring