The Pennsylvania State University

The Graduate School

Department of Mechanical and Nuclear Engineering

DESIGN, DEVELOPMENT AND MANUFACTURING OF ROLLED CYLINDRICAL PVDF ACTUATORS FOR BRAILLE DISPLAYS

A Thesis in

Mechanical Engineering

by

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ABSTRACT

This thesis addresses the challenge of producing miniature and reliable actuators with the requisite displacement and blocking force for tactile Braille displays. Braille displays are an array of characters each with six to eight individually activated pins. Commercially available Braille displays use piezoelectric cantilever beams to actuate the Braille pins, resulting in a bulky, heavy, and expensive device with a limited number of characters. The ElectroActive Polymer EAP actuator introduced in this thesis is in the shape of a long hollow tube and small enough to be placed under the Braille pins, producing a compact, lightweight and scalable design. The condensed size of the devices, material handling, precision required and the large quantity of actuators motivates the development of a semi-automated manufacturing process. The process starts with conductive electrode deposition, lamination to bond the separate films together producing a bi-layer, then cuts and shapes the film, rolls and bonds the bi-layer film into a tube and finally attaches conductive leads. Many rolled actuators are fabricated using this development process and tested for performance and reliability. The results are analyzed and compared to the state of the art.

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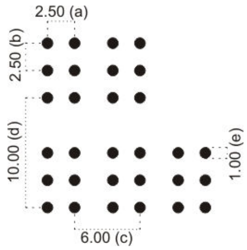
Chapter 1

Introduction

Recently, there has been developing interest and research in the implementation of a full page refreshable tactile Braille displays. The challenge of this technology is the actuation of the Braille pins with sufficient displacement and force output in a compact form factor compared to current commercially available Braille displays. This chapter will describe the physical limitations of Braille cell dimensions, along with the EAP researched actuation alternatives to provide a full page Braille display. Thereafter, previous research on rolled actuator designs will be presented, and finally a description will be provided of EAP film used in the rolled actuator proposed in this thesis.

Industry Standard Braille displays

Braille displays must comply with dimensional standards to be accepted by the blind community; the standards also define pin displacement, exerted force and distance between characters. The typically industry standard character size and character offsets can be seen in Figure 1-1 (a). The distance of 2.5 mm between each pin in both the (a) and (b) dimensions is an exceedingly small space to fit in the pin actuator. The minimum distance the pin must protrude above the surface is 0.5 - 0.9 mm with a 0.5 N force [1].



(a)

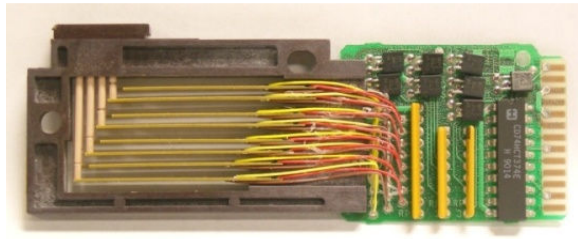

(b)

Figure 1-1: (a) Braille Cell Dimensions in mm (b) Braille Cell from Commercially Available Display

Commercially available Braille displays offset the actuation mechanism using a piezoelectric cantilever beam design shown in Figure 1-1 (b). When the beam is activated the tip bends upward and displaces the pin. A multiline display is difficult to produce because the space used by the piezoelectric actuator is in the Braille display's d dimension.

Literature Review on Alternative Braille Pin Displacement

Other research groups have explored several actuator designs to develop a full page display. The book by Bar-Cohen [2] accelerated the interest in EAP based actuation for Braille displays. Soft actuators that can mold to the finger like a bandage were investigated [3]. Displays that use Dielectric Elastomers shaped in a half dome for pin activation were developed [4]. A bimorph actuator design that uses a locking mechanism to ensure sufficient blocking force was studied [5]. Miniature cantilever beam actuator designs have been arranged in a 2D character array [6]. Dielectric Elastomer stacked actuators are used to elevate the pin when passive and retract when active [7].

Literature Review on Rolled EAP Film Actuators

Rolled EAP actuators were found to be a suitable solution for this application because of their potential for small size, large strain displacement, and reasonable force characteristics. Rajamani et al [8] developed a wound bi-layer DE actuator wrapped around a spring core; capable of 13% strain with a stiffness of 144 N/m. Kiil and Benslimane [9] manufactured DE based rolled actuators for industrial applications. Rolled actuators were developed for force feedback with strains of 31% and a 7.2 N load [10].

PolyVinyliDene Fluoride Film Characteristics

The EAP material utilized in the actuator design presented is patented Poly(VinyliDene Fluoride - TetraFluoroEthylene) P(VDF-TrFE) [11]. The material exhibits unique strain and material properties. With a 150 MV/m field, strains of over 5% have been observed. The material is fabricated so the polymer chains are aligned in the actuation direction for maximum displacement. The modulus of elasticity is on the order of 1 GPa allowing it to withstand relatively high loading [12]. Previously developed hand-rolled actuators with a spring core were found to be capable of satisfying Braille display requirements [13].

Thesis Summary

In *Chapter 2* the rolled PVDF actuator design and modeling characteristics will be described along with the automated material handling techniques and processes. *Chapter 3* will discuss in detail the primary actuator fabrication steps such as electrode application, film lamination, film rolling and electrical contact connection along with methods to optimize the processes. The finished actuator dimensions along with strain and force measurements will be presented in *Chapter 4*. Finally the project conclusions and future plans will be evaluated in *Chapter 5*.

Chapter 2

Actuator Design and Manufacturing Process

The design of the actuator is fundamentally the most important aspect in not only the performance of the device but also in the manufacturing methods required to fabricate it. The goal of the design was to utilize and optimize the strain and force characteristics of the PVDF film while keeping the design simple, to reduce the amount of manufacturing steps necessary. Considering the element of precision and quantity of actuators required a manufacturing process had to be implemented around the design of the actuator.

Actuator Design

The material is strained by compressing the layer in the out-of-plane direction using electrostatic forces provided by thin, conductive and expandable electrodes applied on both sides of the film. The PVDF material is eletrostrictive behaving as a parallel plate capacitor. As shown in Figure 2-1, when polarized the electrodes attract one another.

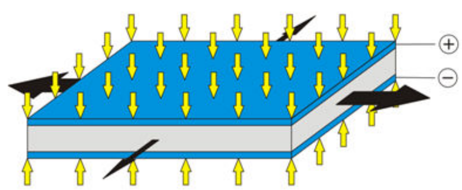


Figure 2-1: Film Polarizing and Strain Change Illustration

The capacitance is a product of air permittivity $\boldsymbol{\varepsilon_0}$, film permittivity $\boldsymbol{k}$, and the active area $\boldsymbol{A}$ and accounting for the thickness $\boldsymbol{d}$ in-between the electrodes.

$$\boldsymbol{C = \frac{k * \varepsilon_0 * A}{d}} \qquad \textbf{2-1}$$

The film in its natural state is extremely fragile and requires a support structure to provide notable force. The process to transform the film is relatively straightforward. For instance, the film sheet can be compared to a flat sheet of paper, initially unstable and unsupportive. Taking the sheet and rolling it about a central axis provides depth to the material and the tubular shape is a low energy and stable structure. The same idea is applied to the PVDF film, rolling and bonding the individually wrapped layers together creates a device that is both comparatively strong but also space and manufacturing efficient.

The film must be in the form of a bi-layer structure so the electrodes do not contact one another from the rolling process. The bi-layer geometry behaves like two capacitors in a parallel configuration, a schematic of the actuator can be seen in Figure 2-2. Figure 2-3 (a) shows the cross-section of the bi-layer tube; Figure 2-3 (b) shows the 3-dimension profile of the actuator along with the active and passive areas of the electrodes. The inactive regions of the actuator serve as electrical connections for the device; the electrode orientation and contact method will be discussed in Chapter 3.

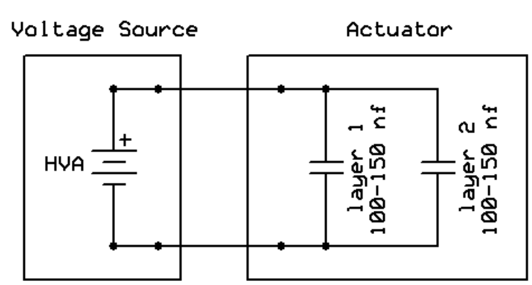
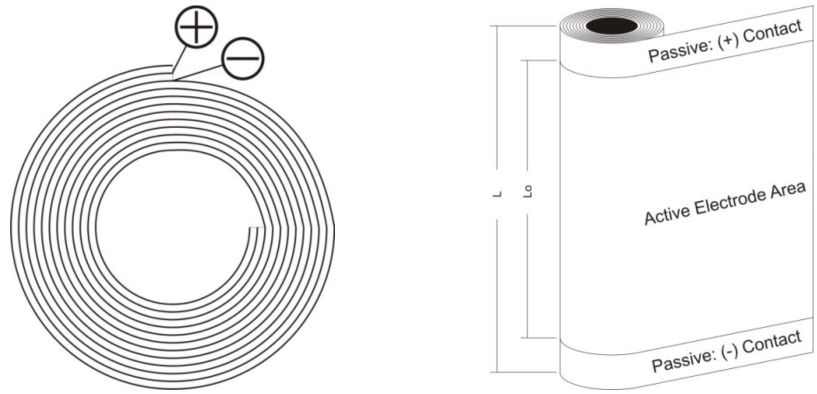


Figure 2-2: Schematic of Individual Bi-Layer Actuator with Estimated Capacitance



(a) (b)

Figure 2-3: (a) Cross-Section of Bi-Layer Actuator (b) Actuator Profile with Active/Passive and Electrical Areas Indicated

The actuator is designed to have an outer diameter less than 2.5 mm, allowing it to fit inside the Braille cell dimensions. The length of the actuator is determined depending on the displacement needed in relation to the percent strain and desired activation voltage. The change in actuator displacement is

$$\Delta = \boldsymbol{\varepsilon L_o}, \qquad \textbf{2-2}$$

where $\boldsymbol{L_o}$ is the active length and $\boldsymbol{\varepsilon}$ is the maximum displacement. The blocking force provided by the strain is defined as

$$\boldsymbol{F_{bl} = EA\varepsilon}, \qquad \textbf{2-3}$$

where $\boldsymbol{E}$ is the Young's modulus of Elasticity and $\boldsymbol{A}$ is the cross-section area,

$$\boldsymbol{A = \pi(r_o^2 - r_i^2)}, \qquad \textbf{2-4}$$

related to the inner and outer radii $\boldsymbol{r_i}$ and $\boldsymbol{r_o}$. The Euler column buckling force,

$$\boldsymbol{F_{bc} = \frac{\pi^2 EI}{L^2}}, \qquad \textbf{2-5}$$

can be calculated for a given length $\boldsymbol{L}$, and moment of inertia $\boldsymbol{I}$,

$$\boldsymbol{I = \frac{\pi}{4}(r_o^4 - r_i^4)}. \qquad \textbf{2-6}$$

With an estimated strain of 3% and a 30 mm long active area, the devices should be able to provide nearly 7N of blocking force with the given $\boldsymbol{E}$ of 1 GPa. However, the weak link lies in the buckling condition which reduces the failure load to 2N.

Manufacturing Process

This thesis objective was not only to design and develop working linear actuators small enough for the full page Braille display, but also design and implement the manufacturing process to produce them. One Braille cell is composed of 6 - 8 pins each requiring their own actuator for operation. If an entire Braille display has 40-80 characters per line with multiple lines total, the number of actuators required would be in the thousands. In addition, the small dimensions of the actuators make the development process difficult to repeat using strictly hand techniques. Therefore, the methods used to develop a single actuator had to be designed with mass production in mind.

In order to successfully realize the possibility of manufacturing the actuators, a prototype automated manufacturing process had to designed, developed, and tested to ensure the Braille display is not only functional but also financially and commercially realistic. The Actuator Fabrication Machine (AFM), PSU fabrication number 09-35, performs several of the production steps needed to manufacture the PVDF film actuators. A SolidWorks rendering of the machine design along with the finished product can be seen in Figure 2-4 and Figure 2-5 respectfully.

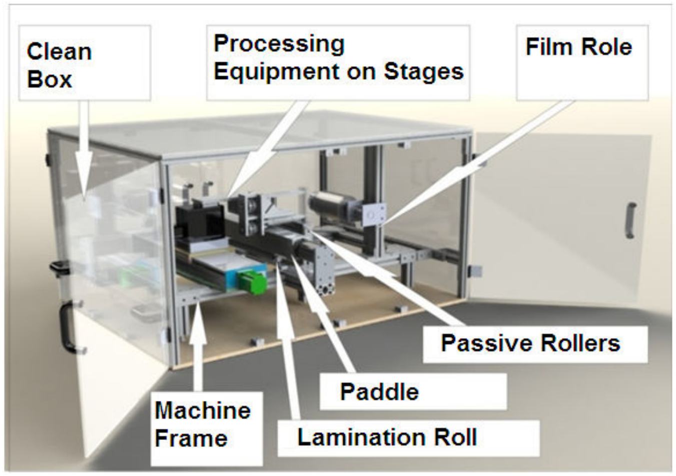


Figure 2-4: SolidWorks Rendering of Actuator Fabrication Machine

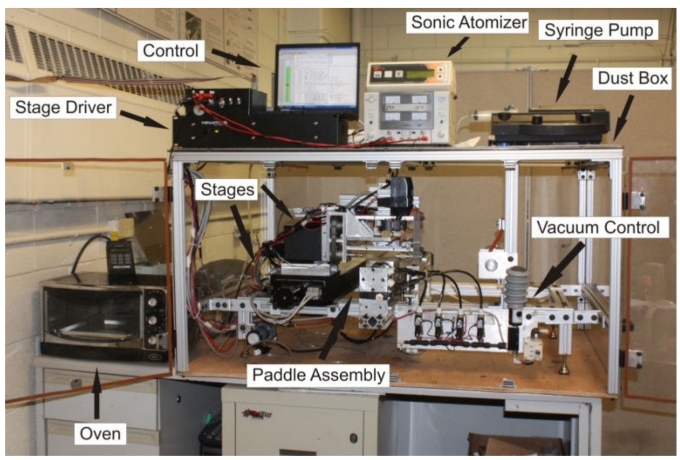


Figure 2-5: Photograph of Actuator Fabrication Machine

In order to develop the actuator proposed, the process must incorporate the application of conductive electrodes, lamination to produce a bi-layer film, rolling the bi-layer into a tube structure, reinforcing the strength of the tube and applying electrical contacts to the ends. It may not be possible at the preliminary level to automate every step, but the less human interaction required the higher the success rate for the devices.

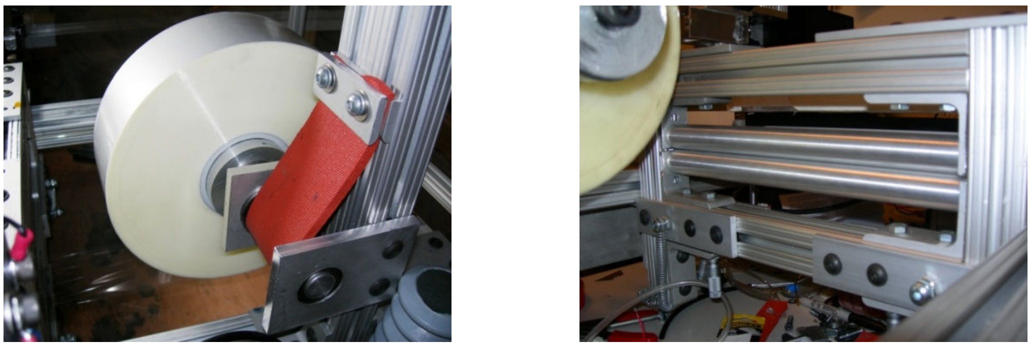
The machine was originally designed to perform almost all of the manufacturing steps continuously and autonomously from film spooled on a roll. However, the film is difficult to fabricate without imperfections especially in larger quantities. Reducing and individually selecting the film area for each sample decreases the frequency of impurities such as pinholes and uneven stretching. The effect of these imperfections is discussed in *Chapter 3*. Therefore, the selected film samples are placed on small metal frames for handling and processing. Separating the film into discrete sections drastically alters the manufacturing process from the originally designed procedure. To accommodate both circumstances two manufacturing techniques were designed, the original for the continuous fabrication, referred to as Film Roll Manufacturing (FRM) and the modified version for small individual samples referred to as Frame Manufacturing (FM). The processing hardware discussed in *Chapter 3* for either manufacturing method is similar; however, the film handling hardware is different for each technique and will be described in the following section.

Manufacturing from Film Roll

Continuous and fully automated manufacturing is not only faster and more reliable but drastically reduces the cost and time per unit. The AFM incorporates several elements of hardware specifically designed to handle the film similar to an assembly line production. The film starts out on a roll and is feed through several rollers for positioning and eventually placed on the paddle which is the working surface for processing.

Film Roll, Passive and Active Rollers

The film is typically wound on a standard 3 inch inner diameter cylinder that is mounted to an expandable chuck securing the roll to a rotating axle. A passive and adjustable friction-breaking system was incorporated into the design to ensure the film would be placed under slight tension as it is pulled off the roll. The material is pulled away from the film roll and passed between two opposing aluminum rollers. The rollers help smooth the wrinkles and creases out of the film as it progresses through the machine. Images of the film roll and aluminum rollers can be seen in Figure 2-6 (a-b).

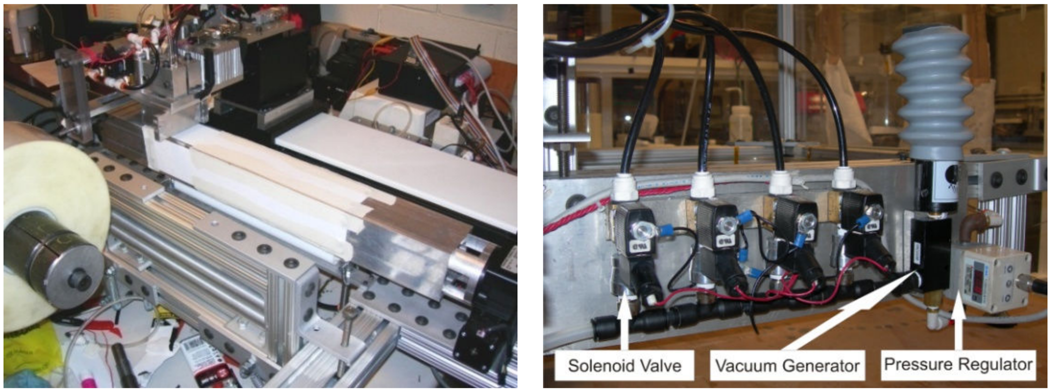


(a) (b)

Figure 2-6: (a) Film Roll Assembly (b) Passive Roller Assembly

The Paddle

The focal point of the machine where all of the operations on the film take place is the paddle. The paddle is primarily comprised of a three-part CNC machined aluminum structure. All three pieces have the same outer square cross-section of nearly 2.75 in^2 and use pocket and protrusion geometry to ensure exact alignment during assembly and hardware fastening. All four flat surfaces of the center section are hollowed out with several machined pockets. Thin Teflon plates cover the exposed pockets on the paddle surface and provide a frictionless smooth surface for the film to be positioned on. Each plate has many small holes drilled along the length which allow a vacuum system to secure the material. Each of the four paddle sides has their own vacuum chamber for independent control. The computer regulated vacuum lines pass through rotary union which also acts as one of the rotational bearings for the assembly. Photographs of the paddle and vacuum control system can be seen in Figure 2-7 (a-b).



(a) (b)

Figure 2-7: (a) Paddle Assembly (film working surface) (b) Vacuum System

The paddle spins about the central axis with the positioning provided by a rotational stage which acts as the opposing bearing and support for the paddle. The Teflon plates on the paddle surfaces are slightly undersized in the paddle's width direction so narrow 0.025" channels exist in-between the plates and the aluminum center. The channels are important for the film cutting operation discussed in *Chapter 3*. An exploded view of the assembly can be seen in Figure 2-8.

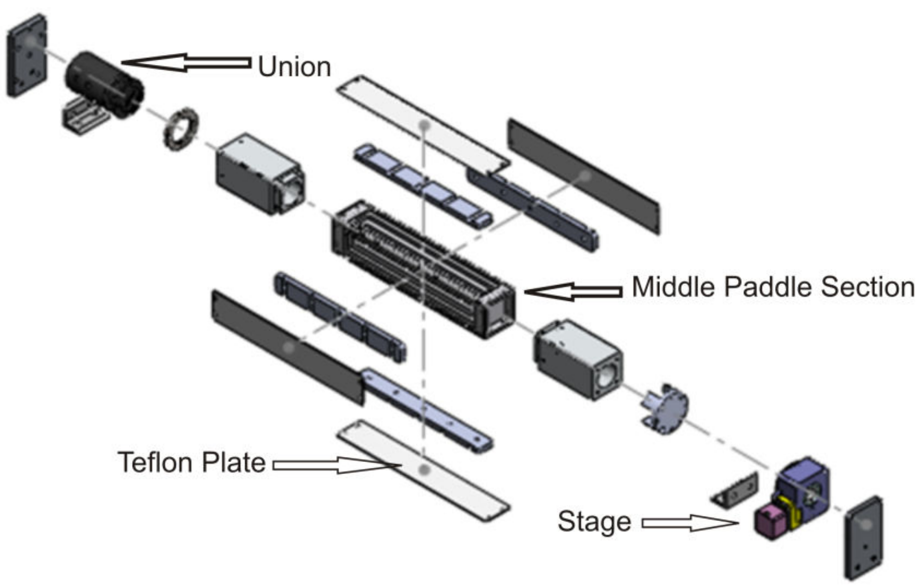


Figure 2-8: Exploded View of Paddle Assembly

A powered roller is used to help the film flatten out on the paddle surface at the point of contact. The roll passively translates up and down while the paddle assembly rotates maintaining nearly constant upward force on the Teflon plate surface. The original design intention of the roll was for film lamination also discussed in *Chapter 3*. Images of the powered roller along with its operation can be seen in Figure 2-9 (a-c)

(a) (b) (c)

Figure 2-9: (a) Lamination Roll Disengaged (b) Lamination Roll Engaged (c) Lamination Roll on Paddle Corner

The FRM equipment operates as follows; as the paddle rotates it pulls the material off the film roll and passes through the roller assembly and finally lays on one of the paddle's flat surfaces. The powered roller can be used to help flatten the material on the surface. The vacuum is engaged once the film is completely covering that side of the paddle. Using the paddle as the working surface, the film is then ready for further processing; refer to Figure 2-10 for visual illustration of this process.

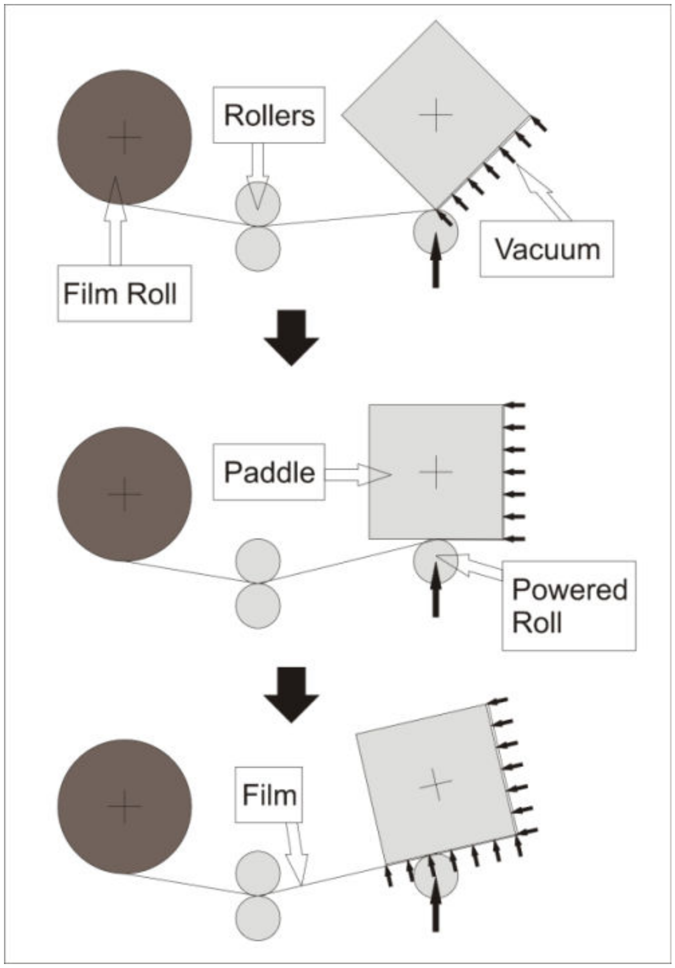
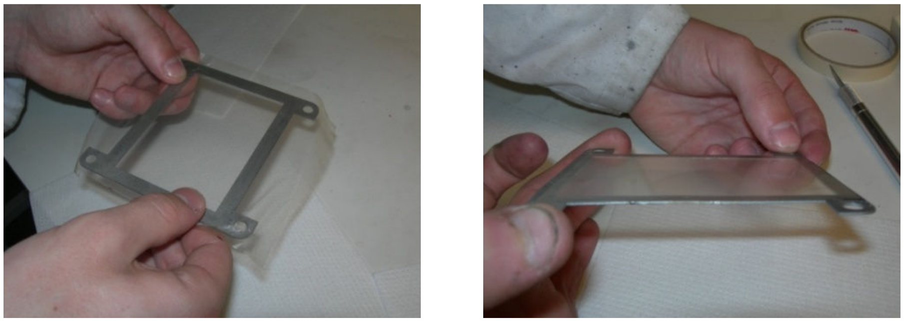


Figure 2-10: Film Roll Manufacturing - Film Handling Illustration

Manufacturing from Frames

Manufacturing from frames allows the user to select discreet sections of the film for actuator development. The film is cut and placed on a thin steel frames using Repositionable-75 adhesive. The frames are easy for the user to position and transport while keeping the film in tension. In addition, the frame method made the testing of processing steps easier to perform because the material did not have to be run from the film roll all the way to the paddle as in the FRM. Figure 2-11 (a) shows the method to properly position the film on the frame and (b) shows the film in its final state with the proper pretension and edges trimmed.



(a) (b)

Figure 2-11: (a) Film Being Placed on Frame by Hand (b) Film Stretched on Frame

The film can be secured to the frames in two different techniques. The film can be secured on all four sides of the frame which provides the most support and is the easiest to position. However, this makes machine cutting impossible, and therefore must be done tediously by hand and then manually positioned on the paddle for rolling. If the user would rather use the machine’s built-in cutting operation, the film can be placed and centered on the two long sides of the frame. This allows for greater repeatability but is harder for the user to prepare. The frames are not ideal for mass production but allow the user to avoid impurities such as holes, tears or gels.

Chapter 3

Actuator Manufacturing

Manufacturing Overview

The first step of the actuator fabrication starts with the application of the conductive electrodes. The film is masked off using Teflon coated aluminum plates so the electrode is only applied to a predetermined area. An ethanol based Conductive Polymer Solution is sprayed on using a nozzle which moves in a repetitive pattern above the film. The film is heated during application, evaporating the excess ethanol. Following the electrode application, the film can then be laminated to become a bi-layer. Two films are placed side by side and subjected to evenly distributed pressure and heated. Afterwards, the film is cut from either the frame or on the paddle.

The primary purpose for the development of the machine was to roll the film into a tightly wound hollow tube. Due to the unpredictable and delicate nature of the thin film, this process cannot be performed by hand to nearly the same level of accuracy and consistency. The rolling process starts out with a steel mandrel which acts as the stable axle for the bi-layer film to wrap around securely. The mandrel is positioned over the film edge on the top surface of the paddle. After a temporary bond has been established between the mandrel and the film, the computer rotates the mandrel CCW to wrap the film into a spool. Slight tension is applied to the film during rolling to reduce wrinkling. When the tailing edge of the film approaches the spool, permanent glue secures the loose edge from unraveling. Refer to Figure 3-1 for a brief illustration of the rolling process.

The mandrel is then removed from the machine and placed into an oven to soften the temporary glue and remove the actuator from the mandrel. The actuator is placed in a vacuum oven to remove trapped air from the device and increase the stiffness. Finally, electrical connections are placed at either end of the actuator completing the manufacturing procedure. A flow chart outlining the major fabrication steps for both techniques can be seen in Figure 3-2.

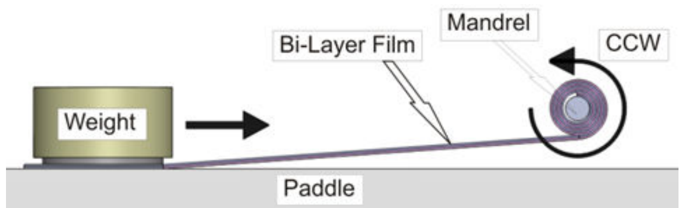


Figure 3-1: Rolling Operation Illustration

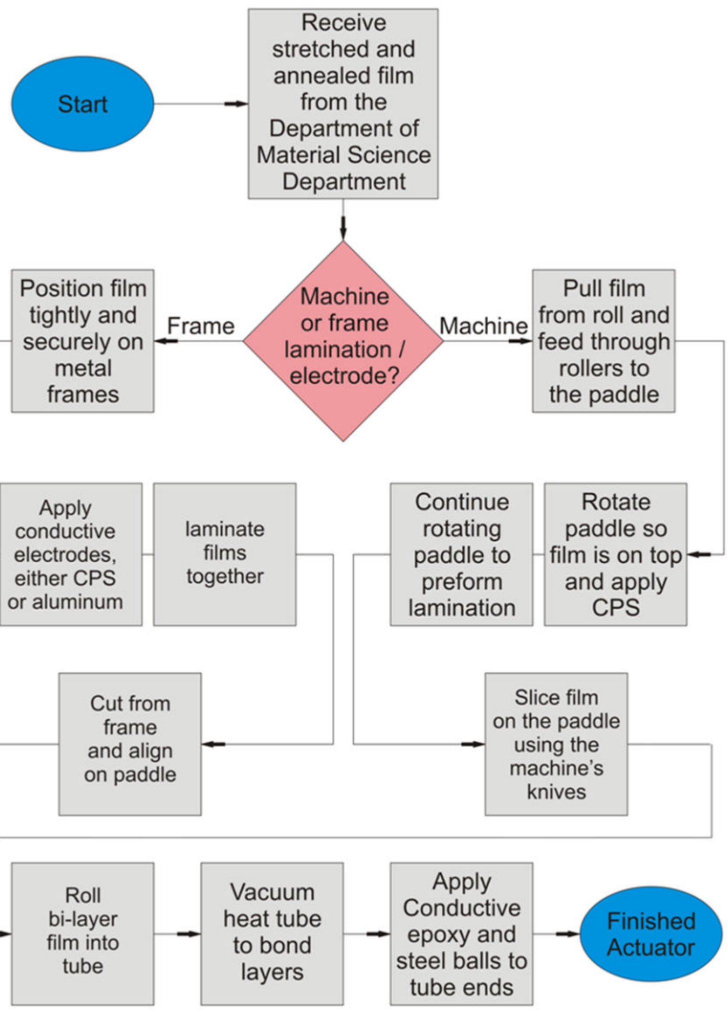


Figure 3-2: Manufacturing Flow Chart

Electrode Deposition

Conductive Polymer Solution Properties

In order for the film to provide actuation, the electrodes must maintain characteristics such as evenly adhering to the film, maintaining flexibility, low resistance expansion to not inhibit strain, and most importantly, provide low resistance conductivity. Conductive Polymer Solution (CPS) is an ethanol based mixture which can be used in spraying applications. The solution contains mostly ethanol, Field Electric Transistor (FE-T) and surfactant. When evenly applied, the resistance observed is typically on the order of 0.2-2KΩ / in depending on thickness and consistency. To achieve maximum displacement a delicate balance of electrode thickness is necessary; too thin and the conductivity across the layer will be very low possibly reducing the capacitance, too thick and the electrode will probably inhibit actuation. Even though the CPS is considered a soft electrode it still acts as a constraint on the active film.

CPS Application Hardware

A syringe pump pushes the CPS to an ultrasonic nozzle that is used to spray and spread the electrode as evenly and consistently as possible. The vibrating tip of the nozzle atomizes the CPS to small droplets which spread out and diffuse. The droplet diameter is determined from the surface tension $\boldsymbol{T}$, fluid density $\boldsymbol{\rho}$ and signal frequency $\boldsymbol{f}$ from [14].

$$\boldsymbol{d_h = 0.73\sqrt[3]{\frac{T}{\rho f^2}}} \qquad \textbf{3-1}$$

The frequency is set at 130 KHz, the density was measured to be nearly 880 kg/m^3 and the surface tension is estimated to be within 0.1-0.6 N/m; these values provide droplet diameters of 10-14 microns. The frequency amplitude is set between 66-79% for optimum performance. The Ultrasonic Atomizer provides the signal for the nozzle to atomize the CPS which along with the syringe-pump is computer automated.

Application Techniques

The nozzle is positioned 150-180 mm above the film to allow for adequate diffusion over a 1 in^2 area and is typically surrounded by a shroud. In order to evenly cover the entire unmasked area of the film the nozzle is translated in a symmetric rectangular path. Repeating the pattern multiple times provides a relatively uniform coating. A computer controlled heating element was placed underneath the film to accelerate the evaporation of the ethanol. The temperature must be within the range of 32-35° C, above this range will result in film damage due to stretching. A finished electrode PVDF sample can be seen in Figure 3-3.

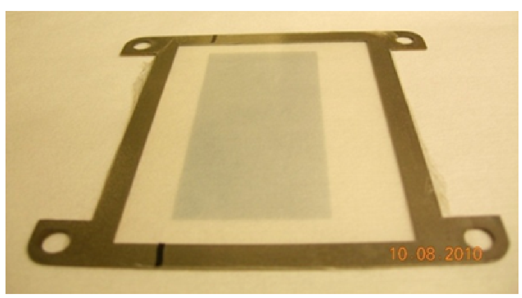
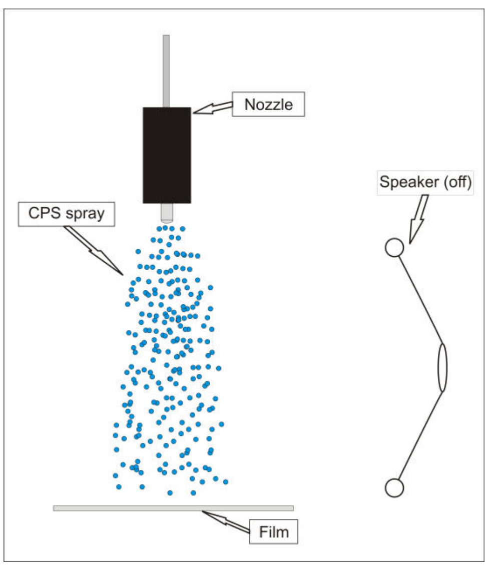
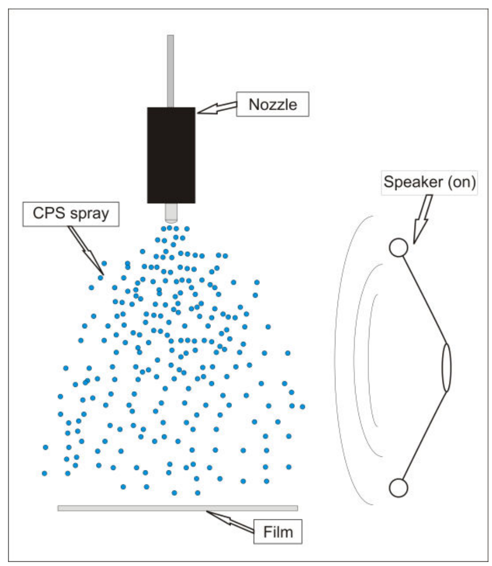


Figure 3-3: Electrode PVDF Sample

The nozzle is sufficient at atomizing the CPS solution but does not always predictably diffuse the solution to a given area. The droplets occasionally become concentrated to the center resulting in uneven coverage. This irregularity occurs unpredictably and must be accounted for immediately to avoid compromising the electrode deposition. If the CPS is being applied by hand the user can maneuver the nozzle to accommodate; however, the machine cannot automatically perform this quick adjustment. Therefore, an additional apparatus is used to accelerate the diffusion process. Encompassed into the shroud is an audible speaker that is oriented perpendicular to the nozzle stream. A square wave input set at 20-40 Hz provides air perturbations in the shroud accelerating the CPS diffusion. A side by side illustration of the apparatus shown in Figure 3-4 (a – b) outlines the speakers effect. This technique is preferable to use than an external fan because the individual droplets would be forced strictly in the direction of the air flow due to their extremely low mass.



(a)



(b)

Figure 3-4: (a) CPS Diffusion with Nozzle Only (b) CPS Diffusion Accelerated with Speaker System

Electrode Orientation

As mentioned in the actuator design section, the electrodes are applied to each film layer to develop two parallel plate capacitors and the ends of the device serve as electrical contacts for activation. This is achieved by the relative location of the electrodes with respect to one another.

Areas of the electrodes that overlap are referred to as active regions; inactive areas do not overlap. These inactive regions are orientated opposite from one another and account for roughly 15% of the electrode area. A visual representation of the electrode configuration can be seen in Figure 3-5.

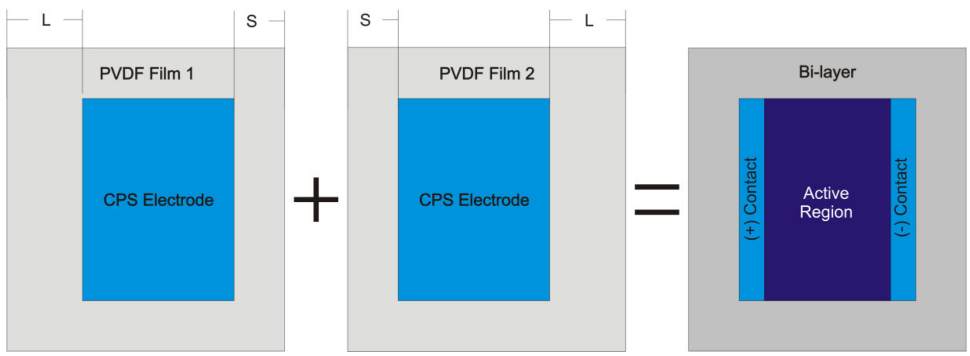


Figure 3-5: Electrode Orientation for Active and Inactive Electrode Areas

Using the frame manufacturing, electrodes can be applied to either side of each film if desired; however they must be in the opposite orientation to be functional. Many of the actuators developed and tested contained at least one film layer with both sides electroded. This was to reduce the effects of improper or weak lamination or mandrel rolling from affecting the capacitance between the layers.

Gold Sputtering Electrode Edges

After the CPS ethanol evaporates from the film, a non-conductive oxidized layer develops on the electrode surface. The oxidation does not affect the internal conduction but makes external electrical connection difficult. This issue was noticed during the development stages when trying to test the samples for capacitance by physically contacting the electrode surfaces. In order to remedy this issue, the films that are processed on frames can be masked and placed in a gold sputtering machine. Shown in Figure 3-6, only the edge of the electrode used for electrical contact is gold sputtered to penetrate through the oxidized layer. The gold essentially acts as a medium from the surface contact to the internal electrode.

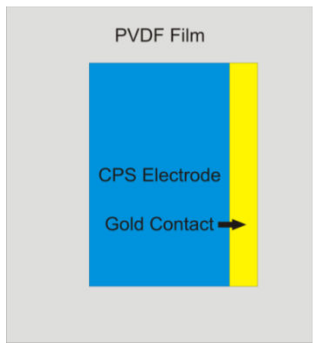


Figure 3-6: Gold Sputtered On CPS Edge for Better Electrical Connection

The gold sputtering was useful for individual sample capacitance and loss measurements but seemed to be unnecessary for the actuator as a whole. Several actuators were fabricated without gold sputtering and functioned properly due to the method the ends are contacted. Applying the actuator's end connections will be discussed in *Final Fabrication Steps*.

Loss Tangent Associated with CPS

The relatively high resistance seen across the electrode develops a noticeable loss tangent, which is the energy lost during activation. The higher the resistance across the layer, the higher the loss tangent becomes. CPS loss is typically minimal for low frequency signals but increases dramatically with high frequencies especially those over 10KHz.

Eighteen samples were measured for capacitance and loss at 5 different frequency settings and their results can be seen in Figure 3-7. The most notable aspect of this plot is the direct inverse relationship between capacitance and loss; as loss increases, the capacitance dramatically decreases. At 20Hz, the capacitance averages 98nF with a 0.07% loss; whereas at 100 KHz, the capacitance is nearly 3nF coupled with a 4.5% loss.

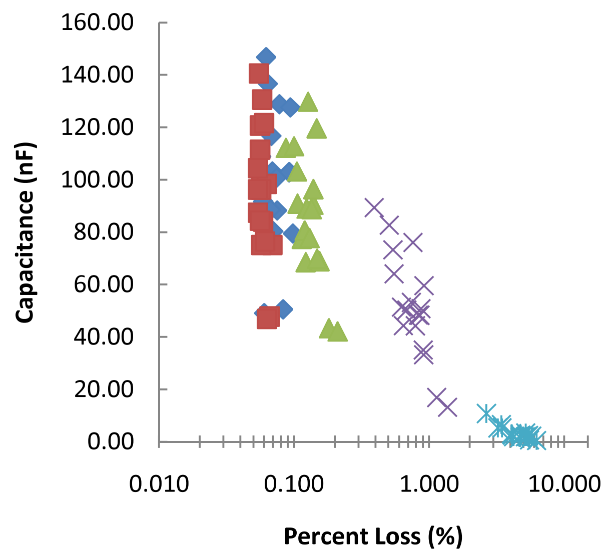


Figure 3-7: Loss and Capacitance Results for CPS Electrode (diamond) 20 Hz (square) 100 Hz (triangle) 1KHz (cross) 10 KHz (star) 100 KHz

Capacitance and Loss variability

Provided the relatively large loss tangents, a more in-depth analysis was performed that was used to determine the primary factors influencing the measurements. Twenty six single layer samples with variable electrode thicknesses were tested for capacitance and loss for frequency ranges of 20, 100 and 1000 Hz. The electrode thickness was judged by the amount of CPS applied, in this case that was set at 0.75 ml, 1 ml, 1.25 ml or 1.5 ml. The average capacitance and loss plotted versus frequency can be seen in Figure 3-8 and Figure 3-9 respectively.

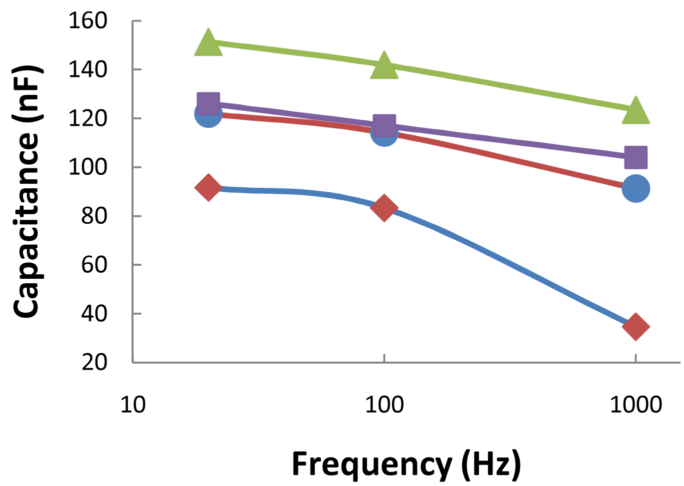


Figure 3-8: Average Capacitance for Electroding Application (diamond) 0.75 ml (circle) 1 ml (triangle) 1.25 ml (square) 1.5ml

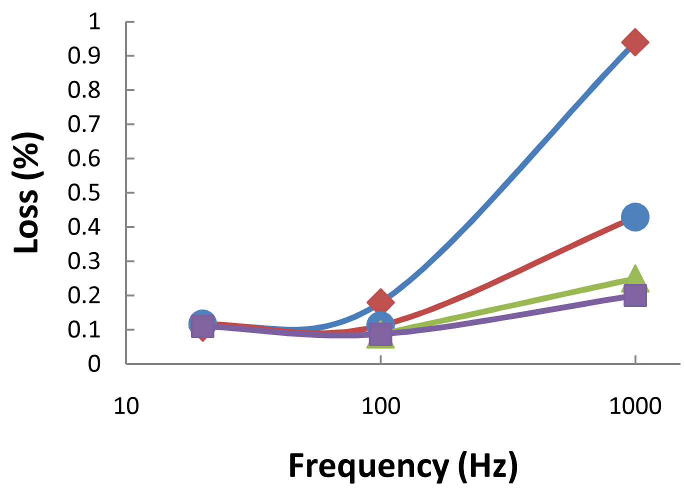


Figure 3-9: Average Loss for Electroding Application - (diamond) 0.75 ml (circle) 1 ml (triangle) 1.25 ml (square) 1.5 ml

The average CPS applied has an obvious impact on the capacitance and loss measurements indicated by the plots. Reducing the applied CPS also reduces the average capacitance especially in higher frequencies. For the 0.75 and 1 mL samples the capacitance was globally lower and reduced with a steeper slope (**0.75mL:** 91.6 nF at 20 Hz brought down to 31.6 nF at 1000 Hz and **1.0mL:** 121.9 nF at 20 Hz brought down to 91.3 nF at 1000 Hz). The capacitance for 1.25 or 1.5 mL samples also decreased with frequency but with a relatively constant and stable slope (**1.25 mL:** 151.33 nF at 20 Hz reduced slightly to 123.5 nF at 1000 Hz and **1.5 mL:** 126 nF at 20 Hz reduced slightly to 104 nF at 1000 Hz).

The reduction in the capacitance measurement is nearly mirrored by the percent loss. Near the 20 Hz measurement frequency, the difference in loss tangent is minimal for the varying thicknesses; however, increasing the frequency to 100 Hz, the plots start to take form with the lowest CPS thickness having the highest loss. At the 1000 Hz measurement frequency the loss value can be clearly identified with the electrode thickness; looking at the 0.75 mL and 1.0 mL samples the loss increased exponentially (**0.75 mL:** 0.11 at 20 Hz increase substantially to 0.94 at 1000 Hz and **1.0 mL:** 0.11 at 20 Hz increase to 0.492 at 1000 Hz). On the other hand the 1.25 and 1.5 ml sprays are relatively constant in comparison (**1.25 mL:** 0.11 at 20 Hz increased slightly to 0.25 at 1000 Hz and **1.5 mL:** 0.11 at 20 Hz increased slightly to 0.20 at 1000 Hz). These experiments strongly suggested that the capacitance and loss measurements seen at higher frequencies are directly related to the CPS electrode thickness. If frequency dependency is a critical issue in the desired application, thicker electrodes should be considered.

The film thickness, which factors directly into the parallel plate capacitance calculation, varies sample to sample. Therefore, the film thickness was also recorded and plotted versus capacitance and loss for a given frequency shown in Figure 3-10 and Figure 3-11. Only the 1.25 and 1.5 mL applications were considered for this experiment to reduce variability seen with the thinner electrode thicknesses.

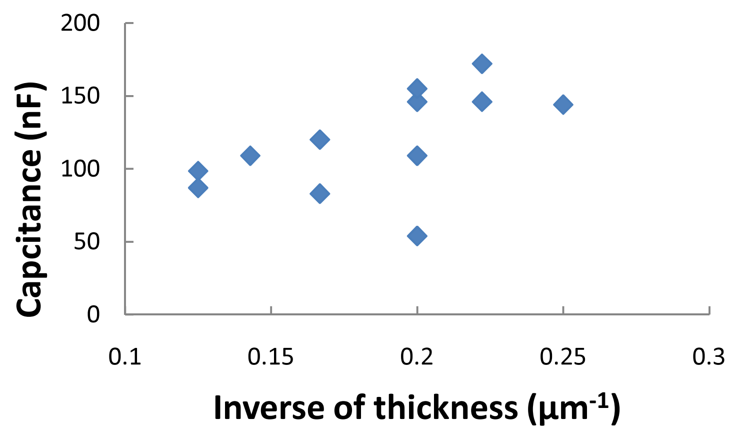


Figure 3-10: Measured Capacitance with Varying Film Thickness, 1.25-1.5 mL Electrode Applications

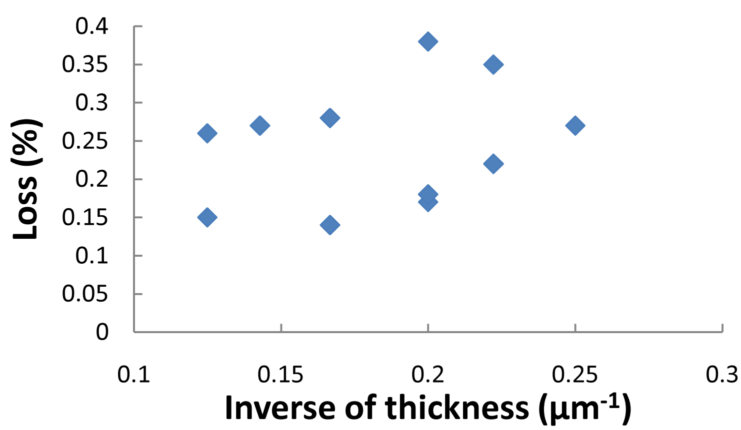


Figure 3-11: Measured Loss with Varying Film Thickness, 1.25-1.5 mL Electrode Applications

The thickness to capacitance plot seems to have a fairly weak inverse relationship, which is expected by the parallel plate capacitance equation. As inverse of the thickness increases, the measured capacitance typically does as well. The film thickness measurement is believed to be relatively inaccurate with at least a 20-30% error given the total thickness of the film is on the several micron level. The varying thickness is not affected by the measuring frequency used and has little to no direct effect on the loss tangent.

Electroding Flow Chart

The electroding process does not necessarily change for the two manufacturing techniques. However, more options regarding the electrode deposition process are available for the frame method. The frame's small profile allows the user to easily adapt each sample to different application techniques, for instance the user can apply electrodes on both sides of the film because the frame can be easily flipped over and the electroding process repeated. This allows for individual sample capacitance and loss measurements. In addition, the frame method allows the process to be performed outside of the machine manually by hand. A flow chart for the electroding process can be seen in Figure 1-1.

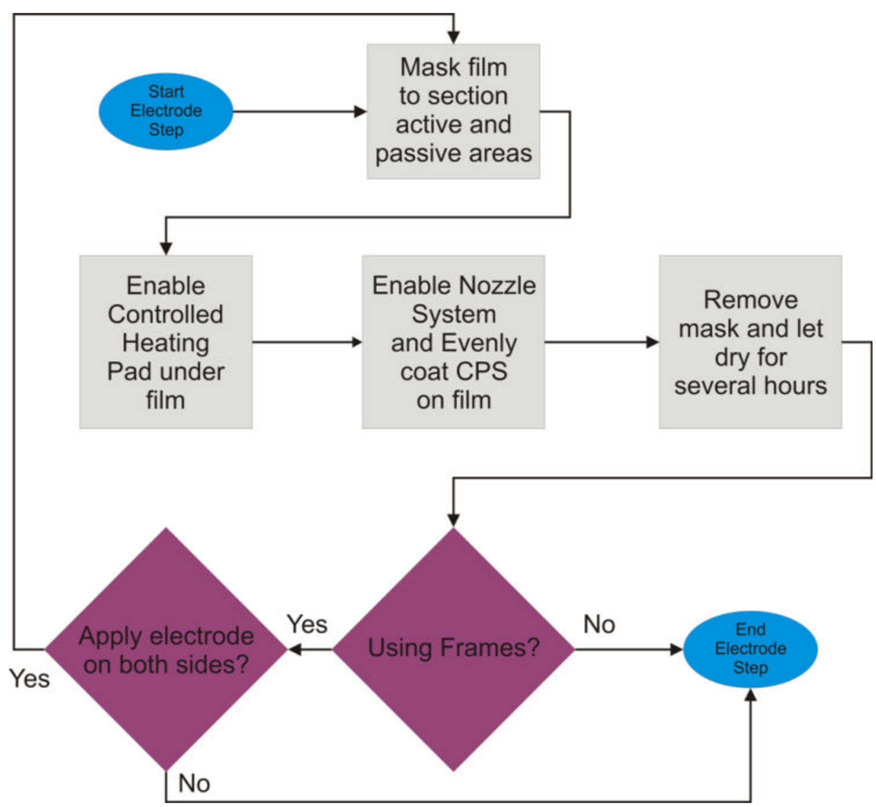


Figure 3-12: Electroding Step Using Frame Manufacturing Flow Chart

Film Clearing

For the duration of this project, the film quality and consistency has been a varying factor greatly affecting subsequent testing of the devices. As discussed in *Chapter 2*, it is not uncommon to observe micron scale holes or other impurities in the film. These imperfections can create passages for the conductive electrodes to contact one another resulting in an electrical short. If measureable impedance is seen across the electrodes, steps must be taken to eliminate the connection(s). Selecting samples with a reduced frequency of imperfections drastically helps with this issue but does not alleviate it. Therefore, another measure must be used to eliminate the effect of these imperfections; this process is referred to as clearing.

Film clearing is the act of applying a low voltage but relatively high current power source to the film to essentially burn the short and break the connection. The heat generated from the current passing through the connection locally burns the CPS but does not propagate to other areas of the material. See Figure 3-13 for an illustration of the clearing process.

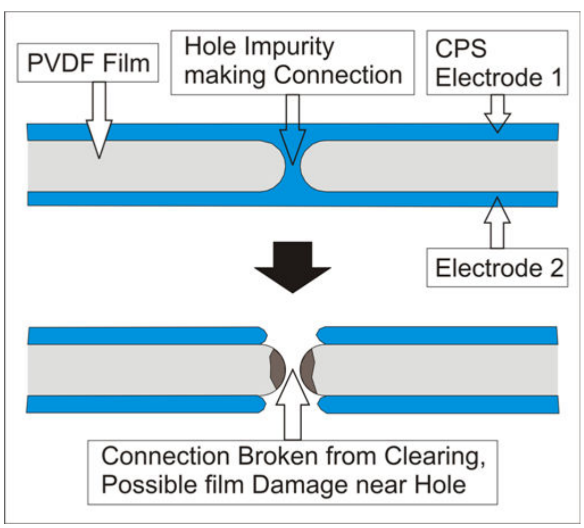


Figure 3-13: Film Clearing Illustration

Clearing can be performed on single layer samples, bi-layer samples and even rolled up actuators. For single and bi-layer unrolled samples, a gold sputtered glass plate is used to contact the top and bottom gold sputtered areas of the film (see Figure 3-14 for photo of apparatus).

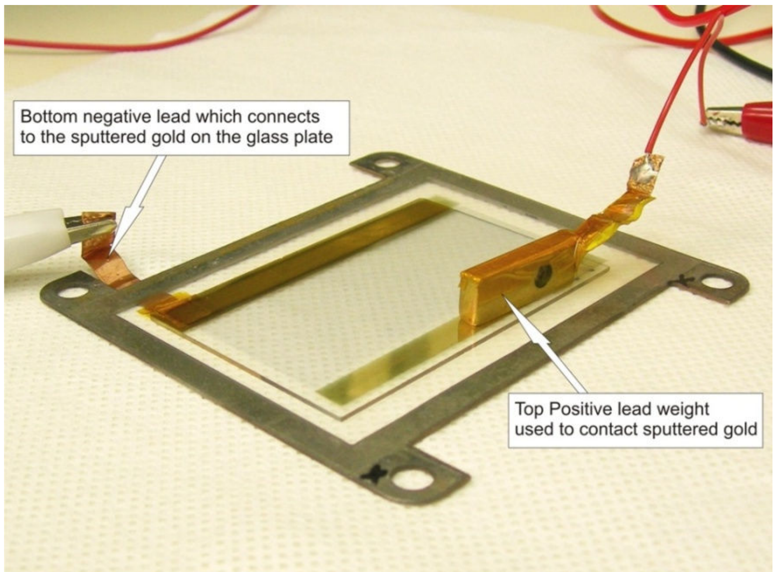


Figure 3-14: Clearing and Capacitance Measuring Apparatus with Film Sample

If any resistance is measured across the electrodes, the leads are connected to a power supply set at 50-100 V with a 100 mA current limit for 10-15 seconds; afterwards, the resistance should be nearly infinite. As a precautionary measure, Golden Oil is usually placed on the film to absorb the heat generated from the short. The Department of Material Science has made large advancements in their film quality making clearing less and less necessary and may only need to be performed after an actuator is fabricated if at all.

Film Lamination

The originally designed machine lamination process is relatively complicated requiring several key hardware components. The process was never officially tested due to the film inconsistency but was theoretically designed to work as follows. After the film secured to the paddle is sprayed, the paddle continues to rotate pulling more film from the roll. Eventually the film feeding in will contact and stack on the electroded film already on the paddle. At this point the powered roll placed below the paddle, elevates and presses the films together while simultaneously providing heat to bond the films. As the paddle rotates, the powered roll is continuously and controllably pressing and bonding the two layers together. Figure 3-15 shows how the roll presses the film against the paddle surface.

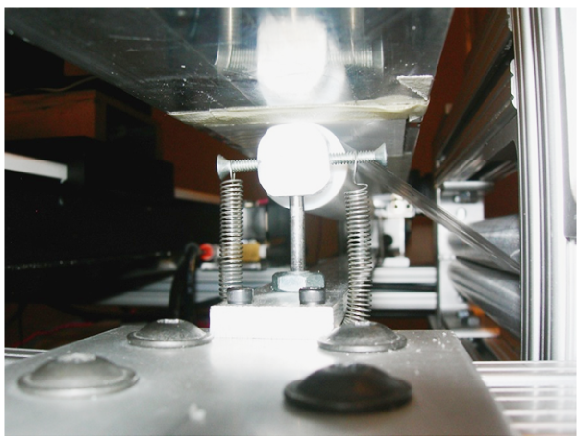


Figure 3-15: Continuous Lamination from Film Roll

Laminating the films using the frame method is comparably simple but requires careful attention to detail. First, the two frames are placed side by side so that the corners are aligned and taped. Teflon sheets with metal backing are placed on both of the exposed areas of the film and also secured with tape. The entire assembly is placed in vacuum bags and sealed applying 24 psi on the film area (see Figure 3-16 (a)). The vacuum bag and the contents are then placed in a temperature controlled oven for a designated temperature and time interval. Typical settings for PVDF film is 1 hour at 95°C. A laminated bi-layer sample can be seen in Figure 3-16 (b).

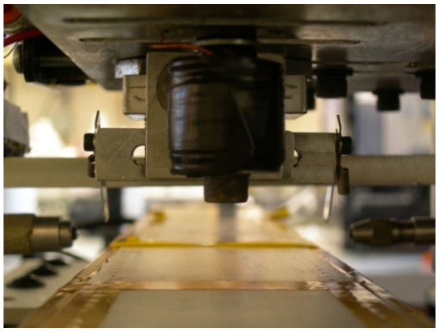
(a) (b)

Figure 3-16: (a) Frame Lamination Using Vacuum Bags (b) Laminated Bi-Layer PVDF Sample

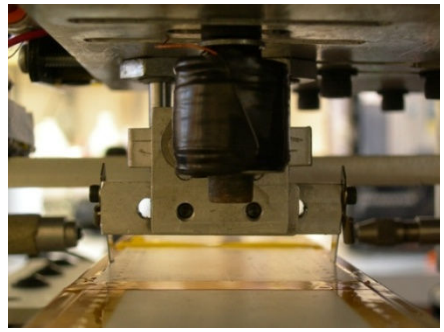
Maintaining the accurate temperature is critical in this process. Low temperature could result in weak lamination whereas high temperature could produce film damage due to polymer chain misalignment. A delicate balance was experimentally found to be 95-100 ˚C, this range is below the temperature settings used during the film development.

Film Cutting and Preparing

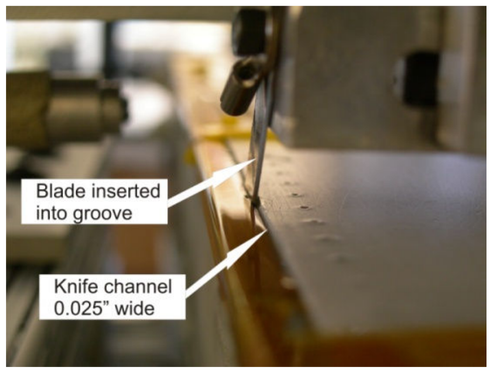
The film whether placed on the paddle directly or secured to frames must be accurately cut and separated for the rolling process to be possible. The machine does this by using two Exacto-knife blades positioned above the paddle channels on either side of the Teflon plates. Computer operated air actuators force the blades into the channels, thereafter the knives are translated down the length of the paddle. The blade’s rounded edges press the film into the channels gradually slicing the material. Figure 3-17 (a - b) shows the operation of the mechanical cutting hardware. A close up of one of the blades in the paddle channel can be seen in Figure 3-17 (c). The film edges cut will become the top and bottom of the actuator tube.



(a)



(b)



(c)

Figure 3-17: (a) Knife Assembly Disengaged (b) Knife Assembly Engaged (c) Close Up Of Knife Assembly in Paddle Groove

If the film is secured to the frame on all four sides it must be cut carefully by hand using a sharp and flat edged blade on a hard surface. The blade must be placed on the inner edge of the metal frame and sheared section by section all around the inner perimeter of the frame. The user must ensure the cuts are straight and take the time to carefully align and secure the film on the paddle for the rolling step.

Rolling Operation

The size of the rod defines the actuators inner diameter and consequently the outer diameter after rolling. The actuator is desired to have an outer diameter of nearly 2 mm to be compatible for the Braille display. The relationship between the inner diameter $\boldsymbol{d_i}$ and outer diameter $\boldsymbol{d_o}$ of the actuator can be determined given the sample thickness,

$$\boldsymbol{t = 2t_f + 2t_e}\,, \qquad \textbf{3-2}$$

defined by the film thickness $\boldsymbol{t_f}$ and electrode thickness $\boldsymbol{t_e}$ in a bi-layer orientation and, the film width,

$$\boldsymbol{W_f \approx \sum_{i=0}^{n} \pi(d_o - it) = n\pi d_o - 2t\pi\left(\frac{(n+1)^2}{2} - \frac{2n+1}{2}\right)} \qquad \textbf{3-3}$$

which is the distance end to end of the material in the rolling direction where $\boldsymbol{n}$ is the number of wound layers. Solving 3-3 for $\boldsymbol{n}$ yields two results with the valid result

$$\boldsymbol{n = \frac{1}{2}\frac{d_o\pi - \sqrt{d_o^2 - 4t\pi W_f}}{t\pi}} \qquad \textbf{3-4}$$

providing the number of wound layers of the actuator. The number of wound layers and film thickness can used to determine the inner diameter (mandrel size)

$$\boldsymbol{d_i = d_o - 2nt}\,. \qquad \textbf{3-5}$$

Applying the typical film parameters ($\boldsymbol{W_f}$ = 76 mm, $\boldsymbol{t_f}$ = 0.008 mm, $\boldsymbol{t_e}$ = 0.0005 mm and $\boldsymbol{d_o}$ = 2 mm) yielded roughly 14 layers with an inside diameter of 1.49 mm (0.059 in). The machine algorithm computes the mandrel size and informs the user during fabrication.

Temporary Bond between Film and Mandrel

The most difficult aspect of the rolling procedure is establishing a temporary bond between the film and the mandrel. The bonding agent must exhibit a relatively high normal force directed towards the center of the mandrel for rolling to be possible (see

Figure 3-18). However, the agent must also maintain low shear stress so that after the film is rolled the actuator can be easily removed from the mandrel illustrated in Figure 3-19.

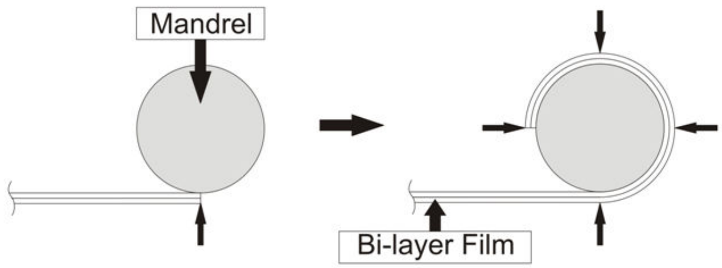


Figure 3-18: High Normal Force for Bi-Layer Film Rolling

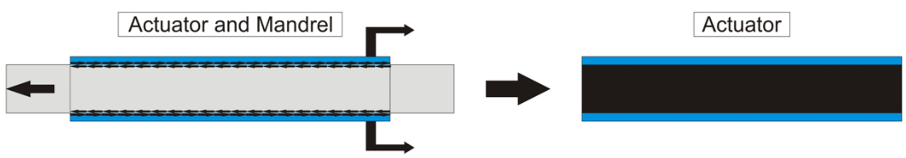


Figure 3-19: Low Shear Force for Actuator Removal

The simplest and most reliable method to develop the bond between the surfaces was found to be using temporary adhesives. The adhesive referred to as Stick-it; is a quick bonding agent that is noncorrosive, biodegradable and most importantly, non-conductive. The primary advantage to the adhesive is it can be broken down and liquefied by heating it to 85˚C. It was desired to make the actuator removal even easier by diluting the glue with lubricants. Several experiments to dilute and alter the glues concentration were conducted. Additives such as grease and petroleum jelly were combined with the Stick-it at varying concentrations and tested for adhesion ability, melting temperature, and removability.

After the actuator is rolled the trailing edge must be secured to the layer below so the actuator will not unravel. A standard permanent glue stick is used to bond the edge to the lower layer. The glue does not break down at the same temperature as Stick-it so it can maintain the integrity of the actuator during removal from the mandrel. The glue only needs to be applied to the top and bottom edge of the film to support the structure.

Tensioning the Film during Rolling

The film must be placed under a specific tension in the non-actuating direction to avoid wrinkles and creases from occurring during the rolling process. The tension also inherently tightens the wound layers together reducing the amount of trapped air. However, the amount of tension required and where it should be applied needed to be evaluated experimentally.

Initially, it was thought the vacuum from the paddle could constrain the edges, like two placed weights, and provide the required drag to keep the film taut shown in Figure 3-20 (a). However, it was noticed that this typically pulled the edges of the film inward creating a large wrinkle in the center. An additional experiment involving a passive roller placed across the entire film length shown in Figure 3-20 (b) was tested for constraint ability but proved unsuccessful due to many incidences of local stretching.

The last experimental configuration was the inverse to the original idea; a weight was placed at the center of the trailing edge as shown in Figure 3-20 (c) because it became apparent that this area needed to be constrained due to the results of the other experiments. The weight not only developed tension acting on the center of the film, but also provided a focal point for the film to self adjust to the mandrel if it was initially misaligned. An illustration of the rolling process using the weight can be seen below in Figure 3-21.

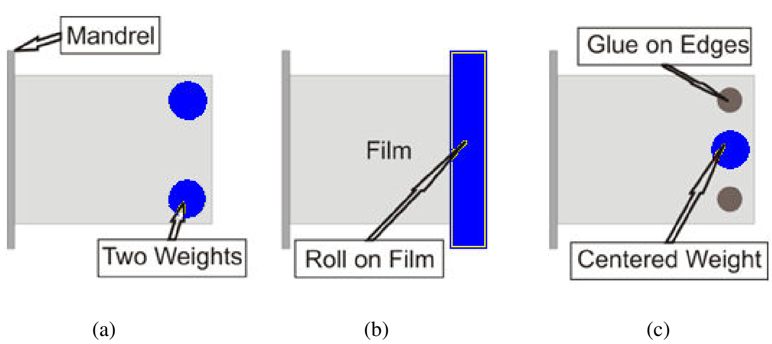


Figure 3-20: (a) Experiment 1, Weights at Opposite Edges (b) Experiment 2, Roll Across Edge (c) Experiment 3, Weight centered on Edge

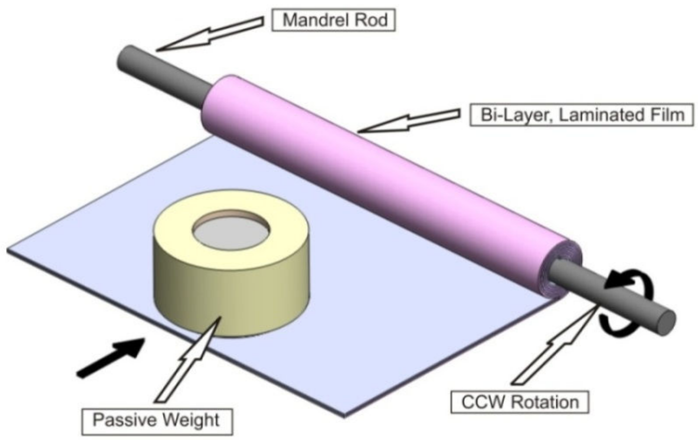


Figure 3-21: Rolling Step Illustration Using the Weight

The weight, set at 24 grams, was determined experimentally to provide the necessary pulling force for winding but not excessive enough to damage the film. An electromagnet holds and positions the weight in the correct area in the film. Figure 3-22 (a) shows the weight and (b) the weight held by the magnet ready for placement.

(a) (b)

Figure 3-22: (a) Brass Weight with Steel Core For Film Tension (b) Electromagnet Holding Weight

Rolling Operation Flow Chart

The rolling operation, similar to the electroding was a heavily experimented step requiring several iterations to optimize. A flow chart outlining the processes can be seen in Figure 3-23. Considering the frames are cut away from the film prior to this step, there is no difference between the FRM and FM.

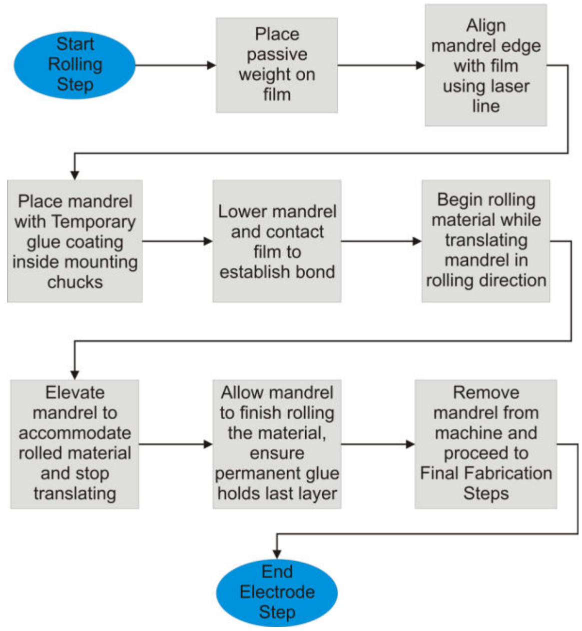


Figure 3-23: Flow Chart for Rolling Operation

Mandrel Assembly Construction

The mandrel is held at both ends using one powered and one passive adjustable chuck. A laser line accurately aligns the mandrel with the film edge by passing through the mounting point of the mandrel and reflecting off the paddle shown in Figure 3-24. The mandrel must be parallel with the film edge to avoid uneven rolling.

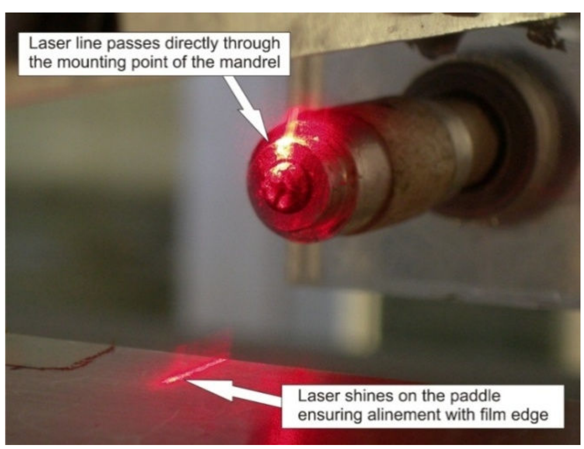


Figure 3-24: Laser Line Projecting Mandrel Location on Paddle

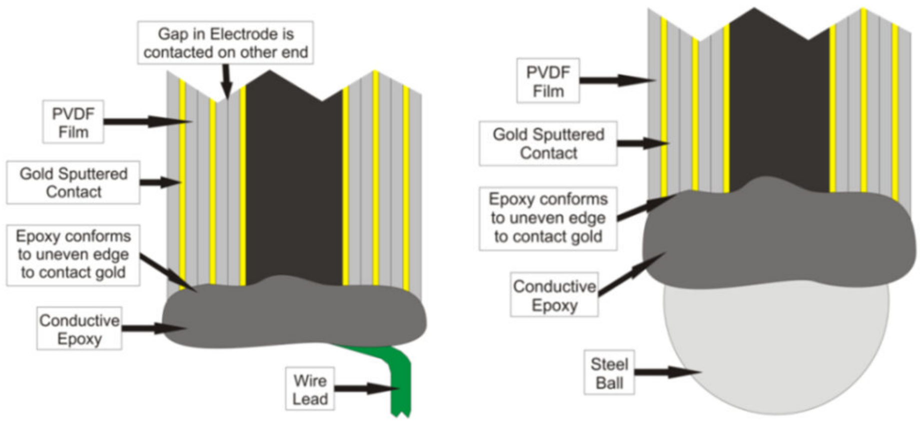
Final Fabrication Steps

Actuator Removal and Reinforcing

As mentioned previously, the glue must be broken down and liquefied in a carefully controlled oven so the actuator can be pulled off using tweezers or finger tips. The action must be performed immediately after the mandrel is removed from the oven or the glue will harden and damage the film. It is believed that air becomes trapped between the wound layers during the rolling process. There are negative consequences which result from trapped air such as reduced actuator buckling strength and possibly a lowered breakdown voltage. In an effort to reduce these effects the actuator is placed inside of a vacuum oven to remove the air and lightly bond the wound layers keeping the air from reentering. After 1 hour at roughly 90˚C the oven transforms the wound film into a continuous hollow tube increasing the overall integrity.

Electrical Contact Establishment

The final fabrication step is application of the electrical contacts. Small quantities of conductive epoxy are applied to the actuator ends which contact the sputtered gold. It was originally thought that the connection between the epoxy and the sputtered gold would be difficult to establish but proved to be rather reliable without much disparity. Shown in Figure 3-25 (a - b), wire leads or steel balls are placed in the compound. Wire leads were used primarily for testing and prototyping whereas the 1.6mm steel balls provided a more modular device for applications such as the Braille cell. Photographs of the two finished actuator designs can be seen in Figure 3-26 (a – b).



(a) (b)

Figure 3-25: (a) Actuator End with Wire Leads (b) Actuator End with Steel Balls Attached

(a)

(b)

Figure 3-26: (a) Actuator with Wire Leads (b) Actuator with Steel Ball Ends

Machine Electronics and Software

The machine uses a variety of mechanical, electrical and pneumatic systems to perform the processing operations on the film. The manufacturing procedure is outlined in the algorithm and the link between the code and the machine is an elaborate array of electronic control systems. Figure 3-27 displays the major components responsible for the mechanical hardware control.

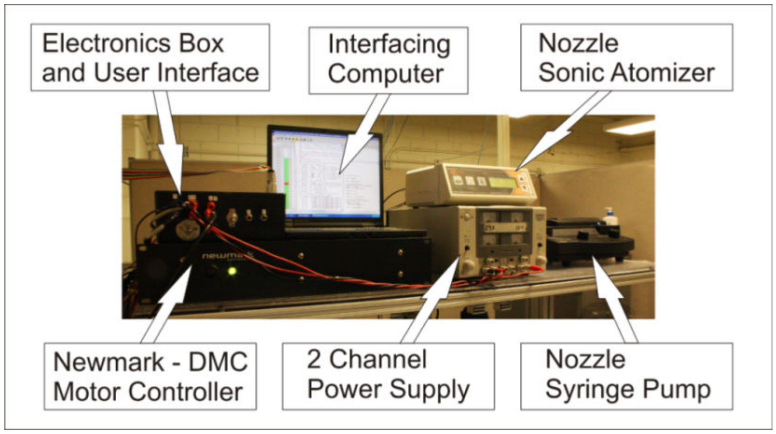


Figure 3-27: Electronics and Control Systems

Controlling the machine begins with the stage motor controller. The controller drives four high precision stepper motor-driven stage channels to provide the various mechanical actuations needed to delicately handle the thin films. The driver contains large interfacing capability to control the various machine accessories. All of the necessary mechanical and electrical machine components in addition to the stages, such as the user interface, pressure regulators, solenoid valves, electromagnet, laser, and relays are also controlled by the imbedded software. The entire electroding nozzle system including the temperature control for the heating element is computer enabled and monitored for hardware safety. Due to the elaborate complexity for the electronic systems; a simple diagnostics test was incorporated into the electronics for enhanced reliability.

The machine software was intended to be relatively easy to use but also extremely versatile, adaptable, and reliable. The primary coding language used is GalilTools which works in conjunction with the Newmark stage driver enabling all of the built in commands to control stage position, acceleration and velocity curves. The code is structured to follow an organized step by step procedure for the user to easily follow and understand; with every major operation such as electroding, laminating, cutting, rolling and lamination defined and outlined. Figure 3-28 shows the flow chart for the algorithm as it proceeds through the major manufacturing operations. The algorithm does allow for on the spot corrections or process modifications at any time due to the multiple thread coding structure of the program. The main algorithm for the machine control can be seen in Appendix A. Appendix B shows the code for the Basic Stamp II which converts binary signals from the main computer to variable voltage outputs using pulse width modulation.

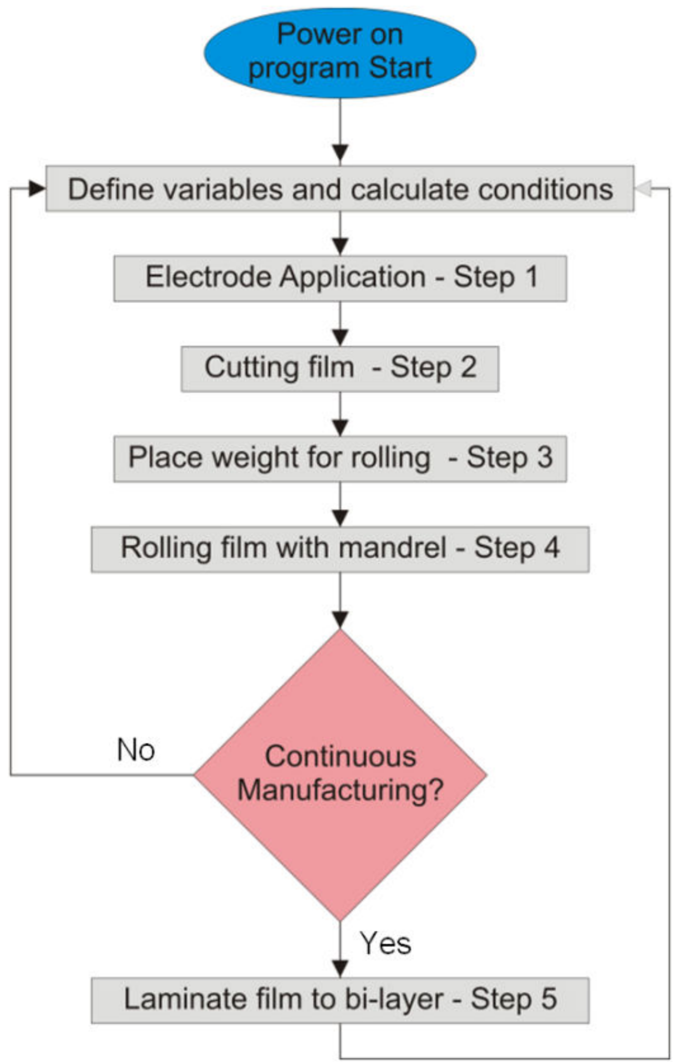


Figure 3-28: Major Operation Flow Chart of Machine Algorithm

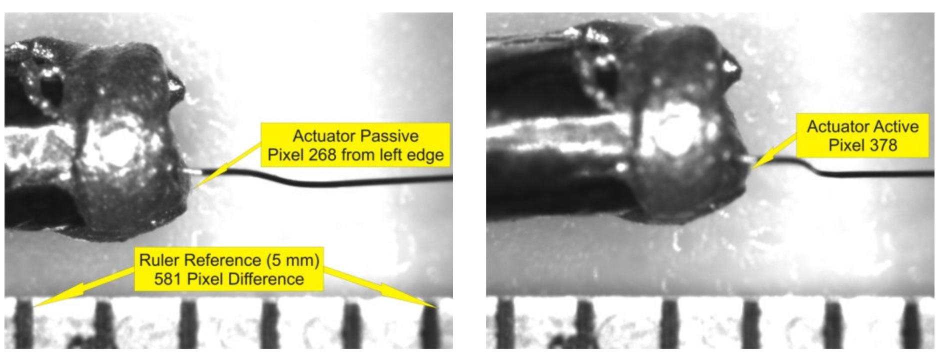
Chapter 4

Film Characteristics and Actuator Performance

The manufacturing operations and techniques outlined determine the actuator's design along with its performance and reliability which must be evaluated for applications such as the Braille display. The following section will discuss the fabricated actuators performance results such as strain, force, reliability and characteristic trends along with developing hardware for the Braille display.

Actuator Capacitance and Displacement

The actuator's percent strain and displacement was first measured using a microscopic camera capable of providing nearly 10 um of resolution. The actuator would be oriented horizontally with a millimeter ruler to use as a reference in the acquired images. The pixel difference between the start and end positions dictated the displacement when compared to the reference. The first and last photos for a 600 V test are shown in Figure 4-1 (a - b) with the pixel references indicated.



(a) (b)

Figure 4-1: Camera Showing Actuator Currently Passive (b) Camera showing Actuator Charged to 600V

The observed linear displacement was about 946 microns providing this actuator with 0.95mm (3.15%) displacement. The images also show the actuator moving slightly in the out of actuation direction; this behavior was observed in many experiments and is believed to be affected by either the boundary conditions or variances in the electrodes. The parabolic displacement versus final DC voltage curve for this actuator can be seen in Figure 4-2.

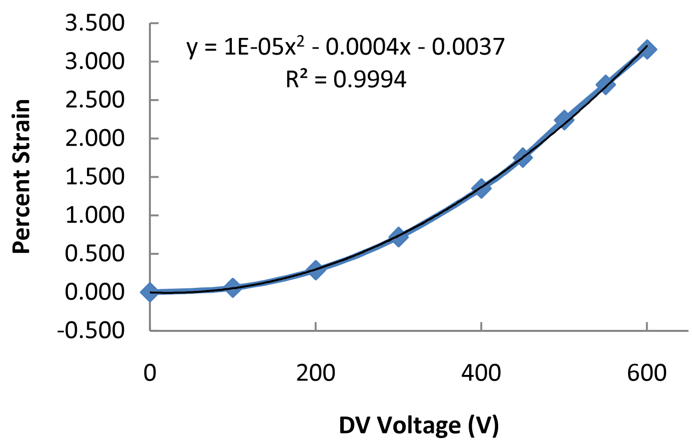


Figure 4-2: Actuator Strain versus Voltage from Microscopic Camera

Initially AC signal tests were performed with the microscopic camera for displacement measurement because it was visually easier to see by eye. However, after several experiments it was noticed that the actuators were not fully retracting to their inactive length because they could not fully discharge during the cycle. As the voltage of the signal was increased the actuator's starting position would drift forward effectively reducing the actuator's total change in displacement (see Figure 4-3 for actuator drift).

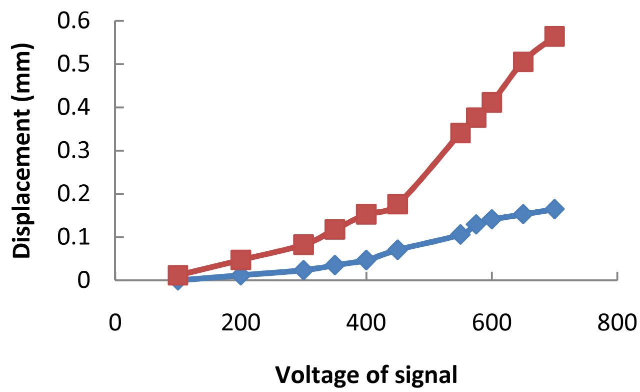


Figure 4-3: Actuator Drifting From 0.1 Hz Sine Signal (square) Active (diamond) Inactive

The AC drift indicated the response time of the devices appeared to be relatively slow; therefore the testing signal was converted to a DC signal for accurate measurement. A plot showing the actuators displacement versus time can be shown in Figure 4-4. After applying a charge the actuator will respond to 60% of its actuation almost instantly, however, above this value and the actuator assumes a transient to the total displacement.

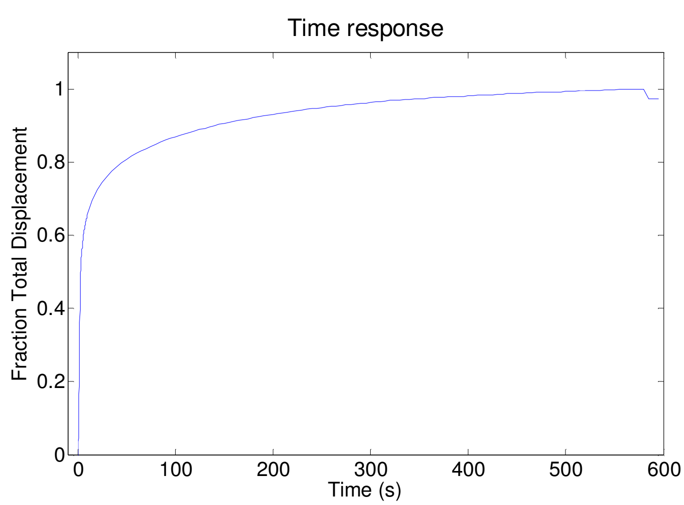


Figure 4-4: Response Time of PVDF Tube Actuator

The actuator is only desired to move in the axial direction; any out of plane movement is essentially wasted energy. A robust technique was used to physically constrict the translation of the device to the actuation direction by placing the actuator in a cylinder. The device was orientated vertically with golden oil filling the vessel. The actuators with the steel ball ends were contacted using small magnets both securing the device and provided electrical connection. In this setup a laser vibrometer coupled to a LabVIEW interface was used to accurately measure the displacement. A photo of the setup can be seen in Figure 4-5.

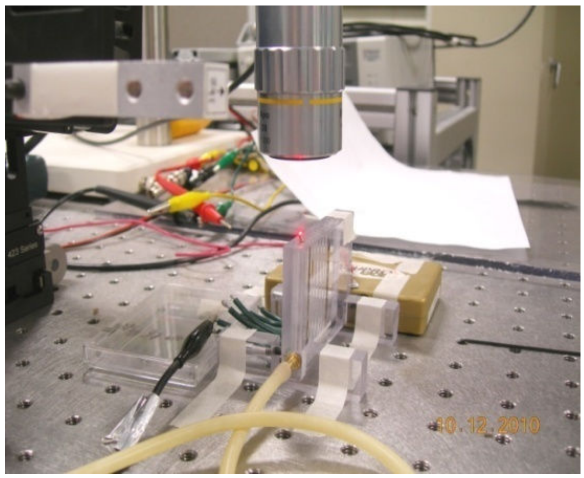


Figure 4-5: Laser Vibrometer Testing Apparatus

The vibrometer setup was able to record the input voltage and current with the matching time step of the displacement for accurate response. A number of actuators were tested under these conditions to provide a reasonable estimate of performance. A plot of the displacement with the corresponding voltage and current draw can be seen in Figure 4-6. The interesting characteristic to take from these plots is the actuator’s response to the linear voltage input. Unlike the displacement, the current draw does not substantially increase with an increase in voltage because of the ramped input; the typical maximum current draw for all voltages is nearly 0.1 mA. Individual actuator results plotted with varying electrode thickness can be seen in Appendix C.

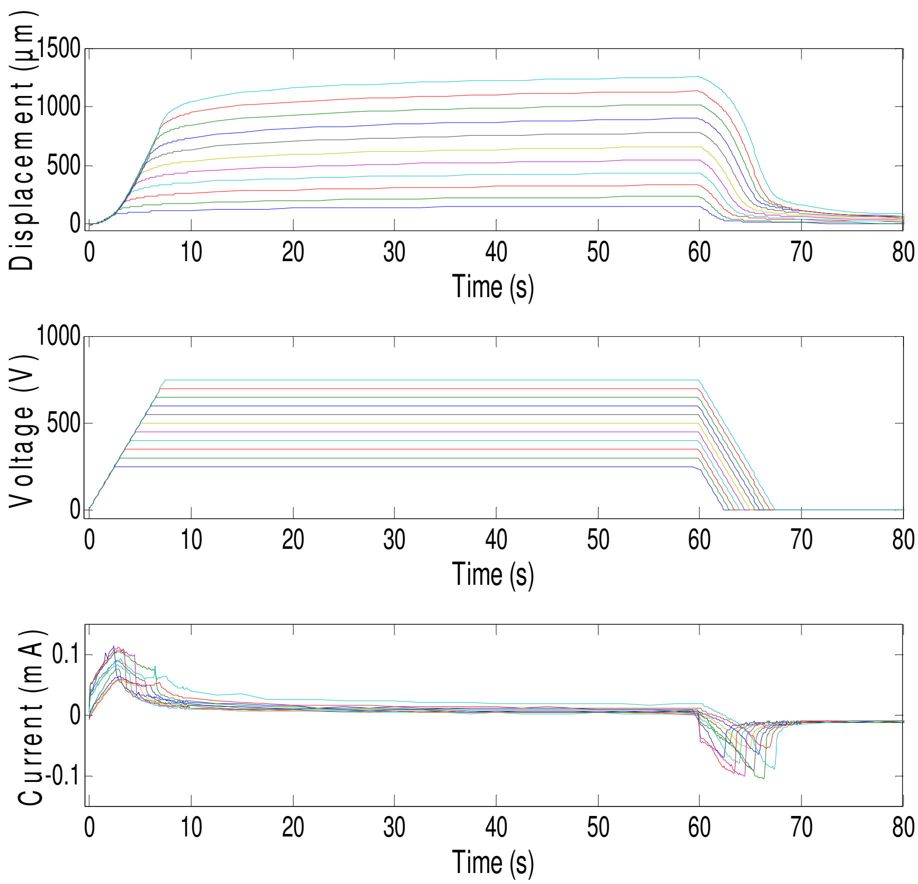


Figure 4-6: Actuator Displacement, Applied Voltage and Current with 50 V Incremental Voltage from 200V-750V versus Time

Estimated Blocking Force

A load cell was placed above the actuator to measure the blocking force and buckling loads. The tubular vessel surrounding the actuator technically increases the buckling load of the device because the material is physically restricted to the dimensions of the cylinder. A LabVIEW generated plot of blocking force can be seen in Figure 4-7. The maximum load seen by the device is nearly 2 N but as the plot shows the actuator permanently fails. Without evidence of buckling, this particular sample was able to withstand 1 N comparing in magnitude to the calculated buckling loads in *Chapter 2*.

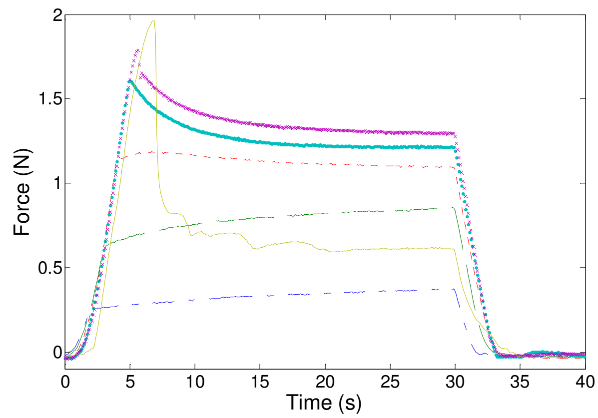


Figure 4-7: Actuator Blocking Force Measurements versus Voltage (-.-.) 200V (- - -) 300V (…) 400V (* * *) 500V (x) 600V (--) 700V

Reliability and Statistics

One of the largest factors affecting cycle life and breakdown voltage aside from the film quality is the type of voltage input provided. Originally it was believed that oscillating wave forms would be better for the actuator because the device is at the maximum voltage for only a fraction of the signal cycle, thus reducing the time period arcing between the electrodes could occur. However after analyzing the LabVIEW data for a DC signal, it was soon realized that the only measureable current was during the charge and discharge of the device (0.1mA) and nearly zero otherwise. The inward and outward current flow from an AC signal could accumulate heat in the electrodes eventually leading to actuator failure. Extending the charge and discharge time drastically reduces the current surge however this makes the response time of the device slower. A number of actuators were tested, analyzed, measured and averaged for key characteristics described in this chapter. A table providing average statistics can be seen in Table 4-1.

Table 4-1: Actuator Performance and Physical Characteristics

Maximum achieved strain (%)	4.25
Average strain at 125 V/µm (≈700V) (%)	2.5
Average settling time (s)	145
Average capacitance at 20Hz (nF)	260
Average force at 550V, after buckling (N)	0.95
Average max current draw 100V/s DC voltage ramping (mA)	0.1
Cycle life at 700V (cycle amount)	1013
Average length (mm)	43
Active length (mm)	30
Average weight (g)	0.2
Average diameter (mm)	2.3

Braille Cell Design and Operation

Provided the performance of the actuators, it was of interest to test them in a 6 pin Braille cell with the commercially standard character dimensions. The design utilizes the magnet lead contacts used in the laser vibrometer apparatus. The actuators would all receive nearly 500 V from a small voltage amplifier engaged by manually operated push button switches. A SolidWorks rendering of the Braille cell with actuators can be seen in Figure 4-8.

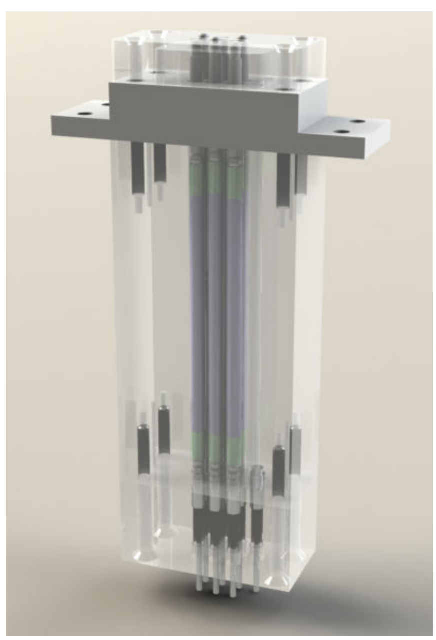


Figure 4-8: SolidWorks Rendering of Braille Cell under Production

Chapter 5

Conclusions and Future Work

Manufacturing Process

This thesis introduces the design and fabrication of PVDF wound rolled actuators. Continuous manufacturing and frame methods were described that apply the electrodes, laminate to form a bi-layer, roll the film into a tube, reinforce the actuator and apply electrical contacts. Automation of key steps reduces human dependency and increases fabrication repeatability.

Manufacturing Hardware

The machines hardware is designed, machined and aligned to handle the film with precision to avoid material damage. A majority of the manufacturing techniques performed as expected successfully processing the film with a higher than predicted product yield. The machines software has all of the manufacturing steps preprogrammed so the hand manipulation required by the technician is minimal for either development technique. The robust hardware and software platform is a useful tool in tubular-shaped linear displacement actuators.

Actuator Performance

The actuator devices provide over 4.25% strain (1.25 mm displacement) with a sustainable blocking force of over 1 N while still maintaining the initial design profile of a

2.2 mm outer diameter by 43 mm length. With the performance characteristics considered, the PVDF film actuators far surpass the listed requirements for a tactile Braille cell while only requiring a modest 450-550V for desired displacement. The tubular devices appear to be a suitable and practical alternative to the commercially available cantilever beam designs and are competitive with currently researched alternatives.

Scope of Future Work

If the film quality is improved enough that several feet of material can be developed with minimal impurities, the continuous manufacturing process should be performed from the film roll. The machine is not completely able to automate the process as it now stands. Hardware modifications, along with new machine code would require further experimentation to ensure the process operates to design specifications.

The software developed on GalilTools is sufficient at running the machines hardware but does not provide a Graphical User Interface (GUI). A Java or LabVIEW GUI platform could be developed to better interface the technician to the GalilTools software allowing for a greater user friendly environment.

The permanent glue applied to the film which holds the wrapped layers together is difficult to manually and repeatedly place at the film edge. If this task could be automated that would further reduce the user dependency required in this fabrication step.

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Appendix A

GalilTools Program Code

Thread 0: Starts, Defines the Variables and Instructs other Threads

```
REM***************************************************************************
REM  PROGRAM IS BURNED INTO THE MEMORY OF THE DMC. MEANING WHEN YOU TURN ON
REM  THE DMC THIS PROGRAM WILL AUTOMATICALLY RUN DEFINING ALL OF THE BELOW
REM  VARIABLES. IF YOU CHANGE ANYTHING HERE YOU WILL HAVE TO RELOAD THE FILE.
REM  TO DO THIS FIRST CLICK ON THE PROGRAM AND PRESS ctrl-down TO LOAD THE
REM  PROGRAM. THEN PRESS ctrl-shift-down TO EXECUTE THE ALGORITHM
REM***************************************************************************
REM
BP;'BURN PROGRAM TO DMC MEMORY
REM  SET I/O BOARD, TURN EVERYTHING OFF, INITALIZE X & Z AXIS
#AUTO; CN1; CO7; AB1; JS#CONDEFN; JS#INITALZ; JP#BEGIN; EN
REM
REM***************************************************************************
REM THREAD 0: THIS STARTS, DEFINES THE VARIABLES AND INSTRUCTS OTHER THREADS
REM***************************************************************************
REM
#BEGIN; HX1; HX2; HX3; HX4; HX5; HX6; HX7
REM
REM  PHYSICAL MACHINE PARAMETERS, BE PRECISE!
  psoti    = 3      ;' WHICH SIDE OF THE PADDLE IS ON TOP
  bladelng = 0.2    ;' (IN) LENGTH OF KNIFE BLADE
  settemp  = 80     ;' (C) TEMPERATURE FOR HEAT SOURCE TO MAINTAIN
REM
REM  PHYSICAL FILM PARAMETERS
  tf       = 0.0080 ;' (MM) THICKNESS OF FILM
  te       = 0.0005 ;' (MM) THICKNESS OF CONDUCTIVE ELECTRODE
  wf       = 90.000 ;' (MM) WIDTH OF FILM SAMPLE
REM  THE MANDREL SIZE IS CALCULATED IN THE CODE BUT YOU CAN OVERWRITE
REM  THE VALUE BY ENTERING A DIAMETER IN THE VARIABLE BELOW
  mandrel  = 0.0    ;' (MM) MANUALLY CHOOSEN MANDREL DIAMETER, 0=AUTOSELECT
REM
REM  OR, YOU CAN ENTER THE THICKNESS OF THE ENTIRE BILAYER FILM, SHOULD BE
REM  ZERO IF DESIRED TO ENTER THE FILM AND ELECTRODE THICKNESS INDIVIDUALLY
  tbt      = 0.0200 ;' (MM) THICKNESS OF BILAYER FILM
REM
REM  PHYSICAL ACTUATOR PARAMETERS
  do       = 2.0000 ;' (MM) DESIRED OUTER DIAMETER OF ACTUATOR
REM
REM  ADJUSTABLE SPRAYING PARAMETERS
  sprsped  = 0.05   ;' (IN/S) SPEED FOR SPRAYING
  xpassde  = 4      ;' SPRAY PASSES (FORWARD / REVERSE)
```

```
REM
REM  THESE ARE MANDREL PARAMETERS, (RATIO OF X TO W) - STEP 4
 ratioxw1 = 0.5    ;' RATIO OF MANDREL ROTATION TO X-AXIS (FIRST REV)
 rolstart = 1      ;' REVOLUTIONS MANDREL WILL ROTATE TO START ROLLING
 offman1  = 0.005  ;' (IN) MANDREL Z-AXIS OFFSET FROM PADDLE (FIRST REV)
 off2mult = 2      ;' OFFMAN2 MULTIPLER TO ADJUST ROLLING HEIGHT (0.5-5)
 ratioxw2 = 0.0    ;' RATIO OF MANDREL ROTATION TO X-AXIS (REST OF FILM)
REM
REM  THESE ARE THE DEFAULT VACUUM SETTINGS FOR THE ELECTRODING STEP (0/1)
 sprvac   = 0;   sprvacfl = 0
REM
REM  THESE ARE THE DEFAULT VACUUM SETTINGS FOR THE ROLLING STEP (0/1)
 manvac1  = 1;   manvac2  = 0;   manvacfl = 0
REM
REM  THESE ARE THE DEFAULT VACUUM SETTINGS FOR THE MAGNET STEP (0/1)
 magvac   = 1;   magvacfl = 0
REM (0/1)
REM  THESE ARE THE DEFAULT VACUUM SETTINGS FOR THE CUTTING STEP (0/1)
 cutvac   = 1;   cutvacfl = 1
REM
REM  THESE ARE X & Z OPERATION OFFSETS (SPRAYER, CUTTER, MANDREL AND MAGNET)
REM  BE VERY CAREFUL ADJUSTING THESE!!!
 DM op_x[4]; DM op_z[4]
 op_x[0]  = 02.750;'(IN) DISTANCE FROM X-HOME EDGE FOR SPRAYER STEP
 op_x[1]  = 11.125;'(IN) DISTANCE FROM X-HOME EDGE FOR CUT STEP
 op_x[2]  = 12.055;'(IN) DISTANCE FROM X-HOME EDGE FOR MAGNET RELEASE
 op_x[3]  = 13.550;'(IN) DISTANCE FROM X-HOME EDGE FOR MANDREL STEP
 op_z[0]  = 0.0000;'(IN) DISTANCE FROM Z-HOME EDGE FOR SPRAYER STEP
 op_z[1]  = -0.300;'(IN) DISTANCE FROM Z-HOME EDGE FOR CUT STEP
 op_z[2]  = -0.752;'(IN) DISTANCE FROM Z-HOME EDGE FOR MAGNET RELEASE
 op_z_625 = -0.570;'(IN) DISTANCE FROM Z-HOME EDGE FOR "1/16" MANDREL
 op_y     = 25
REM
REM  THESE ARE THE SPEED & ACC/DCC VALUES FOR THE W-AXIS (ROLLING STEP)
 pspw[0] = axis_utw*30;'(DEG/S)   MUST BE GREATER THAN ZERO
 padcw[0] = axis_utw*30;'(DEG/S^2) MUST BE GREATER THAN ZERO
REM
REM THIS STARTS THE OTHER THREADS AND PROGRAM PROCEEDS TO MAIN
 JS#VARDEFN; XQ#MONITOR,1; XQ#ERRCHK,2; XQ#MOVLPXY,3; XQ#MOVLPZW,4; adsy=6
 XQ#IOLOOP,5; XQ#NOZSAFE,6; XQ#HEATMON,7; psot=psoti; JS#AMHOLD; JP#STEP0
EN
REM
REM**************************************************************************
REM  THREAD 0: THESE ROUTINE RESET, RESTART AND SKIP MAJOR STEPS
REM**************************************************************************
REM
REM  RESTART/RESET PROGRAM, RESETS VARIABLES, HOMES AXISES AND STEPS STEP=1
#STEP0; fk=0; CN1; WT(hld); JS#VARDEFN; JS#HOMEX; JS#HOMEZ; JS#AMHOLD
 IF((_RPX<>homex)|(_RPZ<>homez)); JS#INITALZ; ENDIF
 jogsx=1; jogsy=0.25; jogsz=0.25; jogsw=5; adx=6; ady=6; adz=6; adw=6
 adsx=5; adsy=5; adsz=5; adsw=5; alloff=1; jog=0; xpass=0
```

```
 adsy=6; retunpad=1; JS#AMHOLD; JS#MGLOOP; MG"- STEP 0 -"; MG; WT(hld)
 type=13; JS#BRKSTP; MG"- LAST STEP PERFORMED WAS",s{Z2.0}," -"
 MG"- PLEASE ENTER STEP TO START AT -"; MG"- DEFAULT IS STEP 1 -"
 MG"- ENTER IN THE FORM (s=x) -"; MG"- x BEING ANY NUMBER 1-5 -"; MG
 MG"- PRESS 1 WHEN READY -"; MG; s=1; JS#HOLDGO; JP#MAIN
EN
REM
REM  ALLOW USER TO JUMP TO ANY STEP WITHOUT RESETTING VARIABLES / CONDITIONS
#STEPSEL; AB1; CN1; xpass=0; ncs=0; endspr=0; jog=0; IF(s<0); s=st; ENDIF
 MG; MG; MG"- PROGRAM STEP SELECT -"; MG; fk=0; retunpad=1; JS#AMHOLD
 MG"- LAST STEP PERFORMED WAS",s{Z2.0}," -"; MG"- PRESS 1 TO RESTART STEP -"
 MG"- OR ENTER DESIRED STEP TO GOTO -"; MG"- ENTER IN THE FORM (s=x) -"
 MG"- x BEING ANY NUMBER 1-5 -"; MG; MG"- PRESS 1 WHEN READY -"; MG
 JS#HOLDGO; JP#MAIN
EN
REM
REM**************************************************************************
REM THREAD 0: THIS IS WHERE THE MAJOR STEPS ARE DEFINED WITH SUBROUTINES
REM**************************************************************************
REM
#MAIN; IF(s<0); s=st; ENDIF; mainrun=mainrun+1
 i=0; CN1; type=6; JS#BRKSTP; JS#HOMEZ; JS#AMHOLD
 #PICSTEP; IF(s=1); JS#SPRYSTP; s=2; JP#MAIN
  ELSE; IF(s=2); JS#CUTSTP; s=3; JP#MAIN
  ELSE; IF(s=3); JS#MAGSTP; s=4; JP#MAIN
  ELSE; IF(s=4); JS#MANSTP; s=5; JP#MAIN
  ELSE; IF(s=5); IF(filmroll=1); JS#SIDETRK; ENDIF; s=1; JP#MAIN
  ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; i=i+1
 JP#PICSTEP,i<2; i=0; MG"- INCORRECT STEP NUMBER ENTERED -"; JP#STEPSEL
EN
REM
REM**************************************************************************
REM  THIS IS WHERE THE SUBROUTINES ARE DEFINED
REM**************************************************************************
REM
REM  IF autoresume IS DISENGAGED, PROVIDE AN EASY TO FOLLOW ROUTINE TO MODIFY
REM  ADJUST, OR SKIP CERTAIN PARAMETERS OR PROCESSES AT RUNTIME
#BRKSTP; WT(hld); IF(bgx+bgy+bgz+bgw>0); JS#AMHOLD; ENDIF
REM  IF autoresume IS ENABLED, RUN EXECUTION WITH PREVIOUSLY SET PARAMETERS
 IF(@IN[auto]=0)
  IF (type=1); MG"- SPRAYING CPS ELECTRODE -"
  ELSE; IF(type=2); MG"- CUTTING FILM -"; brkcut=0
  ELSE; IF(type=3); MG"- DROPPING WEIGHT -"; brkmag=0
  ELSE; IF(type=4); MG"- ROLLING FILM -"; brkman=0
  ELSE; IF(type=5); MG"- JOG POSITION NOT APPLIED TO STEP -"; s=-1
  ELSE; IF(type=6); MG; MG"- STARTING STEP",s{Z2.0}," -"
  ELSE; IF(type=7); MG"- NO CHANGE IN VAC STATUS -"
  ELSE; IF(type=8); MG"- NO CHANGE IN X -"
  ELSE; IF(type=9); MG"- NO CHANGE IN Y -"
  ELSE; IF(type=10); MG"- NO CHANGE IN Z -"
  ELSE; IF(type=11); MG"- NO CHANGE IN W -"
```

```
    ELSE; IF(type=12); MG"- TILTING Y -"; MG; tilty=0
    ELSE; IF(type=13); MG"- MANUFACTURING FROM FRAMES -"; filmroll=0
    ELSE; IF(type=14); MG"- ENGAGING LAMINATION ROLL -"; lr=1
    ELSE; MG"- INCORRECT TYPE, PROGRAM RESTARTING -"; JP#STEP0
    ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF
    ENDIF; ENDIF; ENDIF; ENDIF; MG
REM  IF autoresume IS DISENABLED, PROMPT USER FOR INPUT FOR SPECIFIC ACTION
  ELSE; MG"- AUTORESUME DISENGAGED -"
    MG"- TOGGLE SWITCH ON TO PROCEED -"
    IF(type=1); MG"- PRESS 1 TO SPRAY -"; MG"- PRESS 0 TO SKIP STEP -"
    ELSE; IF(type=2); MG"- PRESS 1 TO CUT -"; MG"- PRESS 0 TO SKIP STEP -"
    ELSE; IF(type=3); MG"- PRESS 1 TO DROP WEIGHT -"
      MG"- PRESS 0 TO SKIP -"
    ELSE; IF(type=4); MG"- PRESS 1 TO ROLL FILM-"; MG"- PRESS 0 TO SKIP -"
    ELSE; IF(type=5); MG"- PRESS 1 TO NOT APPLY JOG POSITION TO STEP -"
      MG-" ENTER STEP TO APPLY JOG SETTINGS -"
      MG"- ENTER IN FORM (s=4) -"; MG"- PRESS 0 WHEN READY -"
    ELSE; IF(type=6); MG"- PRESS 1 TO START STEP",s{Z2.0}," -"
      MG"- PRESS 0 TO SELECT STEP OR STOP -"
    ELSE; IF(type=7); MG"- PRESS 1 FOR VAC ON -"
      MG"- PRESS 0 FOR VAC OFF -"
    ELSE; IF(type=8); MG"- PRESS 1 TO PROCEED -"; MG"- PRESS 0 TO JOG X -"
    ELSE; IF(type=9); MG"- PRESS 1 TO PROCEED -"; MG"- PRESS 0 TO JOG Y -"
    ELSE; IF(type=10); MG"- PRESS 1 TO PROCEED -"; MG"- PRESS 0 TO JOB Z -"
    ELSE; IF(type=11); MG"- PRESS 1 TO PROCEED -"; MG"- PRESS 0 TO JOG W -"
    ELSE; IF(type=12); MG"- PRESS 1 TO TILT Y -"
      MG"- PRESS 0 FOR NO Y TILT -"
    ELSE; IF(type=13); MG"- PRESS 1 TO MANUFACTURE FROM FRAMES -"
      MG"- PRESS 0 TO MANUFACTURE FROM FILM ROLL -"
    ELSE; IF(type=14); MG"- PRESS 1 TO ENGAGE LAMINATION ROLL -"
      MG"- PRESS 0 TO DISENGAGE LAMINATION ROLL -"
    ELSE; MG "- INCORRECT ENTERED, PROGRAM RESTARTING -"; MG; JP#STEP
    ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF
    ENDIF; ENDIF; ENDIF; ENDIF
    stpend=0; brkman=0; brkcut=0; brkmag=0; MG; WT(hld); AIg1; AIs0
REM  PROGRAM WILL WAIT FOR USER INPUT
    #STPCHK; IF(bgx+bgy+bgz+bgw>0); JS#AMHOLD; ENDIF
REM  IF go IS PRESSED, PROCEED WITH PREVIOUSLY SET PARAMETER
      IF(@IN[g1]=0)&(@IN[s0]=1)|(@IN[auto]=0); stpend = 1
        IF(type=1); MG"- SPRAYING CPS ELECTRODE -"
        ELSE; IF(type=2); MG"- CUTTING FILM -"; brkcut=0
        ELSE; IF(type=3); MG"- DROPPING WEIGHT -"; brkmag=0
        ELSE; IF(type=4); MG"- ROLLING FILM -"; brkman=0
        ELSE; IF(type=5); MG"- JOG POSITION NOT SAVED -"; s=-1
        ELSE; IF(type=6); MG; MG"- STARTING STEP",s{Z2.0}," -"
        ELSE; IF(type=7); IF(@IN[auto]=0); MG"- NO CHANGE IN VAC STATUS -"
          ELSE; WT(hld); AIg1; AIs0; MG"- NOW PRESS 1 FOR FULL VAC -"
            MG"- OR, PRESS 0 FOR REGULAR VAC -"; loflvac=0
            #LOFLVAC; IF(bgx+bgy+bgz+bgw>0); JS#AMHOLD; ENDIF
              IF(@IN[auto]=0; v[side]=1; loflvac=1; ENDIF
              IF(@IN[g1]=0); v[side]=1; fv=1; loflvac=1; ENDIF
```

```
          IF(@IN[s0]=0); v[side]=1; fv=0; loflvac=1; ENDIF
         JP #LOFLVAC, loflvac=0
        ENDIF
       ELSE; IF(type=8); MG"- NO CHANGE IN X -"
       ELSE; IF(type=9); MG"- NO CHANGE IN Y -"
       ELSE; IF(type=10); MG"- NO CHANGE IN Z -"
       ELSE; IF(type=11); MG"- NO CHANGE IN W -"
       ELSE; IF(type=12); MG"- TILTING Y -"; tilty=0
       ELSE; IF(type=13); MG"- MANUFACTURING FROM FRAMES -"; filmroll=0
       ELSE; IF(type=14); MG"- ROLL FORCE CAN BE HIGHER lr=(0-3)-"; lr=1
       ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF
       ENDIF; ENDIF; ENDIF; ENDIF; MG
      ENDIF
REM  IF stop IS PRESSED, PROMPT USER OF THE CHANGE AND CONTINUE
      IF(@IN[s0]=0)&(@IN[g1]=1)&(loflvac=0); stpend = 1
       IF(type=1); MG"- SKIPPING SPRAY STEP -"; xpass=xpassde
       ELSE; IF(type=2); MG"- SKIPPING CUT STEP -"; brkcut=1
       ELSE; IF(type=3); MG"- SKIPPING DROP STEP -"; brkmag=1
       ELSE; IF(type=4); MG"- SKIPPING ROLL STEP -"; brkman=1
       ELSE; IF(type=5); MG"- SAVING JOG POSITION TO STEP",s{Z2.0}," -"
       ELSE; IF(type=6); MG"- NOW PRESS 1 TO SELECT NEXT STEP -"
        MG"- OR, PRESS 0 TO TERMINATE PROGRAM -"; WT(hld); AIg1; AIs0
        #STEPSTP; IF(bgx+bgy+bgz+bgw>0); JS#AMHOLD; ENDIF
         IF(@IN[g1]=0)&(@IN[s0]=1); JP#STEPSEL; ENDIF
         IF(@IN[s0]=0)&(@IN[g1]=1); JP#STEP0; ENDIF
        JP#STEPSTP
       ELSE; IF(type=7); v[side]=0; fv=0
       ELSE; IF(type=8); jog=1; JS#JOGHOLD; WT(hld); JS#SETSTPO
       ELSE; IF(type=9); jog=2; JS#JOGHOLD; WT(hld); JS#SETSTPO
       ELSE; IF(type=10); jog=3; JS#JOGHOLD; WT(hld); JS#SETSTPO
       ELSE; IF(type=11); jog=4; JS#JOGHOLD; WT(hld); JS#SETSTPO
       ELSE; IF(type=12); MG"- NO Y TILT -"; tilty=1
       ELSE; IF(type=13); MG"- MANUFACTURING FROM ROLL -"; filmroll=1
       ELSE; IF(type=14); MG"- LAMINATION ROLL OFF -"; lr=0
       ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF; ENDIF
       ENDIF; ENDIF; ENDIF; ENDIF; MG
      ENDIF
    JP#STPCHK, stpend=0; stpend=0; loflvac=0
  ENDIF
EN
REM
REM  PROVIDE EASY FUNCTION TO CHECK AND CLEAN THE NOZZLE
#CHKNOZ; MG"- CHECKING / CLEANING NOZZLE -"; MG
 JS#HOMEZ; JS#HOMEX; JS#AMHOLD; st=s; s=-1; endspr=1; ncs=1
 #CHKLOP; JP#CHKLOP,endspr=1; endspr=0
 MG"- BLOW OUT NOZ WITH AIR WHEN FINISHED -"
 MG"- PRESS 1 TO PROCEED TO STEP SELECT -"; JS#HOLDGO; JP#STEPSEL
EN
REM
REM  THE CUTTING STEP EXECUTION ROUTINE
#CUTON; c=1; type=8; JS#BRKSTP; type=2; JS#BRKSTP
```

```
 IF(brkcut=0)
REM  IF shearint>1, EXECUTE THE SHEARING METHOD TO SEPERATE THE FILM
   IF(shearint>1); adsx=6
     #SHEARST; fk=1; WT(hld/5); IF(c=1); type=10; JS#BRKSTP; ENDIF
       fk=0; pax = op_x[1]+((c*wid_flm)/shearint); c=c+1; JS#AMHOLD
     JP#SHEARST,c<=shearint+1
REM  IF shearint=1, EXECUTE THE SLICING METHOD TO SEPERATE THE FILM
   ELSE; adsx=5; fk=1; WT(hld/5); type=10; JS#BRKSTP
     pax=op_x[1]+wid_flm; JS#AMHOLD; fk=0
   ENDIF; c=1; pax=op_x[1]; JS#HOMEZ; JS#AMHOLD
 ENDIF; brkcut=0
EN
REM
REM  THE CUTTING STEP SETUP ROUTINE
#CUTSTP; jogsx=0.5; IF(cutvac=1); v[side]=1; ELSE; v[side]=0; ENDIF
 IF(cutvacfl=1); fv=1; ELSE; fv=0; ENDIF
 type=7; JS#BRKSTP; adsz=6; paz=op_z[1]; JS#AMHOLD
REM  ASK USER TO CHECK BLADE ALIGNMENT BEFORE PROCEDDING
 MG"- IF NOT DONE SO ALREADY ... -"; MG"- CHECK BLADE ALIGNMENT -"
 MG"- PRESS 1 WHEN READY -"; MG; JS#HOLDGO; adsx=6; pax=op_x[1]; JS#AMHOLD
 JS#CUTON; JS#HOMEX; JS#AMHOLD; MG "- END OF CUT STEP -"; MG
EN
REM
REM  ROUTINE TO EXECUTE ON THE COMMAND JOGGING
REM  PROVIDE OPTION TO RESET OPERATION STAGE POSITIONS AND SETTINGS
#FREEJOG; MG"- FREEJOG ROUTINE -"; st=s; type=5; JS#BRKSTP;
 MG"- ENTER AXIS TO JOG -"; MG"- 1=X, 2=Y, 3=Z, 4=W -"
 MG"- ENTER IN FORM (jog=1-4) -"; JS#JOGHOLD; JS#SETSTPO; s=st; JP#STEPSEL
EN
REM
REM  IN-BETWEEN ROUTINE TO STEP SELECT AFTER CONNECTION IS ESTABLISHED
#HLDMAIN; JS#HOLDGO; JP#STEPSEL; EN
REM
REM  FORCE PROGRAM TO HALT EXECUTION UNTIL THE go BUTTON IS PRESSED
#HOLDGO; holdlop1=0; AIg1; AIs0
 #HOLDLP1; IF(bgx+bgy+bgz+bgw>0); JS#AMHOLD; ENDIF
   IF(@IN[g1]=0); holdlop1=1; WT(hld); ENDIF
   IF(@IN[s0]=0); MG"- 0 HAS NO EFFECT HERE -"; MG; WT(hld); ENDIF
 JP#HOLDLP1,holdlop1=0
EN
REM
REM  FORCE PROGRAM TO HALT EXECUTION UNTIL THE stop BUTTON IS PRESSED
#HOLDSTP; holdlop0=0; AIg1; AIs0
 #HOLDLP0; IF(bgx+bgy+bgz+bgw>0); JS#AMHOLD; ENDIF
   IF(@IN[g1]=0); MG"- 1 HAS NO EFFECT HERE -"; MG; WT(hld); ENDIF
   IF(@IN[s0]=0); holdlop0=1; WT(hld); ENDIF
 JP#HOLDLP0,holdlop0=0
EN
REM
REM  USE THREAD 0 TO INITIALIZE AND HOME THE X AND Z STAGES
REM  THIS IS THE ONLY SIUTATION THREAD 0 HAS ANY CONTROL OVER THE STAGES
```

```
#INITALZ; jog=-1; adsx=-1; adsz=-1; motfrzxy=1; motfrzzw=1; AMX; AMZ
  MG; MG; MG"- SETTING HOME POSITION FOR X&Z STAGES -"
  MG"- PRESS 1 TO SPEED UP X -"
  MG"- RELEASE 1 WHEN X IS NEAR FORWARD EDGE -"
  ACX=padcx[1]; DCX=padcx[7]; SPX=pspx[1]; PRX=axis_utx*-x_t
  ACZ=padcz[1]; DCZ=padcz[7]; SPZ=pspz[0]; PRZ=axis_utz*z_t
  IF((_LRX=1)&(_BGX=0)); BGX; ENDIF; IF((_LFZ=1)&(_BGZ=0)); BGZ; ENDIF
  xac=_ACX; xsp=_SPX; zac=_ACZ; zsp=_SPZ; AIg1; AIs0
REM  PROVIDE THE PAUSE AND SPEED UP OPTIONS AS IN NORMAL USE
  #INILOOP; movxz=_BGX+_BGZ
    IF((@IN[s0]=0)&(@IN[g1]=1)); STXZ; AMXZ
      MG"- PRESS ONE TO RESUME INITIALIZING -"; MG; JS#HOLDGO; JP#INITALZ
    ENDIF
    IF((@IN[g1]=0)&(@IN[s0]=1)); ACX=padcx[6]; SPX=pspx[6]
    ELSE; ACX=xac; SPX=xsp; ENDIF
  JP#INILOOP, movxz>0; adsx=5; adsz=5
  homex=_RPX+@RND[axis_utx*xoff]; homez=_RPZ-@RND[axis_utz*zoff]; jog=0
EN
REM
REM  ROUTINE EXECUTED WHEN STAGE LIMITS ARE ENGAGED BY USER OR PROGRAM ERROR
#LITROUB; type=5; IF(((_LFW=0)|(_LRW=0))&(_CN0=1)); JS#HOLDGO; ENDIF
  IF((_LFX=0)&(_CN0=1)); jog=1; ENDIF; IF((_LRZ=0)&(_CN0=1)); jog=3; ENDIF
  JS#JOGHOLD; JP#STEPSEL
EN
REM
REM  MAGNET STEP EXECUTION ROUTINE
#MAGON; type=8; JS#BRKSTP; type=3; JS#BRKSTP
REM  DROP STAGE AND DISENGAGE MAGENT TO PLACE ON FILM
  IF(brkmag=0); adsz=4; paz=op_z[2]; JS#AMHOLD; type=10; JS#BRKSTP
    type=3; JS#BRKSTP; wm=0; JS#IOHOLD; JS#HOMEZ; JS#AMHOLD
  ENDIF; brkmag=0
EN
REM
REM  MAGNET STEP SETUP ROUTINE
#MAGSTP; IF(magvac=1); v[side]=1; ELSE; v[side]=0; ENDIF
  IF(magvacfl=1); fv=1; ELSE; fv=0; ENDIF; type=7; JS#BRKSTP
REM  ASK USER TO APPLY WEIGHT TO MAGNET, THEN REPOSITION TO DROP WEIGHT
  JS#HOMEX; JS#AMHOLD; MG"- IF NOT DONE SO ALREADY ... -"; wm=1
  MG"- ADD WEIGHT TO MAGNET -"; MG"- PRESS 1 WHEN READY -"; MG; JS#HOLDGO
  adsx=5; pax=op_x[2]; JS#AMHOLD; JS#MAGON; MG "- END OF MAGNET STEP -"; MG
EN
REM
REM  ROLLING STEP EXECUTION ROUTINE
#MANON; type=4; JS#BRKSTP; adsz=-1
REM  DROP Z AND ASK USER TO USE / NOT USE VACUUM
  IF(brkman=0); AMZ; ACZ=padcz[2]; DCZ=padcz[1]; SPZ=pspz[4]
    paz=op_z[3]; JS#AMHOLD
    IF(manvac2=1); v[side]=1; ELSE; v[side]=0; ENDIF
    IF(manvacfl=1); fv=1; ELSE; fv=0; ENDIF
REM  TILT THE PADDLE TO IMPROVE BOND BETWEEN MANDREL AND PADDLE
    type=7; JS#BRKSTP; type=10; JS#BRKSTP; JS#TILTY
```

```
   AMZ; ACZ = padcz[1]; DCZ=padcz[5]; SPZ=pspz[2]
   paz=op_z[3]+offman1; JS#AMHOLD
REM  ROTATE MANDREL ON PADDLE 1 REVOLUTION TO INCREASE BONDING STRENGTH
REM  X WILL TRANSLATE PROPORTIONATLY WITH THE ROTATION OF THE MANDREL
REM  THIS WILL TEMPORARILY REMOVE THE TENSION FROMTHE FILM SO A BETTER
REM  BOND WILL DEVELOP BETWEEN THE TWO SURFACES
   adsw=0; adsx=0; revw=-rolstart
   pax=op_x[3]+(ratioxw1*-rolstart*360*-w_to_x); JS#AMHOLD
   AMZ; ACZ=padcz[1]; DCZ=padcz[5]; SPZ=pspz[2]
REM  STEP MANDREL AT CORRECT HEIGHT FOR CURRENT FILM SAMPLE
   paz=op_z[3]+offman2; JS#AMHOLD
REM  CONTINUE ROTATING MANDREL TO ROLL ENTIRE SAMPLE UNDER TENSION
   adsw=0; adsx=1; revw=wdis_rol
REM  ALLOW OPTION FOR X STAGE TO TRANSLATE BUT SHOULD NOT BE NEEDED
   pax=op_x[3]+(ratioxw1*-rolstart*360*-w_to_x)+(ratioxw2*wid_flm)
REM  ONCE ACTION IS COMPLETE, ASK USER IF THE MANDREL NEEDS TO ROLL MORE
   JS#AMHOLD; jogsw=1; type=11; JS#BRKSTP; v[side]=0
REM  RESET STAGES AND REMOVE MANDREL
   JS#HOMEX; JS#HOMEZ; JS#AMHOLD; MG "- PLEASE REMOVE MANDREL ROD -"
   MG"- THEN PRESS 1 TO PROCEEED -"; MG; JS#HOLDGO
  ENDIF; brkman=0
EN
REM
REM  ROLLING STEP SETUP ROUTINE
#MANSTP; wm=0; IF(manvac1=1); v[side]=1; ELSE; v[side]=0; ENDIF
  IF(manvacfl=1); fv=1; ELSE; fv=0; ENDIF; type=7; JS#BRKSTP
REM  STEP DEFAULT ROLLING POSITIONS BUT ASK USER TO ADJUST WITH LASER
  adsx=6; pax=op_x[3]; JS#AMHOLD; jogsx=0.25; ll=1; type=8; JS#BRKSTP; ll=0
REM  TELL USER TO PLACE MANDREL IN CHUCKS
  MG"- IF NOT DONE SO ALREADY ... -"
  MG"- APPLY STICK-IT GLUE TO MANDREL -"
  MG"- MANREL SHOULD BE",dia_man{Z1.3}, "INCHES IN DIAMETER -"
  MG"- PRESS 1 WHEN READY -"; MG; JS#HOLDGO
  adsw=7; JS#MANON; MG"- END OF MANDREL STEP -"; MG
EN
REM
REM  ELECTRODING STEP EXECUTION ROUTINE
#SPRAYON; xpass=0; type=1; JS#BRKSTP
REM  REPEAT PASSES OVER THE FILM MUTIPLE TIMES
  IF(xpass<>xpassde); IF(ncs=0); ncs=1; JS#SPRHOLD; ENDIF
   #SPRLOOP; base=-1; exp=xpass; JS#POWER; count=xpass+1
    IF(result<0); result=0; ENDIF
REM  INFORM THE USER WHAT PASS THEY ARE ON
    MG"- SPRAYING PASS #",count{Z2.0}," -"; MG; adsx=-1
    IF((xpass<xpassde)&(endspr=0)); xpass=xpass+1; exp=xpass; adsx=-1
     AMX; ACX=padcx[2]; DCX=padcx[3]; SPX=sprsped*axis_utx
     pax=op_x[0]+sproff+(result*wid_flm); JS#AMHOLD
    ENDIF
REM  IF USER HAS ENDED SPRAYING STEP EARLY, EXIT ROUTINE
    IF(endspr=1); WT(hld); xpass=xpassde; ENDIF
    IF(xpass>=xpassde); JS#HOMEX; JS#HOMEZ; JS#AMHOLD; nozhold6=0; ENDIF
```

```
    JP#SPRLOOP,xpass<xpassde; endspr=0; xpass=0
  ENDIF; IF(ncs=1); ncs=0; JS#SPRHOLD; ENDIF
EN
REM
REM  ELECTRODING STEP SETUP ROUTINE
#SPRYSTP; IF(sprvac=1); v[side]=1; ELSE; v[side]=0; ENDIF
  IF(sprvacfl=1); fv=1; ELSE; fv=0; ENDIF; type=7; JS#BRKSTP
REM  ASK USER TO ENSURE ATOMIZER TIMER HAS BEEN RESET
  MG"- RESET SONIC ATMOIZER TIMER -"
  MG"- PRESS 1 WHEN READY -"; MG; JS#HOLDGO
REM  TEST NOZZLE BEFORE SPRAYING
  JS#HOMEX; JS#HOMEZ; JS#AMHOLD; IF(ncs=0); ncs=1; JS#SPRHOLD; ENDIF
REM  WHEN NOZZLE SEEMS CONSISTENT, PROCEED TO APPLYING ELECTRODE
  MG"- PRESS 1 WHEN SPRAY IS CONSISTENT -"; MG; JS#HOLDGO
  adsx=6; adsz=6; pax=op_x[0]; paz=op_z[0]; JS#AMHOLD
  type=8; JS#BRKSTP; type=10; JS#BRKSTP
  JS#SPRAYON; MG"- END OF SPRAY STEP -"; MG
EN
REM
#SIDETRK; v[side]=0; psot=sidel; vaconrot=(sidel+2)
  IF(vaconrot>4); vaconrot=(vaconrot-4); ENDIF
  IF(vaconrot<1); vaconrot=(vaconrot+4); ENDIF
  adsy=3; pry=op_y; JS#AMHOLD; v[vaconrot]=1; JS#IOHOLD
  adsy=3; pry=45-op_y; JS#AMHOLD; type=14; JS#BRKSTP
  adsy=2; psot=sidel+1; JS#AMHOLD
EN
REM  TILT THE PADDLE FOR BETTER FILM CONTACT TO MANDREL
#TILTY; AMXYZW; tilty=0; type=12; JS#BRKSTP
REM  DISENABLE SAFETY CONSTRAINTS SO Y WILL MOVE WHILE Z IS NOT HOMED
  IF(tilty=0); CN-1; adsy=1
    pry=0.25; JS#AMHOLD; pry=-.50; JS#AMHOLD; pry=0.25; JS#AMHOLD
    jogsy=0.05; type=9; JS#BRKSTP; psot=sidel; JS#AMHOLD; CN1
  ENDIF
EN
REM
REM***************************************************************************
REM ALL OF THE FOLLOWING FUNCTIONS HAVE NO OUSIDE RFFFERENCES
REM***************************************************************************
REM
REM  HOLE THE 0 THREAD UNTIL POSITIONING OF ANY / ALL STAGE(S) IS FINISHED
#AMHOLD; WT(hld); amholdxy=1; amholdzw=1
  newxposh=@RND[homex+(axis_utx*pax)]; newyposh=@RND[axis_uty*pay]
  IF(((newxposh<>_RPX)|(newyposh<>_RPY))&(jog=0))
    #HLDLPXY; JP#HLDLPXY,(amholdxy=1)
  ENDIF
  newwposh=@RND[axis_utw*paw]; newzposh=@RND[homez+(axis_utz*paz)]
  IF(((newwposh<>_RPW)|(newzposh<>_RPZ))&(jog=0))
    #HLDLPZW; JP#HLDLPZW,(amholdzw=1)
  ENDIF
EN
REM
```

```
REM PROVIDE ERROR MSG IF THESE FILE DOES NOT LOAD CORRECTLY
#AUTOERR; MG"!VARIABLE FILE CORRUPTED!"; MG"!PLEASE RELOAD FILE!"; MG; EN
REM
REM  HOMES THE ABSOLUTE POSITION OF X TO 0" AT A SET ACC/SPEED/DEC
#HOMEX; IF(_RPX<>homex); MG"- HOMEING X -"; MG; adsx=6; pax=0; ENDIF; EN
REM
REM  HOMES THE ABSOLUTE POSITION OF Z TO 0" AT A SET ACC/SPEED/DEC
#HOMEZ; IF(_RPZ<>homez); MG"- HOMEING Z -"; MG; adsz=4; paz=0; ENDIF; EN
REM
REM  HOLD THE 0 THREAD UNTIL JOG ROUTINE IS FINISHED
#JOGHOLD
  #JOGDLOP; JP#JOGDLOP,jog>0
EN
REM
REM  HOLD O THREAD UNTIL I/O ACTION IS COMPLETE
#IOHOLD; iohold0=1; iohldmax=TIME+10000
  #IOHODLP; JP#IOHODLP,((iohold0=1)|(TIME<iohldmax))
EN
REM
REM  CLEAR COMMAND WINDOW BY PUTTING MANY EMPTY LINES IN OUTPUT WINDOW
#MGLOOP; i=0
  #MGLOP1; MG; i=i+1; JP#MGLOP1, i<35
EN
REM
REM  POWER FUNCTION TO CALCULATE WHOLE NUMBER EXPONENTS
#POWER; result=1
  IF(exp>0)
    #LOOP_PO; result=result*base; exp=exp-1; JP#LOOP_PO,exp>0
  ELSE; IF(exp<0)
    #LOOP_NE; result=result*base; exp=exp+1; JP#LOOP_NE,exp<0
    result=1/result
  ELSE; result=1; ENDIF; ENDIF
EN
REM
REM  ALLOW USER TO SAVE JOG POSITION TO A SPECIFIC MANUFACTURING STEP
#SETSTPO
  IF(s=1); IF(jogl=1); op_x[0]=(_RPX-homex)/axis_utx; ENDIF
    IF(jogl=3); op_z[0]=(_RPZ-homez)/axis_utz; ENDIF
  ELSE; IF(s=2); IF(jogl=1); op_x[1]=(_RPX-homex)/axis_utx; ENDIF
    IF(jogl=3); op_z[1]=(_RPZ-homez)/axis_utz; ENDIF
  ELSE; IF(s=3); IF(jogl=1); op_x[2]=(_RPX-homex)/axis_utx; ENDIF
    IF(jogl=3); op_z[2]=(_RPZ-homez)/axis_utz; ENDIF
  ELSE; IF(s=4); IF(jogl=1); op_x[3]=(_RPX-homex)/axis_utx; ENDIF
    IF(jogl=3); op_z[3]=(_RPZ-homez)/axis_utz; ENDIF
  ENDIF; ENDIF; ENDIF; ENDIF
EN
REM
REM  HOLD THE 0 THREAD UNTIL NOZZLE SYSTEM IS ENABLED
#SPRHOLD; sprhold0=1; sprwtmax=TIME+maxtspr
  #SPRHDLP; JP#SPRHDLP,((sprhold0=1)|(TIME<sprwtmax))
EN
```

```
REM
REM  DEFINE DEFAULT VARAIBLES / CONSTANTS AT STARTUP
#CONDEFN; DM v[5]
REM  CONSTANTS/INITIALLIZED VARIABLES, EITHER 0 OR 1 (DO NOT CHANGE THESE!)
 s       = 1; htcon    = 1; amholdxy = 1; amholdzw = 1; sprhold0 = 1
 wlimitok = 1; xlimitok = 1; zlimitok = 1; disconct = 0; disconil = 0
 st      = 0; side     = 0; c        = 0; i        = 0; endspr   = 0
 pax     = 0; pay      = 0; paz      = 0; paw      = 0; resetzw  = 0
 ycheck  = 0; tilty    = 0; roty     = 0; retunpad = 0; jogl     = 0
 prx     = 0; pry      = 0; prz      = 0; prw      = 0; help     = 0
 prxl    = 0; pryl     = 0; przl     = 0; prwl     = 0; iohold0  = 0
 paxl    = 0; payl     = 0; pazl     = 0; pawl     = 0; iotmout  = 0
 sidel   = 0; side     = 0; revw     = 0; revwm    = 0; sprtmout = 0
 heatcond = 0; avgtemp  = 0; oc       = 0; hcs      = 0; base     = 0
 newxpos  = 0; newypos  = 0; newzpos  = 0; newwpos  = 0; respad   = 0
 brkcut   = 0; brkend   = 0; brkman   = 0; brkmag   = 0; monitor  = 0
 motfreez = 0; motfrezp = 0; trf      = 0; payls    = 0; exp      = 0
 v[0]     = 0; v[1]     = 0; v[2]     = 0; v[3]     = 0; v[4]     = 0
 fk       = 0; wm       = 0; cf       = 0; oldlr    = 0; lr       = 0
 alloff   = 0; fv       = 0; loflvac  = 0; ll       = 0; motfrzzw = 0
 adsx     = 0; adsy     = 0; adsz     = 0; adsw     = 0; jog      = 0
 nozmon   = 0; nozlop1  = 0; nozlop2  = 0; ncs      = 0; xpass    = 0
 axisxy   = 0; amholdxy = 0; movexy   = 0; txy      = 0; bgy      = 0
 jsxyl    = 0; motfrzxy = 0; frezlpxy = 0; resetxy  = 0; bgx      = 0
 axiszw   = 0; amholdzw = 0; movezw   = 0; tzw      = 0; bgw      = 0
 jszwl    = 0; frezlpzw = 0; bgz      = 0; mainrun  = 0; filmroll = 0
 jzpl     = 0; jxpl     = 0; scalx    = 0; scalz    = 0
 jpw      = 0; jipw     = 0; jwpl     = 0; scalw    = 0; jrevwml  = 0
 jpy      = 0; jipy     = 0; jypl     = 0; scaly    = 0; jrcpypl  = 0
 ' THE FOLLOWING SECTION ARE THE OUTPUT/INPUT PINS FOR THE ACCESSORY
 bsic     =53; saic     =51; iosc     =56; asic     = 7; hic      =55
 v1o      =34; v2o      =35; v3o      =36; v4o      =37; fano     =21
 kio      =33; koo      =29; mago     =38; reyo     =23; hs       =44
 lamo1    =28; lamo2    =30; fvo      =32; spo      =22; sao      =20
 heo      =39; g1       =41; s0       =46; auto     =43; las      =25
 tcai     = 1; jgpot    = 3
 '  CONSTANT VALUES FOR MACHINE AND COMPONENTS
 mm2in    = 0.0393701   ;' CONVERSION OF MM TO IN
 maxtspr  = 2400000     ;' MAX TIME ALLOWED FOR NOZZLE TO STAY AT ONCE
 pi       = 3.1415926536;' THIS IS PI ... COME ON NOW
 axis_utx = 317500      ;' (STEPS) FOR X-AXIS TO TRAVEL 1 INCH
 axis_uty = 12500       ;' (STEPS) FOR Y-AXIS TO TRAVEL 1 DEGREE
 axis_utz = 1200000     ;' (STEPS) FOR Z-AXIS TO TRAVEL 1 INCH
 axis_utw = 138.8888889 ;' (STEPS) FOR W-AXIS TO TRAVEL 90 DEGREES
 x_t      = 20          ;' (IN) DISTANCE X CAN TRAVEL
 z_t      = 1           ;' (IN) DISTANCE Z CAN TRAVEL
 prrc     = 0.05        ;' (A) CURRENT PRESSURE REGULATORS USE
 sovc     = 0.2         ;' (A) CURRENT SOLENOID VALVES USE
 magc     = 0.9         ;' (A) CURRENT MAGNET USES
 relc     = 0.10        ;' (A) CURRENT RELAY USES
 fanc     = 0.2         ;' (A) CURRENT DRAWN BY COOLING FAN
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 noztmon  = TIME       ;' EVALUATE CURRENT TIME FOR REFERENCE
REM  THESE VARIABLES CAN BE CHANGED BUT SHOULDN'T NEED TO BE
 jogsx    = 1          ;' (IN/S) DEFAULT JOGING SPEED IN X STAGE
 jogsy    = 0.25       ;' (IN/S) DEFAULT JOGING SPEED IN Y STAGE
 jogsz    = 0.25       ;' (IN/S) DEFAULT JOGING SPEED IN Z STAGE
 jogsw    = 5          ;' (IN/S) DEFAULT JOGING SPEED IN W STAGE
 adx      = 6          ;' (IN/S^2) DEFAULT ACC/DEC SPEED IN X STAGE
 ady      = 6          ;' (IN/S^2) DEFAULT ACC/DEC SPEED IN Y STAGE
 adz      = 6          ;' (IN/S^2) DEFAULT ACC/DEC SPEED IN Z STAGE
 adw      = 6          ;' (IN/S^2) DEFAULT ACC/DEC SPEED IN W STAGE
 temprang = 0.1        ;' (C) ALLOWABLE TEMPERATURE RANGE FROM MEDIUM
 kt       = 0.1        ;' (0-1) PROPORTIONAL CONSTANT TO ALTER RANGE
 tempdisp = 120000     ;' (S) TIME TO DISPLAY TEMPERATURE FROM HEAT SOURCE
 numtoavg = 4          ;' NUMBER OF SAMPLES TO AVERAGE FOR HEAT MEASURING
 heatnois = 0          ;' (C) ENGAGING RELAY MIGHT MAKE NOISE, OFFSET HERE
 sproff   = 0          ;' (IN) OFFSET FROM DEFAULT SPRAYING POSITION
 tempoff  = -3.0       ;' (C) TEMP OFFSET FOR THERMOCOUPLE
 hld      = 500        ;' (MS) TIME TO WAIT FOR INPUTS
 soatstwt = 3000       ;' (MS) TIME FOR ATOMIZER TO TURN ON
 sypuspwt = 3000       ;' (MS) TIME FOR SHYRINGE PUMP TO TURN OFF
 sypustwt = 8000       ;' (MS) TIME FOR SHYRINGE PUMP TO TURN ON
 ' EXERCISE CAUTION CHANGING THESE!
 xoff     = 0.125      ;' (IN) DISTANCE AWAY X-HOME IS FROM FORWARD X LIMIT
 zoff     = 0.0313     ;' (IN) DISTANCE AWAY Z-HOME IS FROM UPPER Z LIMIT
 lkfe     = 5.5        ;' (IN) POSITION IN X WHERE MINIMUM IN Z CHANGES
 zll      = -0.775     ;' (IN) MAXIMUM Z DISPLACEMENT GLOBALLY
 zllh     = -0.635     ;' (IN) MAXIMUM Z DISPLACEMENT NEAR X-HOME POSITON
REM  AXIS SPEEDS
 DM pspx[8]; DM pspy[8]; DM pspz[8]; DM pspw[8]
REM X-AXIS (IN/S)
 pspx[0] = axis_utx*0.125; pspx[1] = axis_utx*0.050
 pspx[2] = axis_utx*0.125; pspx[3] = axis_utx*0.500
 pspx[4] = axis_utx*1.000; pspx[5] = axis_utx*1.375
 pspx[6] = axis_utx*1.500; pspx[7] = axis_utx*2.500
REM Y-AXIS (DEG/S)
 pspy[0] = axis_uty*1.000; pspy[1] = axis_uty*2.000
 pspy[2] = axis_uty*4.000; pspy[3] = axis_uty*6.000
 pspy[4] = axis_uty*8.000; pspy[5] = axis_uty*10.00
 pspy[6] = axis_uty*12.00; pspy[7] = axis_uty*15.00
REM Z-AXIS (IN/S)
 pspz[0] = axis_utz*0.025; pspz[1] = axis_utz*0.050
 pspz[2] = axis_utz*0.100; pspz[3] = axis_utz*0.125
 pspz[4] = axis_utz*0.188; pspz[5] = axis_utz*0.250
 pspz[6] = axis_utz*0.300; pspz[7] = axis_utz*0.375
REM W-AXIS (DEG/S)
 pspw[0] = axis_utw*10.00; pspw[1] = axis_utw*30.00
 pspw[2] = axis_utw*50.00; pspw[3] = axis_utw*75.00
 pspw[4] = axis_utw*90.00; pspw[5] = axis_utw*180.0
 pspw[6] = axis_utw*360.0; pspw[7] = axis_utw*720.0

REM  AXIS ACCELERATIONS & DECCELERATIONS
```

```
 DM padcx[8]; DM padcy[8]; DM padcz[8]; DM padcw[8]
REM X-AXIS (IN/S^2)
 padcx[0] = axis_utx*0.125; padcx[1] = axis_utx*0.500
 padcx[2] = axis_utx*0.750; padcx[3] = axis_utx*1.000
 padcx[4] = axis_utx*1.250; padcx[5] = axis_utx*1.625
 padcx[6] = axis_utx*2.000; padcx[7] = axis_utx*2.250
REM Y-AXIS (IN/S^2)
 padcy[0] = axis_uty*1.000; padcy[1] = axis_uty*2.000
 padcy[2] = axis_uty*4.000; padcy[3] = axis_uty*6.000
 padcy[4] = axis_uty*8.000; padcy[5] = axis_uty*10.00
 padcy[6] = axis_uty*12.00; padcy[7] = axis_uty*15.00
REM Z-AXIS (IN/S^2)
 padcz[0] = axis_utz*0.025; padcz[1] = axis_utz*0.050
 padcz[2] = axis_utz*0.100; padcz[3] = axis_utz*0.125
 padcz[4] = axis_utz*0.188; padcz[5] = axis_utz*0.250
 padcz[6] = axis_utz*0.300; padcz[7] = axis_utz*0.375
REM W-AXIS (IN/S^2)
 padcw[0] = axis_utw*10.00; padcw[1] = axis_utw*30.00
 padcw[2] = axis_utw*50.00; padcw[3] = axis_utw*75.00
 padcw[4] = axis_utw*90.00; padcw[5] = axis_utw*180.0
 padcw[6] = axis_utw*360.0; padcw[7] = axis_utw*720.0
REM
REM JOG AXIS SPEED RATIOS
 ratiox=1; ratioy=5; ratioz=0.375; ratiow=75
EN
REM
REM  CALCULATE VARIABLES DEPENDENT ON THE USER INPUTS
#VARDEFN; wid_flm=wf*mm2in; psot=psoti; sidel=psot
 ysr=90*psoti; ycr=90*psoti; dysr=ysr; dycr=ycr
REM  TOTAL DISTANCE X IS ALLOWED TO TRAVEL FROM HOME
 x_tfh=(x_t-(2*xoff))
REM  (MM) TOTAL THICKNESS OF BI-LAYER FILM
 IF(tbt=0); tbi=(2*tf)+(2*te); ELSE; tbi=tbt; ENDIF
REM  REVOLUTIONS MANDREL WILL EXECUTE TO ROLL SAMPLE
 nr=(do*pi-(@SQR[(do*do*pi*pi)-(4*tbi*pi*wf)])/(2*tbi*pi)); wdis_rol=-nr
REM  (IN AND MM) DIAMETER THE MANDREL SHOULD BE
 IF(mandrel>0); di=mandrel; ELSE; di=(do-(2*nr*tbi)); ENDIF
 dia_man = di*mm2in
REM  (IN) FINAL OFFSET OF MANDREL TO PADDLE DURING ROLLING
REM  OFFSET IS JUDGED BY THE CHANGE IN DIAMETER FROM THE FILM x2
 offman2=((do-di)*mm2in*off2mult); op_z[3]=op_z_625-((0.0625-dia_man)/2)
REM  THESE ARE CALCULATED PARAMETERS BASED ON THE PREVIOUS INPUTS
 shearint=@RND[wid_flm/bladelng];' AMOUNT OF CUTS THE BLADES WILL TAKE
 w_to_x=(pi*dia_man)/360  ;' (REV/IN) RELATIONSHIP BETWEEN W & X
REM  X AXIS DEFINED PARAMETERS FOR ROLL DEFINED BY W
 IF((pspw[0]=0)|(padcw[0]=0))
   pspw[0]=axis_utw*10; padcw[0]=axis_utw*10; padcw[0]=axis_utw*10
 ENDIF
 pspx[0]=(axis_utx*w_to_x*pspw[0]*(ratioxw1+0.01))/axis_utw
 padcx[0]=(axis_utx*w_to_x*padcw[0]*(ratioxw1+0.01))/axis_utw
 pspx[1]=(axis_utx*w_to_x*pspw[0]*(ratioxw2+0.01))/axis_utw
```

```
 padcx[1]=(axis_utx*w_to_x*padcw[0]*(ratioxw2+0.01))/axis_utw
EN
REM
```

Thread 1: Monitor, This Allows Continuous Pause and Terminate Capability

```
REM ***********************************************************************
REM  THREAD 1: MONITOR, THIS ALLOWS CONTINUOUS PAUSE AND TERMINATE CAPABILITY
REM************************************************************************
REM
#MONITOR
REM  IF go AND stop ARE PRESSED AT THE SAME TIME, AT ANY TIME, STOP EXECUTION
 IF((@IN[g1]=0)&(@IN[s0]=0)); monitor=1; HX0; xpass=0; jog=0
  pauend=0; ncs=0; endspr=0; motfrzxy=1; motfrzzw=1; AB1; CN1; AIg1; AIs0
REM  DISPLAY MENU OPTIONS TO USER IN COMMAND WINDOW
  IF(s<0); s=st; ENDIF; MG; MG; MG"- MAIN PROGRAM WILL HALT -"; MG
  IF(@IN[auto]=0); togonoff=0; MG"- FLIP TOG OFF TO CHECK NOZ / JOG -"
  ELSE; togonoff=1; MG"- FLIP TOG ON TO CHECK NOZ / JOG -"; ENDIF
  MG"- PRESS 1 TO SELECT STEP -"; MG"- PRESS 0 FOR STEP0 -"; MG; WT(hld)
REM  ALLOW USER TO CHOOSE FROM A SHORT MENU OF OPTIONS
  #PAUSE1; IF((@IN[g1]=0)&(@IN[s0]=0)); JP#MONITOR; ENDIF
REM  GO WILL PROCEED TO STEP SELECT
   IF((@IN[g1]=0)&(@IN[s0]=1)); HX0; XQ#STEPSEL,0; pauend=1; ENDIF
REM  STOP WILL PROCEED TO PROGRAM RESET
   IF((@IN[s0]=0)&(@IN[g1]=1)); HX0; XQ#STEP0,0; pauend=1; ENDIF
REM  IF TOGGLE IS REVERSED, PROCEED TO A NEW MENU OF OPTIONS
   IF(((@IN[auto]=0)&(togonoff=1))|((@IN[auto]=1)&(togonoff=0)))
    MG"- NOW PRESS 1 TO CHECK/CLEAN THE NOZ -"
    MG"- OR PRESS 0 TO JOG AXIS -"; MG; WT(hld); AIg1; AIs0
    #PAUSE2; IF((@IN[g1]=0)&(@IN[s0]=0)); JP#MONITOR; ENDIF
REM  IF GO IS PRESSED, OPEN CLEAN NOZZLE ROUTINE
     IF((@IN[g1]=0)&(@IN[s0]=1)); HX0; XQ#CHKNOZ,0; pauend=1; ENDIF
REM  IF STOP IS PRESSED, ALLOW THE USER TO JOG FREELY
     IF((@IN[s0]=0)&(@IN[g1]=1)); HX0; XQ#FREEJOG,0; pauend=1; ENDIF
    JP#PAUSE2, pauend=0
   ENDIF
  JP#PAUSE1,pauend=0; pauend=0
 ENDIF; monitor=0
JP#MONITOR
REM
```

Thread 2: Monitors the Power Consumption

```
REM************************************************************************
REM  THREAD 2;  THIS MONITORS THE POWER CONSUMPTION
REM************************************************************************
```

```
REM
#ERRCHK; jgx=_JGW; jgx=_JGX; jgy=_JGY; jgz=_JGZ
REM  CHECK CONDITION OF OUTPUTS AND DETERMINE IF CURRENT IS TOO HIGH
 v1=@OUT[v1o]; v2=@OUT[v2o]; v3=@OUT[v3o]; v4=@OUT[v4o]; fanp=@OUT[fano]
 ki=@OUT[kio]; ko=@OUT[koo]; magp=@OUT[mago]; rey=@OUT[reyo]
REM  CALCULATE THE TOTAL POWER CONSUMPTION
 totpow=sovc*(v1+v2+v3+v4+ki+ko)+(magc*magp)+(relc*rey)+(prrc*2)+(fanp*fanc)
REM  IF REQUIRED CURRENT IS TOO HIGH, DISENGAGE CURRENTLY UNSUED ITEMS
 IF(totpow>=1.9)
  MG"- TOO MUCH CURRENT DRAW -"; MG"- PROGRAM WILL REDUCE OUTPUTS -"; MG
  IF((s<>3)&(magp=1)); wm=0; ELSE; IF((s<>1)&(fanp=1)); cf=0
  ELSE; IF((s<>2)&((ki+ko)>0)); fk=0
  ELSE; MG"- PROGRAM RESTARTING -"; MG; HX0; XQ#STEP0,0
  ENDIF; ENDIF; ENDIF
 ENDIF
REM
REM  CHECK FOR CABLE AND HARDWARE CONNECTION
 IF(((@IN[bsic]+@IN[saic]+@IN[iosc])>0)|(@AN[asic]<4))
  IF(disconil=0); alrtime=TIME; disconil=1; ENDIF
REM  IF CABLE IS DISCONNECTED FOR OVER 2 SECONDS, INFORM THE USER REPEATEDLY
  IF(TIME>(alrtime+2000))
   IF(disconct=0); disconct=1; HX0; CN1; alloff=1; ENDIF
   IF(@IN[bsic]=1); MG"- RECONNECT BASIC STAMP IMMEDIATELY -"; MG
   ELSE; IF(@IN[saic]=1); MG"- RECONNECT SONIC ATOMIZER IMMEDIATELY -"; MG
   ELSE; IF(@IN[iosc]=1); MG"- RECONNECT I/O SIGNAL IMMEDIATELY -"; MG
   ELSE; IF(@AN[asic]<4); MG"- RECONNECT ANALOG SIGNAL IMMEDIATELY -"; MG
   ELSE; MG"- PROGRAM UNABLE TO FIND PROBLEM -"; MG
   ENDIF; ENDIF; ENDIF; ENDIF
  ENDIF
 ENDIF
REM  RESET TIMER IF CONNECTION IS RESTORED
 IF(((@IN[bsic]+@IN[saic]+@IN[iosc])=0)&(@AN[asic]>4)&(disconil=1))
  disconil=0
 ENDIF
REM  INFORM USER IS HEAT CONTROL IS DISCONNECTED BUT DO NO STOP EXECUTION
 IF((@IN[hic]=1)&(htcon=1))
  htcon=0; MG"- HEAT CONTROL DISCONNECTED -"; MG
 ENDIF
REM  INFORM USER IS HEAT CONTROL IS RECONNECTED
 IF((@IN[hic]=0)&(htcon=0))
  htcon=1; MG"- HEAT CONTROL CONNECTED -"; MG
 ENDIF
REM  INFORM USER WHEN CONNECTION HAS BEEN FOUND AND PROCEED TO PROGRAM RESET
 IF(((@IN[bsic]+@IN[saic]+@IN[iosc])=0)&(@AN[asic]>4)&(disconct=1))
  JS#MGLOOP; disconct=0; disconil=0; MG"- CONNECTION FOUND, PRESS 1 -"; MG
  AB1; HX0; XQ#HLDMAIN,0
 ENDIF
REM
REM  LIMIT CHECKING AND MONITORING
REM  CHECK IF W LIMITS HAVE BEEN ENGAGED (CHECK LIMIT SWITCH CAP)
 IF(((_LFW=0)|(_LRW=0))&(wlimitok=1)&(_CN0=1)); ncs=0; motfrzzw=1
```

```
    MG"- W LIMITS ENGAGED -"; MG"- RESOLVE BEFORE CONTINUING -"; MG
    HX0; XQ#LITROUB,0; wlimitok=0
  ENDIF
  IF(((_LFW=1)&(_LRW=1))&(wlimitok=0)&(_CN0=1)); wlimitok=1; ENDIF
REM  CHECK IF FORWARD EDGE X-LIMIT IS ENGAGED, ALLOW USER TO CORRECT ERROR
  IF((_LFX=0)&(_CN0=1)&(xlimitok=1)); ncs=0
    MG "- X STAGE LIMIT ENGAGED -"; MG"- RESOLVE BEFORE CONTINUING -"; MG
    HX0; XQ#LITROUB,0; xlimitok=0
  ENDIF
  IF((_LFX=1)&(_CN0=1)&(xlimitok=0)); xlimitok=1; ENDIF
REM  CHECK IF Y LIMITS ARE ENGAGED (RAISE Z TO DISENABLE THE LIMITS)
  IF(((_LFY=0)|(_LRY=0))&(ycheck=0))
    MG"- Y LIMITS ENGAGED, PADDLE LOCKED -"; MG; ycheck=1
  ENDIF
REM  INFORM USER WHEN PADDLE CAN FREELY ROTATE
  IF(((_LFY=1)|(_LRY=1))&(ycheck=1))
    MG"- PADDLE WILL NOW ROTATE -"; MG; ycheck=0
  ENDIF
REM  CHECK IF THE LOWER Z-LIMIT IS ENAGED, ALLOW USER TO CORRECT ISSUE
  IF((_LRZ=0)&(_CN0=1)&(zlimitok=1)); ncs=0
    MG"- Z LOWER LIMIT ENGAGED -"; MG"- RESOLVE BEFORE CONTINUING -"; MG
    HX0; XQ#LITROUB,0; zlimitok=0
  ENDIF
  IF((_LRZ=1)&(_CN0=1)&(zlimitok=0)); zlimitok=1; ENDIF
REM
REM  DISLAY HELP MENU TO USER TO HELP ENTER COMMANDS
  IF(help=1); help=0; MG; MG
    MG"- STAGE POSITIONING -"; MG
    MG"- JOG AXIS, X=1, Y=2, Z=3, W=4, (jog=2) -"
    MG"- FAST-SLOW JOGING SPEED (IN/S) (X,Y,Z,W), (jogsx=_._) -"
    MG"- MOVING ACCELERATION / DECELERATION / SPEED (X,Y,Z,W), (adsx=0-7) -"
    MG"- JOGGING ACCELERATION / DECELERATION (X,Y,Z,W), (adx=0-7) -"
    MG"- PADDLE SIDE ON TOP, (psot=1-4) -"
    MG"- POSITION ABSOLUTE (IN) (X,Z), (pax=--.----) -"
    MG"- POSITION ABSOLUTE (DEG) (Y,W), (pay=---.--) -"
    MG"- POSITION RELATIVE (IN) (X,Z), (prx=--.----) -"
    MG"- POSITION RELATIVE (DEG) (Y,W), (pry=---.--) -"
    MG"- X RANGE 0-20in, Z-RANGE -1-0"
    MG"- Y & W RANGE CONTINUOUS -"
    MG"- REVOLUTIONS OF W, (revw=--.---) -"; MG; MG
    MG"- ACCESSORIE CONTROL -"; MG
    MG"- ALL ACCESSORIES OFF, (alloff=1) -"
    MG"- COOLING FAN ENABLE/DISENABLE, (cf=0/1) -"
    MG"- FILM KNIVES ENABLE/DISENABLE, (fk=0/1) -"
    MG"- LAMINATION ROLL CONTROL, (lr=0-3) -"
    MG"- LASER LINE ENABLE/DISENABLE, (ll=0/1) -"
    MG"- VACUUM ON SIDE [1-4] ENABLE/DISENABLE, (v[2]=0/1) -"
    MG"- WEIGHT MAGENT ENABLE/DISENABLE, (wm=0/1) -"; MG; MG
    MG"- AUTOMATIC CONTROL SYSTEMS ENABLE / DISENABLE-"; MG
    MG"- HEAT CONTROL SYSTEM ENABLE/DISENABLE, (hcs=0/1) -"
    MG"- NOZZLE CONTROL SYSTEM ENABLE/DISENABLE, (ncs=0/1) -"; MG; MG
```

```
  ENDIF
JP#ERRCHK
REM
```

Thread 3: Controls the X & Y Axis Motions And Jogs

```
REM***********************************************************************
REM  THREAD 3;  THIS CONTROLS THE X & Y AXIS MOTIONS AND JOGS
REM***********************************************************************
REM
REM  THIS ROUTINE IS ALWAYS CHECKING FOR CHANGES IN X&Y STAGE POSITIONS
#MOVLPXY; IF(psot<>side); JS#SETSIDE; ENDIF
REM  IF RETURNPAD IS ENABLED AND THE PADDLE IS NOT ON A SPECIFIC SIDE, RESET
REM  PADDLE TO THE PREVIOUS SIDE SET ON TOP
 IF(((ysr=1)|(ysr=-1)|(ycr=1)|(ycr=-1))&(retunpad=1)); retunpad=0; ENDIF
 IF((ysr<>1)&(ysr<>-1)&(ycr<>1)&(ycr<>-1)&(retunpad=1)); pay=payls; ENDIF
REM  IF RELATIVE POSITION IS ADJUSTED FOR EITHER AXIS, CONVERT RELATIVE
REM  POSITION TO THE ABOSLUTE SCALE
 IF(prx<>0); IF(@ABS[prx]>(x_t-xoff)); prx=(x_t-xoff)*(prx/@ABS[prx]); ENDIF
  prx=@RND[prx*10000]/10000
  pax=prx+(@RND[((_RPX-homex)/axis_utx)*10000]/10000); prxl=prx; prx=0
 ENDIF
 IF(pry<>0); IF(@ABS[pry]>720); pry=720*(pry/@ABS[pry]); ENDIF
  pry=@RND[pry*100]/100; pay=pry+(@RND[(_RPY/axis_uty)*10000]/10000)
  pryl=pry; pry=0
 ENDIF
REM  IF EMERGENCY STOP FOR X-Y IS ENABLED, COUNTINE TO EMERGENCY STOP ROUTINE
 IF(motfrzxy=1); JS#ERMOTXY; ENDIF
REM  BOTH STAGES CAN BE RESET TO POWER ON CONDITION IF NEEDED
 IF(resetxy=1); MG"- RESET X & Y -"; MG; pax=0; pay=0; resetxy=0; ENDIF
REM  IF JOG ROUTINE IS NOT ENABLED, CHECK TO SEE IF POSITIONS HAVE CHANGED
 IF((jog<>1)&(jog<>2)); IF(pax<0); pax=0; ENDIF
REM  SET NEW ABSOLUTE STAGE POSITIONS
  IF(pax>(x_t-xoff)); pax=x_t-xoff; ENDIF
REM  ROUND ADJUSTED POSITION CHANGES TO PRESET DECIMAL VALUES
  pay=@RND[pay*10000]/10000; pax=@RND[pax*10000]/10000
  newypos=@RND[axis_uty*pay]; newxpos=@RND[homex+(axis_utx*pax)]
  IF((newypos<>_RPY)|(newxpos<>_RPX)); axisxy=axisxy+1
REM  CYCLE LOOP TWICE INCASE TWO COMMANDS ARE GIVEN SIMULTANEOUSLY
   IF(axisxy>1); JS#MOVEXY; axisxy=0; ENDIF
  ENDIF
REM  IF JOG IS ENABLED, COUNTINE TO JOG ROUTINE
 ELSE; IF((jog=1)|(jog=2)); JS#JOGXY
 ELSE; IF(jog>4); jog=0; MG"- INVALID JOG AXIS -"; MG; ENDIF; ENDIF; ENDIF
REM  IF EITHER STAGE WAS MOVED, DETERMINE CURRENT POSITIONS
 IF((bgx=1)|(bgy=1)); JS#CPXY; ENDIF
JP#MOVLPXY
REM
REM  DETERMINE CURRENT ABSOLUTE POSITION FOR X-Y
```

```
#CPXY; cpx=@RND[((_RPX-homex)/axis_utx)*10000]/10000; paxl=cpx
  cpy=@RND[(_RPY/axis_uty)*10000]/10000; rcpy=cpy-payl; payl=cpy
REM  IF X WAS MOVING, OUTPUT NEW X-POS
  IF(bgx=1); MG"- X IS",cpx{Z2.4}," IN FROM HOME -"; MG; bgx=_BGX; ENDIF
REM  RELATE Y-RADIAL POSITION TO xy COORDINATES
  ysr=@RND[@SIN[cpy+(90*psoti)]*10000]/10000
  ycr=@RND[@COS[cpy+(90*psoti)]*10000]/10000
REM  DETERMINE IF ANY SIDE 1-4 IS FACING UP AND SET side TO VALUE
  IF((ysr=1)&(ycr=0)); side=1; ELSE; IF((ycr=1)&(ysr=0)); side=4
  ELSE; IF((ysr=-1)&(ycr=0)); side=3; ELSE; IF((ycr=-1)&(ysr=0)); side=2
REM  IF NO SIDE IS UP< SET side TO -1
REM  IF side>0, SET REFERENCE COORIDINATE AND OUTPUT NEW psot
  ELSE; side=-1; ENDIF; ENDIF; ENDIF; ENDIF
REM  IF Y WAS MOVING, UPDATE psot TO CURRENT side
  IF(bgy=1); MG"- Y MOVED",rcpy{Z4.2}," DEGS -"; MG; bgy=_BGY; psot=side
    IF(side>0); payls=payl; sidel=side
      MG"- PADDLE SIDE",side{F1.0}," ON TOP -"; MG
    ENDIF
  ENDIF; amholdxy=0
EN
REM
REM  IF motfrzxy=1, SET CURRENT X-Y POSITION TO THE DESIRED POSITION
#ERMOTXY; motfrzxy=0; axisxy=0; jog=0
  pax=@RND[((_RPX-homex)/axis_utx)*10000]/10000
  pay=@RND[(_RPY/axis_uty)*100000]/100000
EN
REM
REM  THIS ROUTINE ALLOWS THE USER TO MANUALLY ADJUST STAGE POSITONS WITH POT
#JOGXY; jogloop1=0; jsxyl=0; STXY; AMXY; adxl=adx; adyl=ady
  IF((s=4)&(jog=1)); ll=1; ENDIF
REM  CHECK WHICH AXIS TO JOG AND APPLY ACC.DEC VALUES TO MOTION
  IF(jog=1); MG"- X JOG ROUTINE -"; ACX=padcx[adx]; DCX=padcx[adx]; ENDIF
  IF(jog=2); MG"- Y JOG ROUTINE -"; ACY=padcy[ady]; DCY=padcy[ady]; ENDIF
REM  PROVIDE DIRECTIONS TO THE USER TO USE THE JOGGING ROUTINE
  MG"- ADJUST JOG SPEED/DIRECTION WITH POT -"; MG"- POT L = -SPEED -"
  MG"- POT MID = 0 SPEED -"; MG"- POT R = +SPEED -"
  MG"- PRESS 1 WHEN FINISHED -"; MG; WT(hld)
REM  BEGIN JOG LOOP TO MONTIOR THE CHANGES MADE BY THE USER
  #JOGLPXY; IF((jog<>2)&(_CN0=-1)); CN1; ENDIF
REM  IF USER CHANGES ACC?DEC VALUES< RESTART ROUTINE
    IF((adxl<>adx)|(adyl<>ady)); JP#JOGXY; ENDIF
REM  CHECK ANALOG POT VALUE AND TRANSLATE TO 0-1 SCALE WITH SIGN
    jsxy=(@RND[20*((@AN[jgpot]-2.5)/2.5)]/20)
REM  IF X IS ENABLED, SET MEASURED JOG VALUE TO AXIS
REM  IF X IS CLOSE TO EITHER EDGE, FIRST SLOW DOWN JOG, STOP IF AT LIMIT
    IF(jog=1); STY; jogl=jog
      jxp=@RND[((_RPX-homex)/axis_utx)*10000]/10000; scalx=@RND[jxp]
      IF((jxp>=scalx)&(jxpl<scalx))|((jxp<=scalx)&(jxpl>scalx))
        MG"- X IS",scalx{Z2.4}," IN FROM HOME -"; MG; jxpl=jxp
      ENDIF
      IF((jxp<=1)&(jxp>0)&(jsxy<0))|((jxp>=(x_tfh-1))&(jxp<x_tfh)&(jsxy>0))
```

```
      jgspx=(jsxy*ratiox*jogsx)/3; JGX=jgspx*axis_utx
     ELSE; IF((jxp<=0)&(jsxy<0))|((jxp>=x_tfh)&(jsxy>0))
      jgspx=0; JGX=jgspx*axis_utx; STX
     ELSE; jgspx=jsxy*ratiox*jogsx; JGX=jgspx*axis_utx; ENDIF; ENDIF
REM  DISPLAY JOG SPEED TO USER
     IF(jgspx<>jsxyl); MG"- X JOG SPEED",jgspx{Z2.2},"IN/S-"; MG; ENDIF
REM  CHECK BOUNDARY CONDITIONS AND BEGIN MOTIONS IF CONDITIONS ARE SATISFIED
     IF(_LRX=0); IF((_BGX=0)&(jgspx>0)); BGX; bgx=_BGX; ENDIF
     ELSE; IF(_LFX=0); IF((_BGX=0)&(jgspx<0)); BGX; bgx=_BGX; ENDIF
     ELSE; IF(_BGX=0); BGX; bgx=_BGX; ENDIF; ENDIF; ENDIF; jsxyl=jgspx
REM  IF Y IS ENABLED, SET MEASURED JOG VALUE TO AXIS
    ELSE; IF(jog=2); STX; jogl=jog; jyp=@RND[((_RPY)/axis_uty)*10000]/10000
     IF(_BGY=0); jipy=jyp; jrcpypl=0; ENDIF; jrcpy=jyp-jipy
     jrcpyp=@RND[jrcpy*8*1000/360]*45/1000; scaly=@RND[jrcpyp*8/360]*45
     IF((jrcpyp>=scaly)&(jrcpypl<scaly))|((jrcpyp<=scaly)&(jrcpypl>scaly))
      MG"- Y MOVED",scaly{Z4.2}," DEGS -"; MG; jypl=jyp; jrcpypl=jrcpyp
     ENDIF; jgspy=jsxy*ratioy*jogsy; JGY=jgspy*axis_uty
REM  DISPLAY JOG SPEED TO USER
     IF(jgspy<>jsxyl); MG"- Y JOG SPEED",jgspy{Z2.2},"DEG/S -"; MG; ENDIF
REM  CHECK BOUNDARY CONDITIONS AND BEGIN MOTIONS IF CONDITIONS ARE SATISFIED
     IF((_LFY=1)&(_LRY=1)); IF(_BGY=0); BGY; bgy=_BGY; ENDIF
     ELSE; MG"- Y LIMITS ENGAGED -"; MG; ENDIF; jsxyl=jgspy
    ELSE; STXY; ENDIF; ENDIF
REM  IF 1 IS PRESSED OR jog=0, EXIT JOG ROUTINE
    IF((@IN[g1]=0)|(jog<1)|(motfrzxy=1)); STXY; jogloop1=1; ENDIF
  JP#JOGLPXY,jogloop1=0; jogloop1=0; motfrzxy=1; jog=0; WT(hld)
  MG"- END JOG ROUTINE -"; MG; ll=0
EN
REM
REM  MAKE SURE MOTION IS STOPPED ON X-Y, THEN SET NEW POSITIONS TO AXIS
#MOVEXY; STXY; AMXY; PA newxpos,newypos,,; adsxl=adsx; adsyl=adsy
REM  SET ACCERLATION/DECCELERATION AND SPEED VALUES FOR X-Y
  IF(adsx>-1); ACX=padcx[adsx]; DCX=padcx[adsx]; SPX=pspx[adsx]; ENDIF
  IF(adsy>-1); ACY=padcy[adsy]; DCY=padcy[adsy]; SPY=pspy[adsy]; ENDIF
REM  MOVE X IF POSITION CHANGE IS SEEN AND AXIS IS NOT RESTRICTED BY LIMIT
REM  IF AT LIMIT, ENSURE DIRECTION IS OPPOSITE THE CURRENT ACTIVE LIMIT
  IF((newxpos<>_RPX)&(_BGX=0)&(_CN0=1)); IF(_CN0=-1); CN1; ENDIF
    IF(_LFX=0)
     IF(newxpos<_RPX); BGX; ELSE; MG"- X AT LIMIT -"; MG; ENDIF
    ELSE; IF(_LRX=0)
     IF(newxpos>_RPX); BGX; ELSE; MG"- MUST RESET X -"; ENDIF
    ELSE; BGX; ENDIF; ENDIF; IF(_BGX=1); bgx=_BGX; ENDIF
  ENDIF
REM  MOVE X IF POSITION CHANGE IS SEEN AND AXIS IS NOT RESTRICTED BY LIMIT
  IF((newypos<>_RPY)&(_BGY=0))
    IF(((_LRY+_LFY)=2)|(_CN0=-1)); BGY; bgy=_BGY
    ELSE
     MG"- Y LIMITS ENGAGED, RAISE Z -"; MG; motfrzxy=1; psot=sidel
    ENDIF
  ENDIF
REM  SAVE INITIAL ACC/DCC/SPD VALUES INCASE ADJUSTMENTS ARE MADE
```

```
 xsp=_SPX; xac=_ACX; xdc=_DCX; ysp=_SPY; yac=_ACY; ydc=_DCY; AIs0
REM  ENTER MOVING LOOP WHICH RUNS THE ENTIRE TIME EITHER X-Y IS MOVING
 #PAUSTXY; movexy=_BGX+_BGY
REM  ACC/DCC/SPD VALUES ARE CHANGED-PAUSE MOVEMENT AND REASSIGN VALUES
  IF((adsxl<>adsx)|(adsyl<>adsy)); JP#MOVEXY; ENDIF
REM  IF ACC/DCC/SPD VALUES ARE ACCIDENTALLY SET TO ZERO, SET TO NON-ZERO
  IF(((_SPX=0)|(_ACX=0)|(_DCX=0))&(_BGX=1)); adsx=2; ENDIF
  IF(((_SPY=0)|(_ACY=0)|(_DCY=0))&(_BGY=1)); adsy=2; ENDIF
REM  IF X-Y FREEZE WAS ENABLED OR JOG WAS SET TO 1OR2, STOP MOTION AND EXIT
  IF((motfrzxy=1)|(jog=1)|(jog=2)); movexy=0; ENDIF
REM  IF STOP BUTTON PUSHED, PAUSE MOTION UNTIL GO BUTTON PUSHED
  IF((@IN[s0]=0)&(ncs=0)&(movexy>0)&(monitor=0)); STXY; AMXY; WT(hld/2)
   IF(motfrzxy=0); MG"- PRESS 1 TO RESUME MOTION -"; MG; ENDIF
   #FREZXY; IF((motfrzxy=1)|(@IN[g1]=0)); frezlpxy=1; ENDIF
   JP#FREZXY,frezlpxy=0; frezlpxy=0; JP#MOVLPXY
  ENDIF
REM  IF STOP IS PUSHED AND MACHINE IS SPRAYING CPS, PAUSE CURRENT MOTION
  IF((@IN[s0]=0)&(@IN[g1]=1)&(movexy>0)&(ncs=1)); motfrzxy=1; ENDIF
REM  IF GO IS PUSHED FOR MORE THAN 62ms, MAXIMIZE ACC/SPD
  IF((@IN[g1]=0)&(txy=0)&(movexy>0)); txy=TIME+(hld/8); ENDIF
  IF((@IN[g1]=1)&(txy>0)); txy=0; ENDIF
  IF(@IN[g1]=0)&(@IN[s0]=1)&(movexy>0)&(motfrzxy=0)&(TIME>txy)&(monitor=0)
   ACX=padcx[7]; SPX=pspx[7]; ACY=padcy[7]; SPY=pspy[7]
REM  IF GO IS NOT PUSHED LEAVE ACC/DCC/SPD VALUES AS THEY WERE
  ELSE; ACX=xac; SPX=xsp; ACY=yac; SPY=ysp; ENDIF
 JP#PAUSTXY,movexy>0
EN
REM
REM  ROUTINE TO DETERMINE WHAT PADDLE SIDE IS ON TOP AND WHERE TO MOVE IT
#SETSIDE
REM  MEASURE CURRENT Y-AXIS IN DEGREES AND TRASFORM TO xy COORDINATES
 cpy=@RND[(_RPY/axis_uty)*10000]/10000
 ysr=@RND[@SIN[cpy+(90*psoti)]*10000]/10000
 ycr=@RND[@COS[cpy+(90*psoti)]*10000]/10000
REM  CALCULATE CURRENT ANGLE W.R.T. ZERO ANGLE
 IF(ycr<-0.7071); actside=180-(@RND[@ASIN[ysr]*100]/100)
 ELSE; IF((ycr>=-0.7071)&(ycr<0))
  IF(ysr>=0); actside=180-(@RND[@ACOS[ycr]*100]/100)
  ELSE; actside=180+(@RND[@ACOS[ycr]*100]/100); ENDIF
 ELSE; IF((ycr>=0)&(ycr<0.7071))
  IF(ysr>=0); actside=@RND[@ACOS[ycr]*100]/100
  ELSE; actside=360-(@RND[@ACOS[ycr]*100]/100); ENDIF
 ELSE; IF(ycr>=0.7071); actside=@RND[@ASIN[ysr]*100]/100
  IF(actside<0); actside=360+actside; ENDIF
 ENDIF; ENDIF; ENDIF; ENDIF
REM DETERMINE DESIRED xy COORDINATES DEPENDING ON VALUE OF psot
 IF(psot=5); psot=1; ENDIF; IF(psot=0); psot=4; ENDIF
 IF(psot=1); dysr=1; dycr=0; ELSE; IF(psot=2); dysr=0; dycr=-1
 ELSE; IF(psot=3); dysr=-1; dycr=0; ELSE; IF(psot=4); dysr=0; dycr=1
 ELSE; IF(psot=-1); dysr=ysr; dycr=ycr
 ELSE; MG"- INVALID SIDE, MUST BE # 1-4 -"; MG; psot=sidel
```

```
 ENDIF; ENDIF; ENDIF; ENDIF; ENDIF
REM  CALCULATE DESIRED ANGLE W.R.T. ZERO ANGLE
 IF(dycr<-0.7071); desside=180-(@RND[@ASIN[dysr]*100]/100)
 ELSE; IF((dycr>=-0.7071)&(dycr<0))
  IF(dysr>=0); desside=180-(@RND[@ACOS[dycr]*100]/100)
  ELSE; desside=180+(@RND[@ACOS[ycr]*100]/100); ENDIF
 ELSE; IF((dycr>=0)&(dycr<0.7071))
  IF(dysr>=0); desside=@RND[@ACOS[dycr]*100]/100
  ELSE; desside=360-(@RND[@ACOS[dycr]*100]/100); ENDIF
 ELSE; IF(dycr>=0.7071); desside=@RND[@ASIN[dysr]*100]/100
  IF(desside<0); desside=360+desside; ENDIF
 ENDIF; ENDIF; ENDIF; ENDIF
REM  SET DIFFERENCE BETWEEN DESIRED-CURRENT ANGLE TO pry
REM  DEPENDING ON ANGLE VALUES, CHOOSE SHORTEST PATH TO DESIRED LOCATION
 IF(desside<=0); desside=360+desside; ENDIF
 IF(actside<=0); actside=360+actside; ENDIF
 IF(@ABS[desside-actside]<=180); pry=(desside-actside)
 ELSE; IF(desside-actside>0); pry=(360-(desside-actside))
 ELSE; IF(desside-actside<0); pry=(360+(desside-actside))
 ENDIF; ENDIF; ENDIF
EN
REM
```

Thread 4: Controls The Z & W Axis Motions And Jogs

```
REM
REM  THIS ROUTINE IS ALWAYS CHECKING FOR CHANGES IN Z&W STAGE POSITIONS
#MOVLPZW; IF(motfrzzw=1); JS#ERMOTZW; ENDIF
REM  ALLOW USER TO ENTER NUMBER OF REVOLUTIONS IF SO DESIRED
 IF(revw<>0); IF(@ABS[revw]>500); revw=500*(revw/@ABS[revw]); ENDIF
  prw=revw*360; revw=0
 ENDIF
REM  IF RELATIVE POSITION IS ADJUSTED FOR EITHER AXIS, CONVERT RELATIVE
REM  POSITION TO THE ABOSLUTE SCALE
 IF(prz<>0)
  IF(@ABS[prz]>@ABS[zll]); prz=@ABS[zll]*(prz/@ABS[prz]); ENDIF
  prz=@RND[prz*10000]/10000
  paz=prz+(@RND[((_RPZ-homez)/axis_utz)*10000]/10000); przl=prz; prz=0
 ENDIF
 IF(prw<>0); IF(@ABS[prw]>180000); prw=180000*(prw/@ABS[prw]); ENDIF
  prw=@RND[prw*100]/100
  paw=prw+(@RND[(_RPW/axis_utw)*10000]/10000); prwl=prw; prw=0
 ENDIF
REM  APPLY Z-STAGE LIMITATIONS TO AVOID ACCIDENTAL COLLISIONS
 IF((paxl<lkfe)&(paz<zllh)); paz=zllh; ENDIF
 IF((paxl>lkfe)&(paz<zll)); paz=zll; ENDIF
 IF((ysr<>1)&(ysr<>-1)&(ycr<>1)&(ycr<>-1)&(paz<pazl)); paz=pazl
  MG"- PADDLE MUST BE FLAT FOR Z TO MOVE -"; MG
 ENDIF
```

```
REM  BOTH STAGES CAN BE RESET TO POWER ON CONDITION IF NEEDED
 IF(resetzw=1); MG"- RESET W & Z -"; MG; paw=0; paz=0; resetzw=0; ENDIF
REM  IF JOG ROUTINE IS NOT ENABLED, CHECK TO SEE IF POSITIONS HAVE CHANGED
 IF((jog<>3&(jog<>4)); IF(paz>0); paz=0; ENDIF
REM  ROUND ADJUSTED POSITION CHANGES TO PRESET DECIMAL VALUES
   paw=@RND[paw*10000]/10000; paz=@RND[paz*10000]/10000
REM  SET NEW ABSOLUTE STAGE POSITIONS
   newwpos=@RND[axis_utw*paw]; newzpos=@RND[homez+(axis_utz*paz)]
   IF((newwpos<>_RPW)|(newzpos<>_RPZ)); axiszw=axiszw+1
REM  CYCLE LOOP TWICE INCASE TWO COMMANDS ARE GIVEN SIMULTANEOUSLY
     IF(axiszw>1); JS#MOVEZW; axiszw=0; ENDIF
   ENDIF
REM  IF JOG IS ENABLED, COUNTINE TO JOG ROUTINE
 ELSE; IF((jog=3)|(jog=4)); JS#JOGZW; ENDIF; ENDIF
REM  IF EITHER STAGE WAS MOVED, DETERMINE CURRENT POSITIONS
 IF((bgz=1)|(bgw=1)); JS#CPZW; ENDIF
JP#MOVLPZW
REM
REM  DETERMINE CURRENT ABSOLUTE POSITION FOR Z-W
#CPZW
 cpz=@RND[((_RPZ-homez)/axis_utz)*10000]/10000; pazl=cpz
 cpw=@RND[(_RPW/axis_utw)*10000]/10000; rcpw=cpw-pawl; pawl=cpw
REM  CONVERT RELATIVE W-ANGULAR DISTANCE TO REVOLUTIONS
 revwm=@RND[rcpw*1000/360]/1000
REM  IF Z WAS MOVING, OUTPUT NEW ABSOLUTE Z-POS
 IF(bgz=1); MG"- Z IS",cpz{Z1.4}," IN FROM HOME -"; MG; bgz=0; ENDIF
REM  IF W WAS MOVING, OUTPUT DISTANCE IN ROTATIONS W HAS MOVED
 IF(bgw=1); MG"- W ROTATED",revwm{Z3.3}, " REVS -"; MG; bgw=0; ENDIF
 amholdzw=0
EN
REM
REM  IF motfrzzw=1, SET CURRENT Z-W POSITION TO THE DESIRED POSITION
#ERMOTZW; motfrzzw=0; axiszw=0; jog=0; paw=@RND[(_RPW/axis_utw)*10000]/10000
 paz=@RND[((_RPZ-homez)/axis_utz)*10000]/10000
EN
REM
REM  THIS ROUTINE ALLOWS THE USER TO MANUALLY ADJUST STAGE POSITONS WITH POT
#JOGZW; jogloop2=0; jszwl=0; STZW; AMZW; adzl=adz; adwl=adw
REM  CHECK WHICH AXIS TO JOG AND APPLY ACC.DEC VALUES TO MOTION
 IF(jog=3)
   IF(bgy=1); MG"- CANNOT JOG Z WHILE Y IS MOVING -"; MG; jog=0; ENDIF
 ELSE; MG"- Z JOG ROUTINE -"; ACZ=padcz[adz]; DCZ=padcz[adz]; ENDIF
 IF(jog=4)
   MG"- W JOG ROUTINE -"; ACW=padcw[adw]; DCW=padcw[adw]
 ENDIF
REM  PROVIDE DIRECTIONS TO THE USER TO USE THE JOGGING ROUTINE
 MG"- ADJUST JOG SPEED/DIRECTION WITH POT -"; MG"- POT L = -SPEED -"
 MG"- POT MID = 0 SPEED -"; MG"- POT R = +SPEED -"
 MG"- PRESS 1 WHEN FINISHED -"; MG; WT(hld)
REM  BEGIN JOG LOOP TO MONTIOR THE CHANGES MADE BY THE USER
 #JOGLPZW; IF((jog<>2)&(_CN0=-1)); CN1; ENDIF
```

```
REM  IF USER CHANGES ACC?DEC VALUES< RESTART ROUTINE
   IF((adzl<>adz)|(adwl<>adw)); JP#JOGZW; ENDIF
REM  CHECK ANALOG POT VALUE AND TRANSLATE TO 0-1 SCALE WITH POS/NEG DIRECTION
   jszw=(@RND[20*((@AN[jgpot]-2.5)/2.5)]/20)
REM  IF Z IS ENABLED, SET MEASURED JOG VALUE TO AXIS
REM  IF Z IS CLOSE TO EITHER EDGE, FIRST SLOW DOWN JOG, STOP IF AT LIMIT
   IF(jog=3); STW; jogl=jog
    jzp=@RND[((_RPZ-homez)/axis_utz)*10000]/10000; scalz=@RND[jzp*10]/10
    IF((jzp>=scalz)&(jzpl<scalz))|((jzp<=scalz)&(jzpl>scalz))
     MG"- Z IS",scalz{Z2.4}," IN FROM HOME -"; MG; jzpl=jzp
    ENDIF
    IF((jzp>=-0.1)&(jzp<0)&(jszw>0))|((jzp<=(zll+0.1))&(jzp>zll)&(jszw<0))
     jgspz=(jszw*ratioz*jogsz)/3; JGZ=jgspz*axis_utz
    ELSE; IF((jzp>=0)&(jszw>0))|((jzp<=zll)&(jszw<0))
     jgspz=0; JGZ=jgspz*axis_utz; STZ
    ELSE; jgspz=jszw*ratioz*jogsz; JGZ=jgspz*axis_utz; ENDIF; ENDIF
REM  DISPLAY JOG SPEED TO USER
    IF(jgspz<>jszwl); MG"- Z JOG SPEED",jgspz{Z2.2}," IN/S -"; MG; ENDIF
REM  CHECK BOUNDARY CONDITIONS AND BEGIN MOTIONS IF CONDITIONS ARE SATISFIED
    IF(_LRZ=0); IF((_BGZ=0)&(jgspz>0)); BGZ; bgz=_BGZ; ENDIF
    ELSE; IF(_LFZ=0); IF((_BGZ=0)&(jgspz<0)); BGZ; bgz=_BGZ; ENDIF
    ELSE; IF(_BGZ=0); BGZ; bgz=_BGZ; ENDIF; ENDIF; ENDIF; jszwl=jgspz
REM  IF W IS ENABLED, SET MEASURED JOG VALUE TO AXIS
   ELSE; IF(jog=4); STZ; jogl=jog; jwp=@RND[((_RPW)/axis_utw)*10000]/10000
    IF(_BGW=0); jipw=jwp; jrevwml=0; ENDIF; jrcpw=jwp-jipw
    jrevwm=@RND[jrcpw*1000/360]/1000; scalw=@RND[jrevwm]
    IF((jrevwm>=scalw)&(jrevwml<scalw))|((jrevwm<=scalw)&(jrevwml>scalw))
     MG"- W ROTATED",scalw{Z3.3}, " REVS -"; MG; jwpl=jwp; jrevwml=jrevwm
    ENDIF; jgspw=jszw*ratiow*jogsw; JGW=jgspw*axis_utw
REM  DISPLAY JOG SPEED TO USER
    IF(jgspw<>jszwl); MG"- W JOG SPEED",jgspw{Z3.2}," DEG/S -"; MG; ENDIF
REM  CHECK BOUNDARY CONDITIONS AND BEGIN MOTIONS IF CONDITIONS ARE SATISFIED
    IF((_LRW=1)&(_LRW=1)); IF(_BGW=0); BGW; bgw=_BGW; jip=_RPW; ENDIF
    ELSE; MG"- W LIMITS ENGAGED -"; MG; ENDIF; jszwl=jgspw
   ELSE; STZW; ENDIF; ENDIF
REM  IF 1 IS PRESSED OR jog=0, EXIT JOG ROUTINE
   IF((@IN[g1]=0)|(jog<1)|(motfrzzw=1)); STZW; jogloop2=1; ENDIF
  JP#JOGLPZW,jogloop2=0; jogloop2=0; motfrzzw=1; jog=0; WT(hld)
  MG"- END JOG ROUTINE -"; MG
EN
REM
REM  THIS ROUTINE SETS THE FINAL POSITIONS, ACC/DEC RATES FOR THE Z&W AXIS
#MOVEZW; STZW; AMZW; PA ,,newzpos,newwpos; adszl=adsz; adswl=adsw
  IF(adsw>-1); ACW=padcw[adsw]; DCW=padcw[adsw]; SPW=pspw[adsw]; ENDIF
  IF(adsz>-1); ACZ=padcz[adsz]; DCZ=padcz[adsz]; SPZ=pspz[adsz]; ENDIF
REM  CHECK TO ENSURE W-LIMITS ARE NOT ENGAGED AND BEGIN MOTION
  IF((newwpos<>_RPW)&(_BGW=0)&(_CN0=1))
   IF((_LRW+_LFW)=2); BGW; bgw=_BGW
   ELSE; MG"- W LIMITS ENGAGED -"; MG; ENDIF
  ENDIF
REM  CHECK TO ENSURE Z-LIMITS ARE NOT ENGAGED AND BEGIN MOTION
```

```
  IF((newzpos<>_RPZ)&(_BGZ=0)&(_CN0=1))
    IF(_LRZ=0); IF(newzpos>_RPZ); BGZ; ELSE; MG"- Z AT LIMIT -"; MG; ENDIF
    ELSE; IF(_LFZ=0); IF(newzpos<_RPZ); BGZ; ELSE; MG"- RESET Z -"; ENDIF
    ELSE; BGZ; ENDIF; ENDIF; IF(_BGZ=1); bgz=_BGZ; ENDIF
  ENDIF
REM  TEMPORAILIY STORE THE ACC/DEC RATES FOR BOTH STAGES
  zsp=_SPZ; zac=_ACZ; zdc=_DCZ; wsp=_SPW; wac=_ACW; wsp=_DCW; AIs0
REM  BEGIN MOTION LOOP AND CHECK WHICH STAGE(S) ARE MOVING
  #PAUSTZW; movezw = _BGZ+_BGW
REM  IF EMERGENCY STOP IS ENABLED FOR Z-W, STOP MOTION AND EXIT LOOP
    IF((jog=3)|(jog=4)|(motfrzzw=1)); movezw=0; ENDIF
REM  CHECK IF ACC/DEC RATES ARE CHANGED DURING MOTION
    IF((adszl<>adsz)|(adswl<>adsw)); JP#MOVEZW; ENDIF
REM  MAKE SURE STAGES SPEEDS ARE NOT ZERO TO AVOID ERROR
    IF((_SPZ=0)&(_BGZ=1)); adsz=2; ENDIF
    IF((_SPW=0)&(_BGW=1)); adsw=2; ENDIF
REM  IF THE STOP BUTTON IS ENABLED, PAUSE MOTION FOR BOTH STAGE(S)
    IF((@IN[s0]=0)&(ncs=0)&(movezw>0)&(monitor=0)); STZW; AMZW; WT(hld/2)
REM  TELL USER TO PRESS 1 TO RESUME THE CURRENT MOTION / ACTION
      IF(motfrzzw=0); MG"- PRESS 1 TO RESUME MOTION -"; MG; ENDIF
      #FREZZW; IF((motfrzzw=1)|(@IN[g1]=0)); frezlpzw=1; ENDIF
      JP#FREZZW,frezlpzw=0; frezlpzw=0; JP#MOVLPZW
    ENDIF
REM  IF EXECUTING THE ELECTRODING STEP, STOP ACTION WHEN 0 IS PRESSED
    IF((@IN[s0]=0)&(@IN[g1]=1)&(movezw>0)&(ncs=1)); motfrzzw=1; ENDIF
REM  HOLD 1 FOR A SHORT TIME THEN ACCELERATE THE STAGE(S)
    IF((@IN[g1]=0)&(tzw=0)&(movezw>0)); tzw=TIME+(hld/8); ENDIF
    IF(@IN[g1]=0)&(@IN[s0]=1)&(movezw>0)&(motfrzzw=0)&(TIME>tzw)&(monitor=0)
      ACZ=padcz[7]; SPZ=pspz[7]; ACW=padcw[7]; SPW=pspw[7]
REM  IF 1 IS NOT PRESSED, RESUME MOTION AT PRESET VALUES (DEFAULT)
    ELSE; ACZ=zac; SPZ=zsp; ACW=wac; SPW=wsp; ENDIF
REM  RESET TIMER IF 1 IS RELEASED
    IF((@IN[g1]=1)&(tzw>0)); tzw=0; ENDIF
  JP#PAUSTZW,movezw>0
EN
REM
```

Thread 5: Controls I/O Function

```
REM**************************************************************************
REM  THREAD 5;  THIS CONTROLS I/O FUNCTION
REM**************************************************************************
REM
#IOLOOP; v[0]=@OUT[v1o]+@OUT[v2o]+@OUT[v3o]+@OUT[v4o]
```

```
REM  IF alloff=1, TURN OFF ALL OUTPUT PORTS EXCEPT FOR OVEN CONTROL
 IF(alloff=1); MG"- BITS CLEARED -"; MG; alloff=0; fk=0; wm=0; cf=0
  fv=0; lr=0; ncs=0; v[1]=0; v[2]=0; v[3]=0; v[4]=0; ll=0
 ENDIF
REM  CONSTANTLY CHECK AND ADJUST FOR CHANGES IN ALL ACCESORY CONDITIONS
 IF(cf<>@OUT[fano]); JS#FANCNTL; iohold0=0; nozhold6=0; ENDIF
 IF(fk<>@OUT[kio]); JS#KNFCNTL; iohold0=0; ENDIF
 IF(wm<>@OUT[mago]); JS#MAGCNTL; iohold0=0; ENDIF
 IF(ll<>@OUT[las]); JS#LASCNTL; iohold0=0; ENDIF
 IF(fv<>@OUT[fvo]); JS#HILOVAC; iohold0=0; ENDIF
 IF((lr<>oldlr)); oldlr=lr; JS#LMRLLVL; iohold0=0; ENDIF
 IF((v[1]=1)&(@OUT[v1o]=0))
  MG"- SIDE 1 VAC ON -"; MG; SBv1o; WT(hld/4); iohold0=0
 ENDIF
 IF((v[1]<>1)&(@OUT[v1o]=1)); v[1]=0
  MG"- SIDE 1 VAC OFF -"; MG; CBv1o; WT(hld/4); iohold0=0
 ENDIF
 IF((v[2]=1)&(@OUT[v2o]=0))
  MG"- SIDE 2 VAC ON -"; MG; SBv2o; WT(hld/4); iohold0=0
 ENDIF
 IF((v[2]<>1)&(@OUT[v2o]=1)); v[2]=0
  MG"- SIDE 2 VAC OFF -"; MG; CBv2o; WT(hld/4); iohold0=0
 ENDIF
 IF((v[3]=1)&(@OUT[v3o]=0))
  MG"- SIDE 3 VAC ON -"; MG; SBv3o; WT(hld/4); iohold0=0
 ENDIF
 IF((v[3]<>1)&(@OUT[v3o]=1)); v[3]=0
  MG"- SIDE 3 VAC OFF -"; MG; CBv3o; WT(hld/4); iohold0=0
 ENDIF
 IF((v[4]=1)&(@OUT[v4o]=0))
  MG"- SIDE 4 VAC ON -"; MG; SBv4o; WT(hld/4); iohold0=0
 ENDIF
 IF((v[4]<>1)&(@OUT[v4o]=1)); v[4]=0
  MG"- SIDE 4 VAC OFF -"; MG; CBv4o; WT(hld/4); iohold0=0
 ENDIF
 IF((iohold0=1)&(iotmout=0)); iotmout=TIME+hld/4; ENDIF
 IF((iohold0=1)&(iotmout<TIME)); iohold0=0; iotmout=0; ENDIF
JP#IOLOOP
REM
REM  ENABLE/DISENABLE COOLING FAN, AND DISPLAY STATUS
#FANCNTL; IF(cf=1); MG"- FAN ON -"; MG; SBfano; WT(soatstwt)
 ELSE; cf=0; MG"- FAN OFF -"; MG; CBfano; WT(soatstwt); ENDIF
EN
REM
REM  ENABLE/DISENABLE HIGH VACUUM, AND DISPLAY STATUS
#HILOVAC; IF(fv=1); SBfvo; MG"- VAC LEVEL IS HIGH -"; MG; WT(hld/4)
 ELSE; fv=0; CBfvo; MG"- VAC LEVEL IS LOW -"; MG; WT(hld/4); ENDIF
EN
REM
REM  ENABLE/DISENABLE FOR FILM KNIFE, AND DISPLAY STATUS
#KNFCNTL; IF(fk=1); MG"- KNIVES ON! -"; MG; CBkoo; WT(25); SBkio; WT(50)
```

```
  ELSE; fk=0; MG"- KNIVES OFF -"; MG; CBkio; SBkoo; WT(250); CBkoo; ENDIF
EN
REM
REM  ENABLE/DISENABLE FOR LASER LINE, AND DISPLAY STATUS
#LASCNTL; IF(ll=1); SBlas; MG"- LASER ON! -"; MG; WT(hld/4)
  ELSE; ll=0; CBlas; MG"- LASER OFF -"; MG; WT(hld/4); ENDIF
EN
REM
REM  SET LAMINATION ROLL LEVEL, AND DISPLAY STATUS
#LMRLLVL; times=times+1; MG"- LAMINATION ROLL AT LEVEL =",lr{Z1.0}," -"; MG
  IF(lr=1); CBlamo2; SBlamo1; ELSE; IF(lr=2); CBlamo1; SBlamo2
  ELSE; IF(lr=3); SBlamo1; SBlamo2; ELSE; lr=0; CBlamo1; CBlamo2
  ENDIF; ENDIF; ENDIF; WT(hld/4)
EN
REM
REM  ENABLE/DISENABLE FOR WEIGHT MAGNET, AND DISPLAY STATUS
#MAGCNTL; IF(wm=1); SBmago; MG"- MAGNET ON -"; MG; WT(hld)
  ELSE; wm=0; CBmago; MG"- MAGENT OFF -"; MG; WT(hld*2); ENDIF
EN
REM
```

Thread 6: Monitors and Controls Nozzle And Syringe Outputs

```
REM***************************************************************************
REM  THREAD 6;  THIS MONITORS AND CONTROLS NOZZLE AND SYRINGE OUTPUTS
REM***************************************************************************
REM
#NOZSAFE
REM  IF ncs IS SET TO 1, ENABLE NOZZLE MONITORING SYSTEM
  IF(ncs=1); JS#NOZON; noztime=TIME; nozlop1=0; AIg1; AIs0
    MG"- PRESS 1 TO SPRAY LONGER -"; MG"- PRESS 0 TO FINISH-"; MG; WT(hld)
    #NOZLOP1; IF(ncs=0); endspr=0; nozlop1=1; JP#NOZSAFE; ENDIF
REM  IF go IS PRESSED WHEN RUNNING, RESET NOZZLE TIMEOUT
      IF((@IN[g1]=0)&(@IN[s0]=1)); ncs=1; noztime=TIME; ENDIF
REM  IF stop IS PRESSED, TELL THREAD 0 TO RESPOSITION STAGE, THEN DISENAGE
      IF((@IN[s0]=0)&(@IN[g1]=1)); MG"- NOZZLE STOPPED -"; MG; endspr=1
        IF(xpass>0); motfrzxy=1; JS#NOZHOLD; nozlop1=1
        ELSE; ncs=0; nozlop1=1; ENDIF
      ENDIF
REM  PROVIDE NOZZLE TIMEOUT TO AVOID DAMAGE IF LEFT UNATTENDED
      IF((TIME>(noztime+maxtspr))&(nozlop1=0))
        MG"- NOZZLE TIMED OUT -"; MG; endspr=1
        IF(xpass>0); motfrzxy=1; JS#NOZHOLD; nozlop1=1
        ELSE; JS#NOZOFF; nozlop2=0; AIg1; AIs0
          MG"- NOZZLE TIMED OUT -"; MG"- PRESS 1 TO CONTINUE SPRAYING -"
          MG"- PRESS 0 TO EXIT -"; MG; WT(hld)
REM  ASK USER TO EITHER RESTART NOZZLE OR TO EXIT ROUTINE
          #NOZLOP2; IF(ncs=0); nozlop2=1; ENDIF
            IF((@IN[g1]=0)&(@IN[s0]=1)); nozlop2=1; JS#NOZON; ENDIF
```

```
      IF((@IN[s0]=0)&(@IN[g1]=1)); nozlop1=1; endspr=1; ncs=0; ENDIF
     JP#NOZLOP2,(nozlop2=0)&(nozlop1=0); noztime=TIME; WT(hld)
    ENDIF
   ENDIF
  JP#NOZLOP1,nozlop1=0; nozlop1=0; nozlop2=0
 ELSE; JS#NOZOFF; endspr=0; ENDIF
 IF((sprhold0=1)&(sprtmout=0)); sprtmout=TIME+hld/4; ENDIF
 IF((sprhold0=1)&(sprtmout<TIME)); sprhold0=0; sprtmout=0; ENDIF
JP#NOZSAFE
REM
REM  DISENGAGE SONICE ATOMIZER AND SYRINGE PUMP WHEN ROUTINE OPENED
#NOZOFF; IF((@OUT[spo]=1)|(@OUT[sao]=0))
 MG"- SYRINGE PUMP OFF -"; MG"- SONIC ATOMIZER OFF -"; MG
 CBspo; WT(sypuspwt); SBsao; cf=0; JS#NOZHOLD; sprhold0=0; ENDIF
EN
REM
REM  ENABLE SONICE ATOMIZER AND SYRINGE PUMP WHEN OPENED
#NOZON; IF((@OUT[sao]=1)|(@OUT[spo]=0)); cf=1; JS#NOZHOLD
 MG"- SONIC ATOMIZER ON -"; MG"- SYRINGE PUMP ON -"; MG
 CBsao; WT(soatstwt); SBspo; WT(sypustwt); sprhold0=0; ENDIF
EN
REM
REM  PROVIDE WAIT ROUTINE FOR THREAD 0 TO REPOSITION STAGES
#NOZHOLD; nozhold6=1; noztmout=TIME+900000
 #NOZHDLP; JP#NOZHDLP, ((nozhold6=1)&(noztmout>TIME)&(xpass>0))
EN
REM
```

Thread 7: Monitors Oven Temperature

```
REM***************************************************************************
REM  THREAD 7;  THIS MONITORS OVEN TEMPERATURE
REM***************************************************************************
REM
#HEATMON
REM  CHECK AD594 FOR CURRENT SIGNAL
 IF((@IN[hs]=0)|(hcs=1)); curtemp=(@RND[(@AN[tcai]*1000)]/10)+tempoff
  IF(@OUT[heo]=1); curtemp=curtemp+heatnois; ENDIF
REM  TELL USER CONTROL IS ON AND OUTPUT FIRST TEMP VALUE
  IF(heatcond=0); MG"- HEAT CONTROL ON -"; MG; heatcond=1
   heattime=TIME; MG"- HEAT TEMP IS",curtemp{Z3.1},"C -"; MG
  ENDIF
REM  COLLECT DATA POINTS AND COMPUTE AVERAGE TO AVOID NOISE
  IF(oc=0); avgtemp=curtemp; ELSE; avgtemp=avgtemp+curtemp; ENDIF
  IF(oc=(numtoavg-1)); avgtemp=avgtemp/numtoavg; oc=0
REM  ENGAGE / DISENGAGE OVEN TO REACH DESIRED TEMP
   IF(avgtemp<=(settemp-(temprang*(1-kt)))); JS#HEATON; ENDIF
   IF(avgtemp>=(settemp+(temprang*kt))); JS#HEATOFF; ENDIF
   IF(TIME>(heattime+tempdisp)); heattime=TIME
```

```
     MG"- HEAT TEMP IS",avgtemp{Z3.1},"C -"; MG
    ENDIF
   ELSE; oc=oc+1; ENDIF
REM  IF SWITCH IS OFF, SHUT OFF OVEN CONTROL AND TELL USER
  ELSE; IF(((@IN[hs]=1)|(hcs<>1))&(heatcond=1)); heatcond=0; oc=0
   hcs=0; MG"- HEAT CONTROL OFF -"; MG; JS#HEATOFF
  ENDIF; ENDIF
JP#HEATMON
REM
REM ENABLE / DISALBE HEAT ELEMENT
#HEATOFF; IF(@OUT[heo]=1); CBheo; ENDIF; EN
#HEATON; IF(@OUT[heo]=0); SBheo; ENDIF; EN
```

Thread Descriptions, Communication, Priority and Control

A-Table A-1: Thread Communication

Thread	Primary Responsibility	Priority (1-5)	Communication In	Communication Out
0	Provides Instruction for threads	2	1, 2, 3, 4, 5, 6	3, 4, 5, 6, 7
1	Emergency Pause, Stop and Resume	1	none	0, 3, 4, 6
2	Monitors power, connections and stage limits	1	none	0, 3, 4, 5
3	Controls X & Y stage positioning	3	0	0, 4
4	Controls X & Y stage positioning	3	0	0
5	Accessory output enable / disenable	4	0	0
6	Nozzle system control and monitoring	3	0	0, 3
7	Oven heat control and monitoring	5	0	none

A-Table A-2: Thread Characteristics

Thread	Command window Communication	Button Interface Communication	Direct machine execution?	Checks Machine Conditions
0	yes	yes	At Startup	yes
1	no	yes	no	no
2	no	yes	no	yes
3	yes	yes	X&Y stages	yes
4	yes	yes	Z&W stages	yes
5	yes	no	Accessories	yes
6	yes	yes	Nozzle	yes
7	yes	yes	Oven	yes

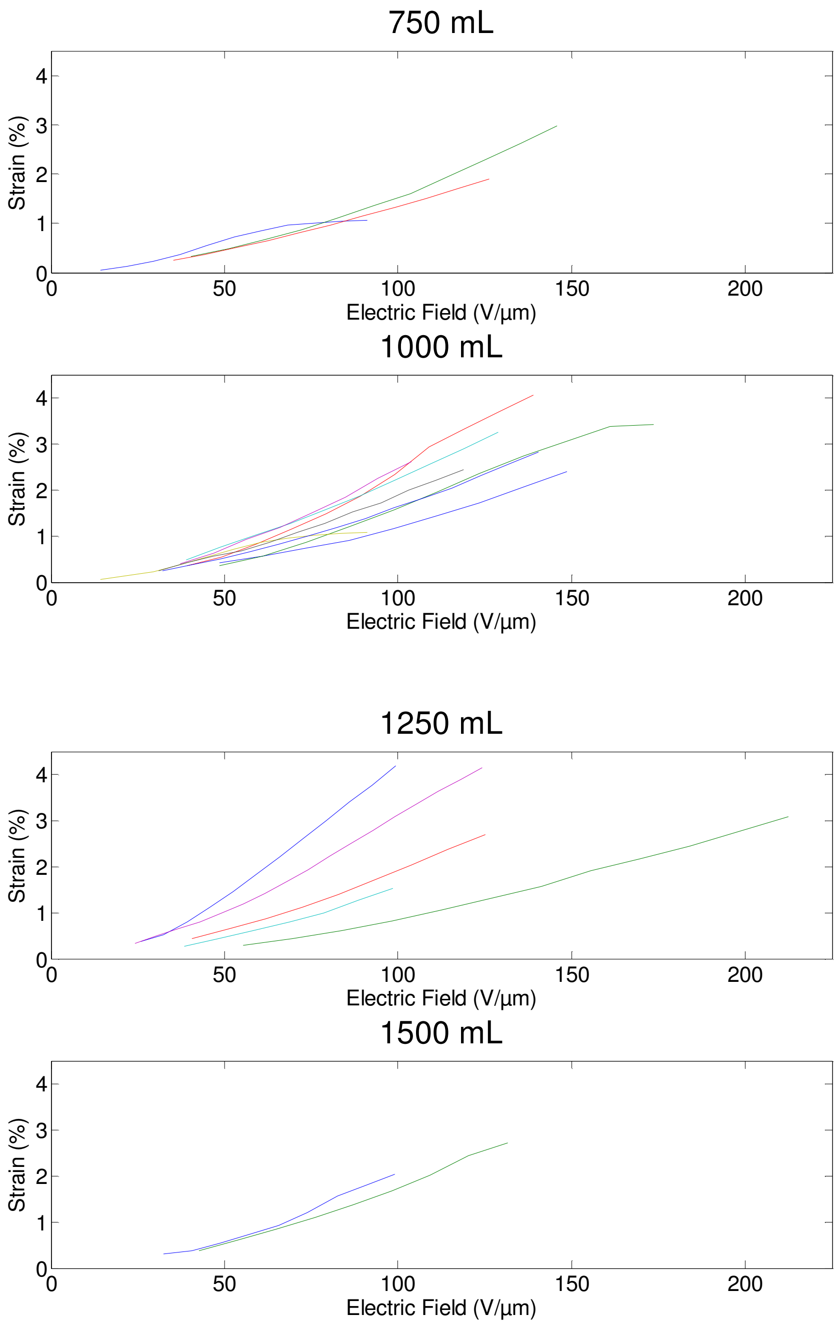
Appendix B

Basic Stamp II Code

```
' {$STAMP BS2}
' {$PBASIC 2.5}
' {$PORT COM1}
' Declare Variables
ref1    VAR Nib:  ref2    VAR Nib
duty1   VAR Byte: duty2   VAR Byte

' Repeat loop indefinitely
START

' Determine which pins are high from the DMC
' ref1 can be between 0-4
  ref1 = IN8+IN10+IN11+IN12

' ref2 can be between 0-3
  ref2 = IN15+(2*IN14)

  ' Pressure Regulator 1 (Paddle Vacuum)
  ' Set duty cycle depending on value of ref1
  SELECT ref1
    CASE 1: duty1 = 116
    CASE 2: duty1 = 160
    CASE 3: duty1 = 192
    CASE 4: duty1 = 255
    CASE ELSE: duty1 = 0
  ENDSELECT

  ' Pressure Regulator 2 (Lamination Roll)
  ' Set duty cycle depending on value of ref2
  SELECT ref2
    CASE 1: duty2 = 160
    CASE 2: duty2 = 210
    CASE 3: duty2 = 255
    CASE ELSE: duty2 = 0
  ENDSELECT

  ' If pin13 is high, set high vacuum
  IF IN13=1 THEN: duty1 = 255: ENDIF

  ' Provide PWM signal to regulators
  PWM 2, duty1, 30: PWM 4, duty2, 24

GOTO START: END
```

Appendix C

Strain Performance Based on Parameters



A-Figure C-1: Strain versus Electric Field Plotted by Electrode Thickness