KGCOE MSD Detailed Design Review

P10551: Nano-Ink Deposition System

Meeting Purpose:

1.) Project Overview

2.) Verify Customer Needs and Specifications

3.) Evaluate Chosen Concept

4.) Discuss Feasibility of Design

Meeting Date: February 12, 2010

Meeting Location: Room 09-2030

Meeting Time: 11:00am-1:00pm

Materials Reviewed:

1.) Project Overview
2.) Customer Needs and Specifications
3.) Review Concept Development
4.) Material Delivery (Drawings, BOM, Feasibility)
5.) Motion Control (Drawings, BOM, Feasibility)
6.) Curing System (Drawings, BOM, Feasibility)
7.) Risk Assessment
10.) Test Plans

FAB AMERICA

Meeting Timeline		
Start time	**Topic of Review**	**Required Attendees**
11:00	Project Overview	All
11:05	Customer Needs and Specifications	All
11:07	Review Concept Development and Selection	All
11:10	Material Delivery (Drawings, BOM, Feasibility)	All
11:35	Control System (Drawings, BOM, Feasibility)	All
11:55	Curing System (Drawings, BOM, Feasibility)	All
12:20	Risk Assessment	All
12:35	Test Plans	All

Project Description

Project Background:

3-Dimensional printing allows a user to turn a geometric drawing file into a 3-Dimensional physical model. The field of 3-Dimensional printing is fairly new and growing fast. Nano-ink depositions systems are the next stage in the game and will grant the ability to print functioning micro-scale parts (i.e. batteries, cell phones, etc.). Fab@Home is a project designed to be low cost and pave the way for nano-ink deposition systems. Currently under the Fab@Home architecture it is only possible to print a single material. A nano-ink deposition system will be capable of printing multiple materials and color similar to an inkjet printer; through the deposition of discrete droplets of color.

Problem Statement:

Demonstrate ability to print multiple materials by designing a system capable of printing a multi-color photopolymer and a base material.

Objectives/Scope:

1. Redesign Fab@Home print head to print multi-color photopolymers
2. Stay within Fab@Home spirit (~$3000 machine cost)

Core Team Members:

- Eric Hettler
- Bill Gallagher
- Greg Ryan
- Chris Mieney
- Joseph Cole

Faculty Guides:

- Denis Cormier
- Gerry Garavuso

Strategy Approach

Assumptions and Constraints:

Design will be capable of printing photopolymers (light curable polymer) in multiple colors to demonstrate the ability to print multiple materials. Apparatus must adhere to Fab@Home spirit by not costing more than approximately $1000.

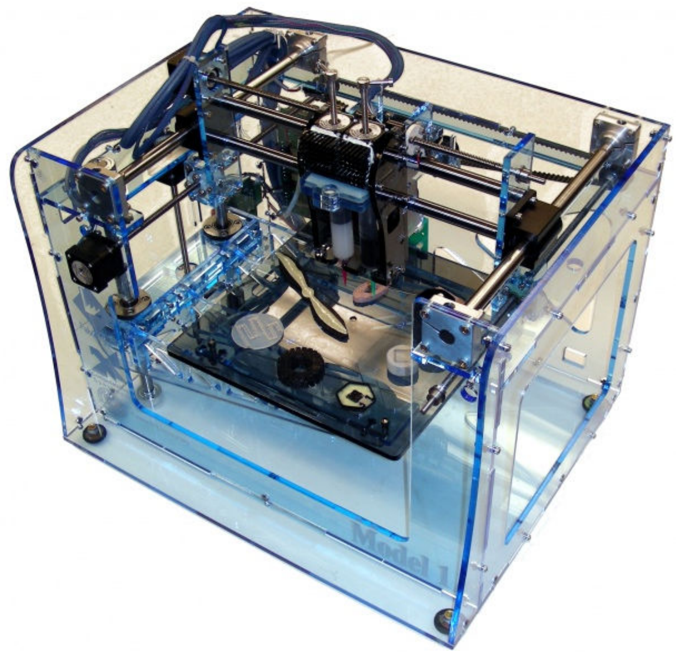


Fig 1: Current Fab@Home System

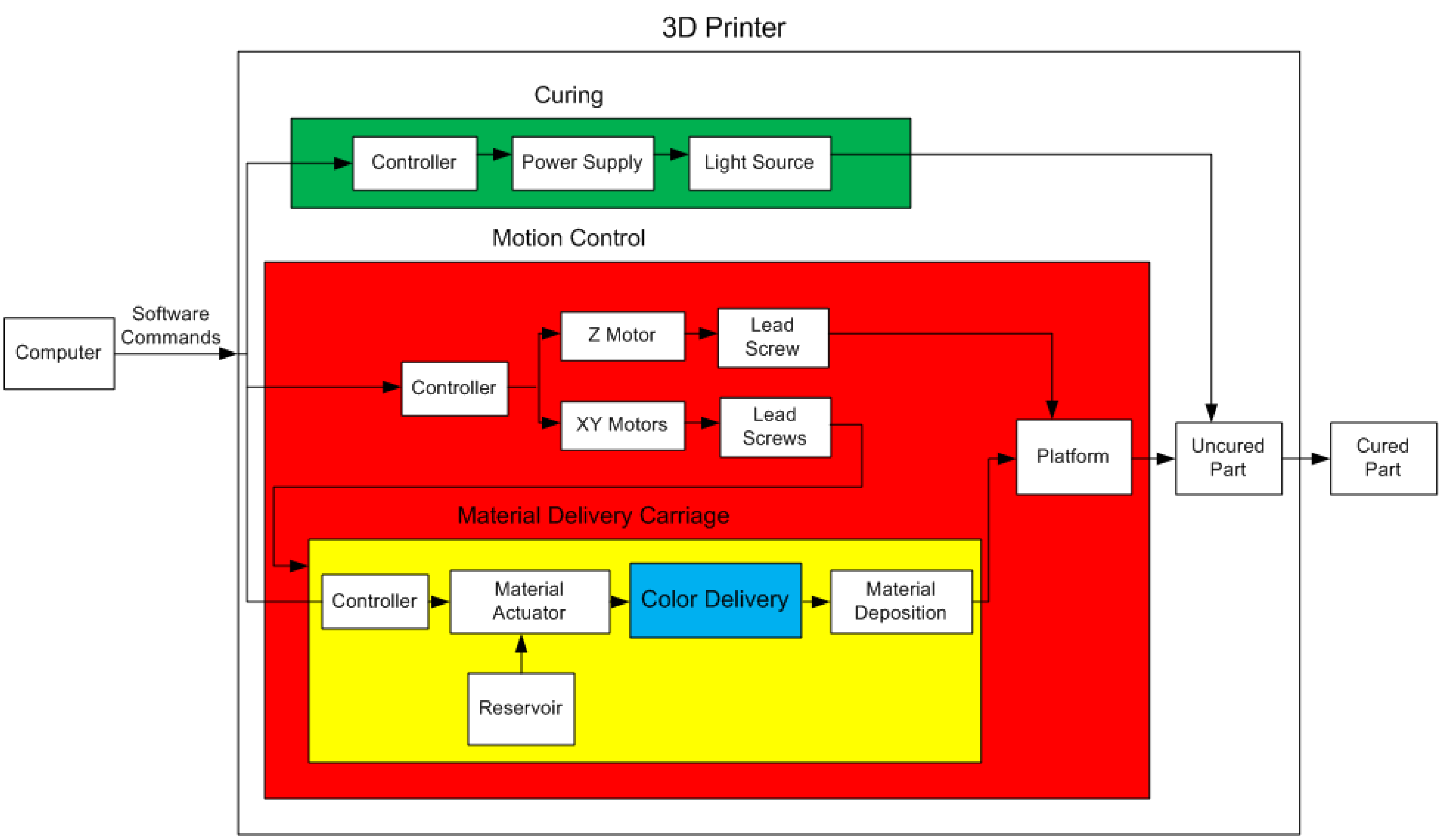


Fig 2: Input Process Output Diagram for New System

Customer Needs

Quantifiable

Customer Need #	Importance	Description
		Safety
CN1	High	Emits no harmful UV radiation
		Multicolor/Material
CN2	High	Capable of depositing multiple materials (colors) suspended in a single resin
CN3	High	Capable of depositing photopolymer (UV cured)
		Repeatability
CN4	Med	Capable of printing a similar part several times
		Accuracy
CN5	Med	Printed part is close to nominal size
CN6	Med	Capable of printing desired color material ratio
		Fab@home mindset
CN7	High	Low cost, could be bought for average home user
		Speed
CN8	Med	Does not take a copious amount of time to cure
CN9	Low	Can be set up quickly and easily
CN10	Low	Smooth trouble free operation

Non-Quantifiable

Customer Need #	Importance	Description
		Fab@home mindset
CN11	Med	User manual is easy to use and understand
		Aesthetics
CN12	Med	Machine looks presentable
CN13	Med	Operation is smooth and observable

Specifications

Eng. Spec #	Importance	Source	Specification	Description of Metric	Unit of Measure	Acceptable Value	Desired Value
ES1	High	CN1	Contain the UV radiation	Harmful UV Transmission	Watt	< 4	<2
ES2	High	CN2	Can Print Multicolor	Number of Base Colors	#	3	3
ES3	High	CN3	Can Print Viscous Material	Viscosity of resin	cP	> 165	> 300
ES4	Med	CN4	XY Repeatability	Mean/standard deviation of XY locations of deposited materials	mm	TBD	TBD
ES5	Med	CN4	Z Repeatability	Mean/standard deviation of layer thicknesses	mm	TBD	TBD
ES6	Med	CN5	Part Size (XYZ)	Mean/standard deviation of Error length/length of desired part	mm/mm	TBD	TBD
ES7	Low	CN5	Printable area	Maximum printable area	mm x mm	> 50 x 50	> 100 x 100
ES8	Med	CN5	Minimum Feature Size	Resolution in XY plane	mm	< 0.1	0.0158
ES9	Med	CN5	Minimum Feature Size	Combined Cured Droplet Diameter	mm	< 0.5	< 0.1
ES10	Med	CN6	Color Variability	Uncombined Uncured Droplet Volume	nL	< 25	< 10
ES11	Med	CN6	Color Variability	Uncombined Uncured Droplet Volume Precision	nL	TBD	TBD
ES12	High	CN7	Low Cost	Deposition System Parts Cost	$	< 1,000	< 1000
ES13	High	CN7	Low Cost	Total Budget	$	< 3,000 - Parts	< 3,000 - Parts
ES14	Med	CN8	Curing Time	Time to cure a layer of epoxy	sec	< 180	< 60
ES15	Low	CN9	Setup Time	Time to prepare machine for operation	mins	< 30	< 15

Concept Screening

All starting ideas are listed. Screening and Selection matrices were created and eventual choice is bolded.

1. Material Delivery
    a. **Micro Valve**
    b. Ball Point Approach
    c. Micro Rocker Valve
    d. Inkjet (Thermal)
    e. Inkjet (Piezoelectric)
    f. Disposable Syringe
2. Curing
    a. **Ambient Light (fluorescent)**
    b. Mini Halogen Bulbs
    c. LEDs
    d. Lasers
    e. Fiber Optics
3. Motion Control
    a. **Stepper Motor**
    b. Servo Motor
    c. Pulleys
    d. Pneumatically Actuated
    e. Rack and Pinion
4. Color Mixing
    a. **3 Premixed Reservoirs that mix into a Manifold**
    b. Inkjet individual inks into stream of resin
    c. Mix Inks then inject into stream of resin
    d. Print like Inkjet with 3 precolored reservoirs
    e. Print layer of uncolored resin then print inks like Inkjet

Material Delivery Drawings and Schematics

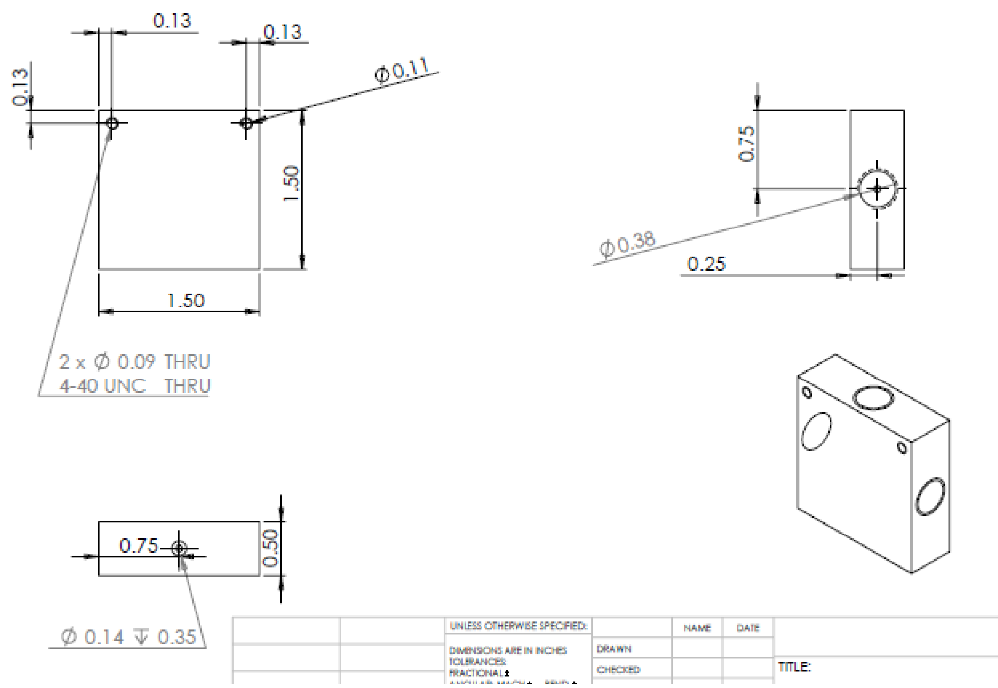


Fig 3: Print Manifold

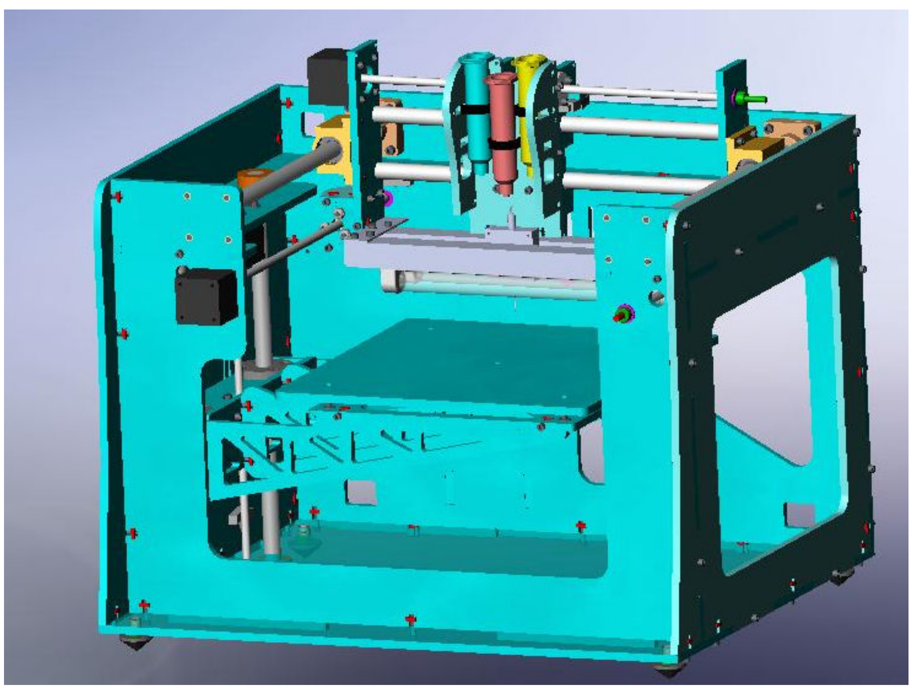


Fig 4: Fab@home system

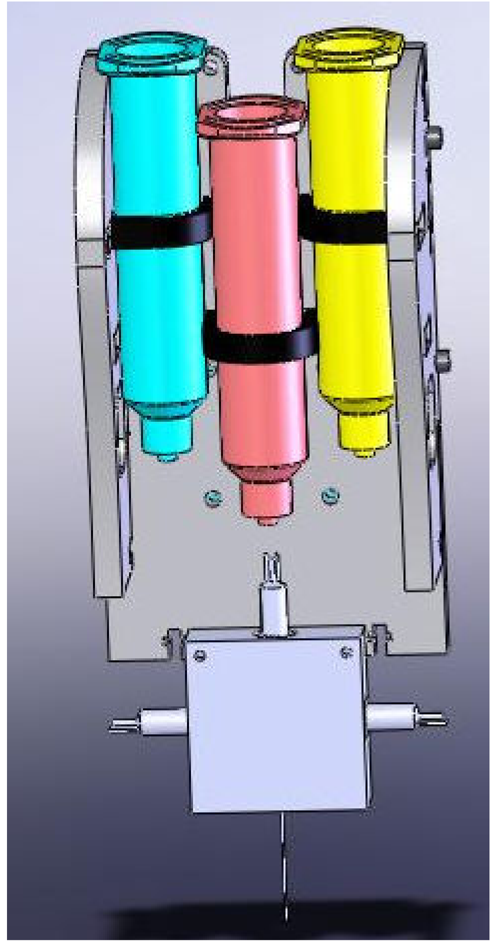


Fig 5: Print head. Tubes were not drawn in but connect from reservoirs to connectors on manifold.

Material Delivery Bill of Materials

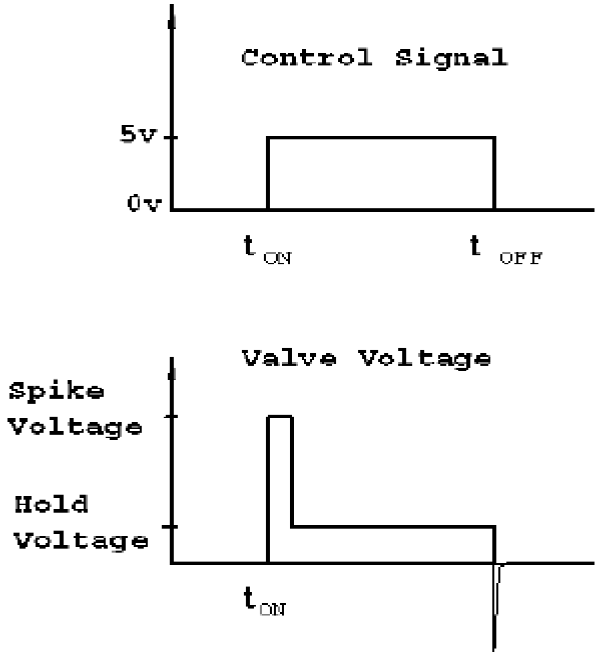
Component	Specs	Item #	Supplier	Quantity	Unit Cost	Total Cost
Air Adapter Assembly	10cc Adapter 3ft hose	7012339	EFD	3	$23.25	$69.75
Reservoirs	Syringe Barrel and Piston Set (10 cc UV Light Block)	7012126	EFD	30	$1.33	$39.78
Solenoid air valve (optional)	Solenoid Valve, NPT Port 1/8 Inch, Coefficient of Volume 0.2, Air Flow 6.9 CFM, Coil 12 VDC, Maximum Operating Pressure 120 PSI, Maximum Temperature 0-180 Degrees Fahrenheit, Actuator/Return Solenoid/Spring, Length 1.32 Inches, Height 2.4 Inches, Width .75 Inch, 3 Way Direct, Body Ported	35A-AAA-DDBA-1BA	Grainger	0	$33.30	$0.00
Material Tubing	Tubing, PTFE, All Natural, 1/16th x .040" (1.0mm) ID. Low Pressure, Translucent. 5 Meter Roll.	49210-40	MicroSolv Tech	1	$13.21	$13.21
Material Tubing Covering	Polyvinyl Chloride (PVC) Heat Shrink Tubing - 5 Pack Color: Black Minimum Conductor Range: 1/16 Maximum Conductor Range: 1/8 Length: 6 In. Expanded/Recovered Inside Diameter: 0.125/0.062	65546111	MSC	1	$1.82	$1.82
Material Tubing (second choice)	PTFE Thin Wall Spaghetti Flexible Tubing Inside Diameter: 0.038 In. Outside Diameter: 0.062 In. Wall Thickness: 0.012 In. Material: Teflon Color: Natural White	48703094	MSC	0	$0.20	$0.00
Air Regulator	Air Regulators with Pressure Gauge Type: Dial Air Regulator Port Size: 1/4 Gauge Port Thread Size: 1/4 Minimum PSI: 10 Maximum PSI: 120 Fluid Type: Compressed Air Material: Zinc Width: 1.97 In.	74381435	MSC	1	9.24	$9.24
Hose Adapter	Nylon Push-To-Connect Fittings - Fractional Tube Outside Diameter: 5/32 Thread Size: 1/4 Material: Nylon	48618565	MSC	1	$5.19	$5.19
3-way air separator	Nylon Push to Connect Fittings - Metric Sizes Tube Outside Diameter: 5/32 Metric Tube OD: 4 Material: Nylon	85333789	MSC	1	$10.62	$10.62
Cable Ties	TY-Rap« High Performance Cable Ties Type: General Material: Nylon Maximum Bundle Diameter: 5/8 Maximum Bundle Diameter: 0.625 Package Quantity: 100 Color: Natural Tensile Strength: 18 Body Width: 0.091	54065842	MSC	100	$0.12	$12.43
Air fittings	Female Luer to 1/16" barbed connector	11520	QOSINA	0	$0.00	$0.00
Air fittings (second choice)	Female Luer to 1/32" barbed connector	11733	QOSINA	3	$0.00	$0.00
Lee Micro valve	Lee VHS P/2 Solenoid Valve	INKA2424212H	The Lee Co	3	$135.79	$407.37
Manifold mount	Lee VHS valve manifold mount kit	IKTX0322170A	The Lee Co	3	$25.03	$75.09
Nozzle	0.010" ID MINSTAC nozzle	INZA5102514K	The Lee Co	1	$38.58	$38.58

Material Delivery Feasibility

Component	Specs	Feasibility
Air Adapter Assembly	10cc Adapter 3ft hose	Designed to operate with systems outputting up to 100psi
Reservoirs	Syringe Barrel and Piston Set (10 cc UV Light Block)	Designed to operate with systems outputting up to 100psi
Material Tubing	Tubing, PTFE, All Natural, 1/16th x .040" (1.0mm) ID. Low Pressure, Translucent. 5 Meter Roll.	will fit Lee valve fitting; will fit luer fitting; will be secured with tie wraps
Material Tubing Covering	Polyvinyl Chloride (PVC) Heat Shrink Tubing - 5 Pack Color: Black Minimum Conductor Range: 1/16 Maximum Conductor Range: 1/8 Length: 6 In. Expanded/Recovered Inside Diameter: 0.125/0.062	opaque so as not to allow any UV radiation through; correct size to fit to tubing
Air Regulator	Air Regulators with Pressure Gauge Type: Dial Air Regulator Port Size: 1/4 Gauge Port Thread Size: 1/4 Minimum PSI: 10 Maximum PSI: 120 Fluid Type: Compressed Air Material: Zinc Width: 1.97 In.	rated for up to 120 psi; has correct fittings
hose adapter	Nylon Push-To-Connect Fittings - Fractional Tube Outside Diameter: 5/32 Thread Size: 1/4 Material: Nylon	rated for up to 290 psi
3-way air separator	Nylon Push to Connect Fittings - Metric Sizes Tube Outside Diameter: 5/32 Metric Tube OD: 4 Material: Nylon	rated for up to 290 psi
Cable Ties	TY-Rap« High Performance Cable Ties Type: General Material: Nylon Maximum Bundle Diameter: 5/8 Maximum Bundle Diameter: 0.625 Package Quantity: 100 Color: Natural Tensile Strength: 18 Body Width: 0.091	small enough to secure small fillings; rated for 18 lb
Air fittings	Female Luer to 1/32" barbed connector	Will fit tubing and barrel
Lee Micro valve	Lee VHS P/2 Solenoid Valve	Ran Preliminary Valve Testing; could not achieve jet with high viscosity liquid; was able to achieve small liquid volumes consistently; tubing with clamp claimed feasible by Lee applications engineer
Manifold mount	Lee VHS valve manifold mount kit	cheapest way to mount valves; designed for this application; claimed feasible by Lee applications engineer
Nozzle	0.0075 ID MINSTAC nozzle	Ran Preliminary Valve Testing; worked well for liquid delivery as long as it is close enough to surface

Preliminary Valve Testing for Feasibility

1. Procedure
    a. Assemble the liquid container as shown in Figure 1
    b. Attach the MINSTAC tubing and nozzle to the valve
    c. Attach control board to power supply and signal generator as shown in the Lee Co instructions (CD)
2. Water Test
    a. Fill liquid container with water through quick connect fitting using syringe
    b. Attach air hose to quick connect and turn air on
    c. Set regulator to 10 psi
    d. Turn on power supply and signal generator
    e. Cycle signal from .1 Hz to 500 Hz and make sure water is jetting from the nozzle
    f. Turn off signal generator and power supply
    g. Disconnect air from quick connect
    h. Empty out remaining water
3. Corn Syrup Test
    a. Mix corn syrup with water until the viscosity roughly matches that of the resin (visually test by rocking the container back and forth)
    b. Fill liquid container with solution through quick connect fitting using syringe
    c. Attach air hose to quick connect and turn air on
    d. Set regulator to 10 psi
    e. Turn on power supply
    f. Set signal generator to 1 Hz and turn on
    g. Gradually increase pressure using regulator while observing the output of the valve
    h. Check to see if solution is jetting from nozzle
    i. Stop one jet has been reached or when max pressure is reached (~80psi)
    j. Turn off signal generator and power supply
    k. Disconnect air from quick connect
    l. Empty out remaining solution
4. Cleaning
    a. Rinse container with water to remove any remaining solution
    b. Carry out Water Test as shown in part B only this time using rubbing alcohol



- Constant 24 volts applied for the spike voltage. The spike voltage is required to open the valve
- Constant 3.5 volts applied for the hold voltage. The hold voltage keeps the valve open for the duration of the pulse
- A 5 volt square wave is pulsed when the valve wants to open
- The rising edge initiates the spike and hold

Fig 7: Valve Controller Waveform

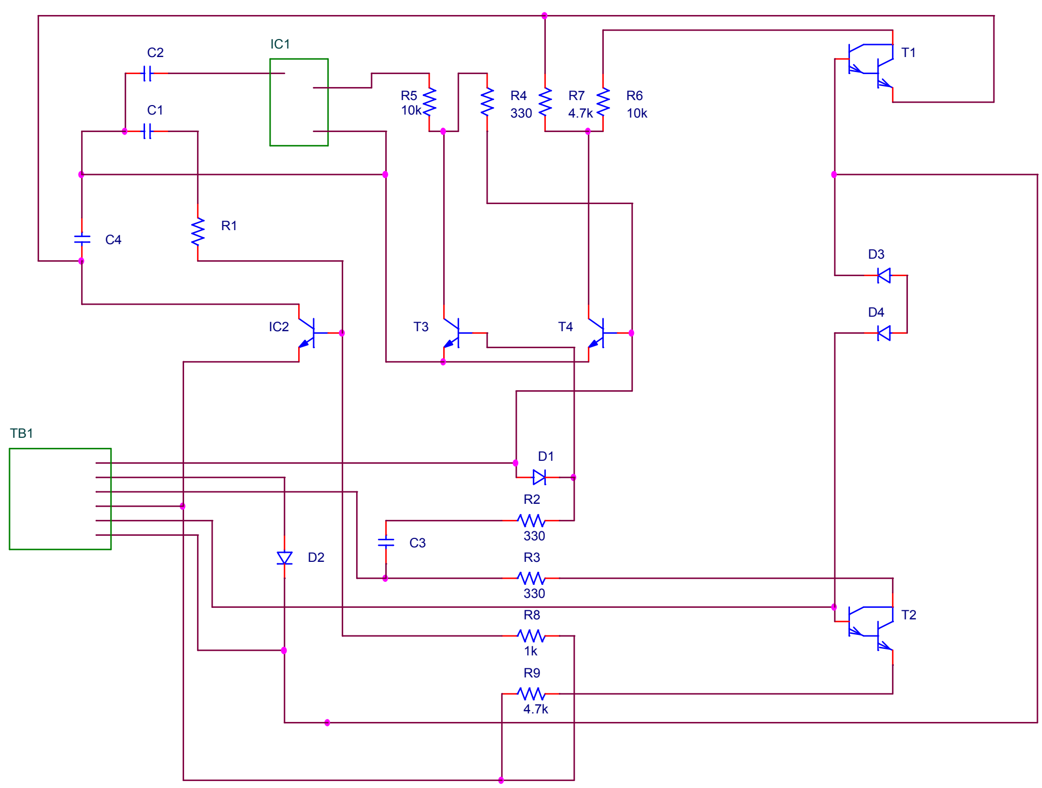


Fig 5: Valve Controller Schematic

Motion Control Bill of Materials

Component	Specs	Item #	Supplier	Quantity	Unit Cost	Total Cost
Power Supply	3.3VDC @ 4.55A	341-0008-01	Power Supply Depot	1	$5.95	$5.95
Transistor	400 @ 10A, 5V	MJH11022	Digikey	1	$4.37	$4.37
Transistor	400 @ 10A, 5V	MJH11019	Digikey	1	$3.93	$3.93
IC	555 single timer	NE555P	Digikey	1	$0.56	$0.56
Resistor	10kΩ		In house	2	free	free
Resistor	330Ω		In house	3	free	Free
Resistor	4.7kΩ		In house	2	free	Free
Resistor	1kΩ		In house	1	free	Free
Capacitors	10pf		In house	1	free	Free
Capacitors	10nf		In house	1	free	Free
Capacitors	47nf		In house	1	free	Free
Capacitors	100nf		In house	1	free	Free
IC	Adjustable voltage regulator 1.2V-37V	LM317LZ	Digikey	1	$0.55	$0.55
Transistor	Small signal transistor	MPS A42	Digikey	2	$0.53	$1.06

Curing System Drawings and Schematics

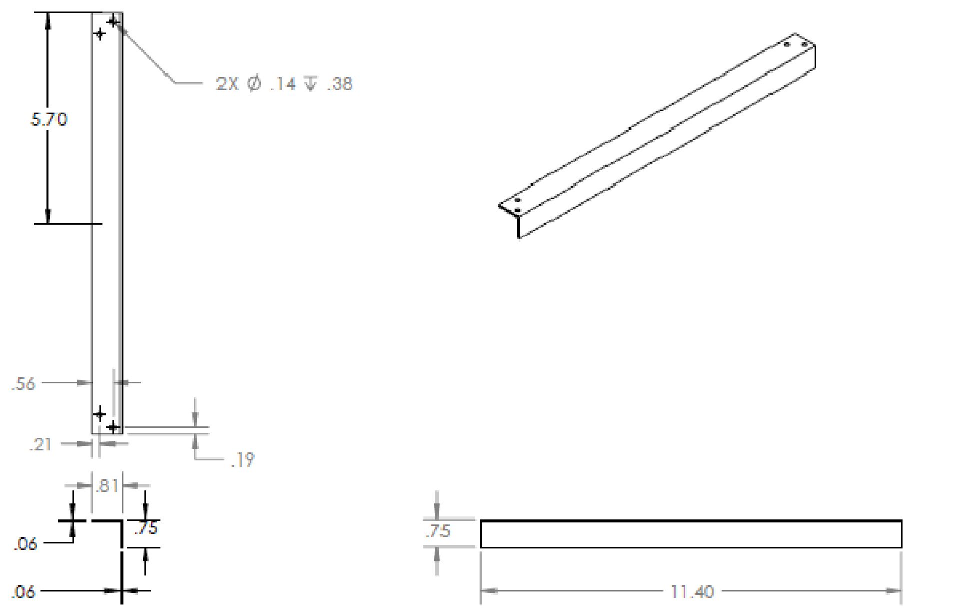


Fig 8: Cure Frame Cross Rail

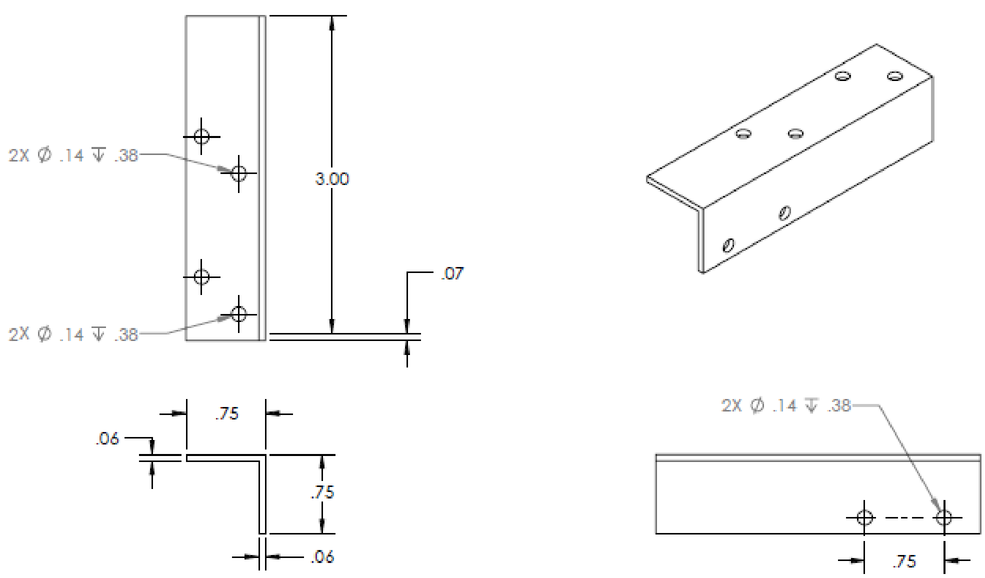


Fig 9: Cure Frame Side Rail Left

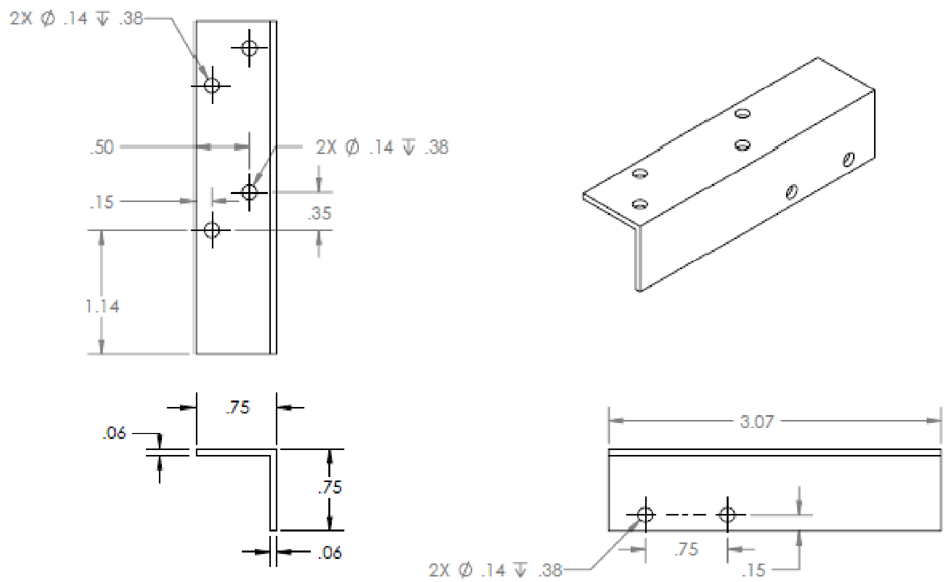


Fig 10: Cure Frame Side Rail Right

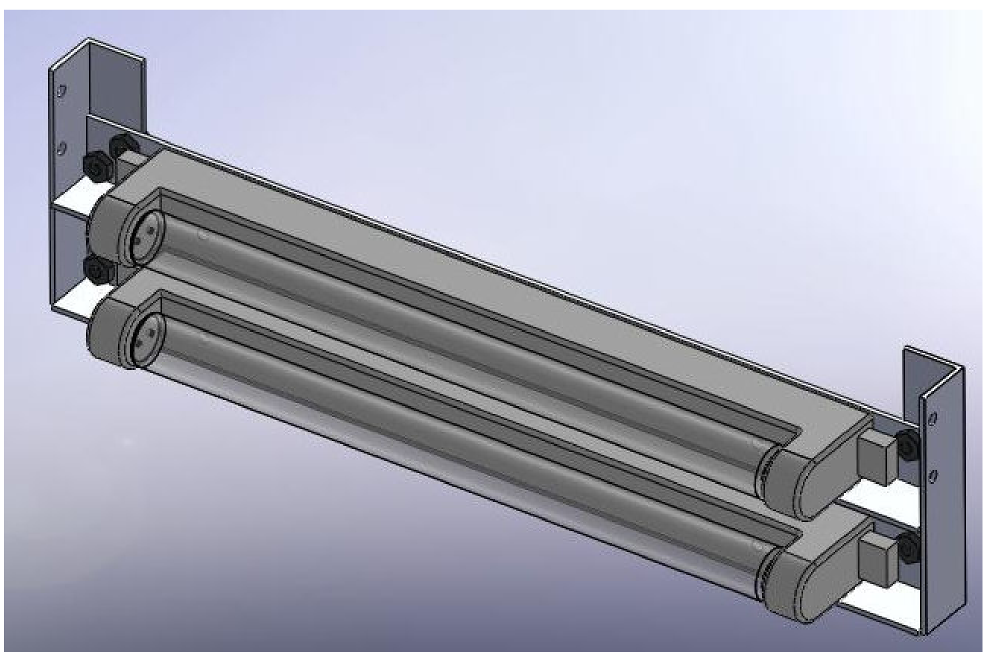


Fig 11: Cure System

Curing System Bill of Materials

Component	Specs	Item #	Supplier	Quantity	Unit Cost	Total Cost
Bulbs	6 Watt T5 Fluorescent Black light Miniature Bipin Base	F6T5/BL	Top Bulb	4	$3.99	$15.96
Light fixture	Micro fluorescent T5 Grounded Light Fixture (6 watt)	PSG5-6-xx	Pegasus Associates Lighting	2	$21.90	$43.80
Framing Material	Architectural Aluminum (Alloy 6063) (3/4" x 3/4" x 1/16" x 6')	4630T14	McMaster	1	$10.85	$10.85
Reflector	Arcadia Aquarium Lighting Reflector T-8		Ebay	1		$0.00
Power Cable	Micro fluorescent Grounded Flexible L Connector	PSG-CC6L	Pegasus Associates Lighting	1	$3.90	$3.90

Curing System Feasibility

Irradiance at the Bulb Surface:

$$I_1 = \frac{UV\ Output\ of\ Bulb}{Bulb\ Suface\ Area}$$

$$I_1 = \frac{1000\ \mu w}{101.34\ cm^2}$$

Irradiance at the Work Part:

$$I_2 = \frac{I_1 * r_1^2}{r_2^2}$$

$$I_2 = \frac{\left(9.867\ \frac{\mu w}{cm^2}\right) * (0.79375\ cm)^2}{(2.89375\ cm)^2} = .7424\,\frac{\mu w}{cm^2}$$

Total Cure Time:

$$Cure\ Time = \frac{E_{10}}{(I_2) * (\#\ bulbs)}$$

$$Cure\ Time\ = \frac{\left(47\,\frac{\mu J}{cm^2}\right)}{\left(.7424\,\frac{\mu w}{cm^2}\right) * (2\ bulbs)} = 31.65\ secon$$

$Where$:
$r_1 = Radius\ at\ the\ bulb\ surface$
$r_2 = Radius\ at\ the\ work\ part$
$I_1 = Irradiance\ at\ the\ bulb\ surface$
$I_2 = Irradiance\ at\ the\ work\ part$
$E_{10} = Exposure\ required\ for\ 0.01"\ layer\ thickness$

Assumptions:

- The center line of the bulb is considered to be the source of light for purposes of measuring radii
- The layer thickness is taken to be 0.01 inches thick
- The entire UV output of the bulb (1 watt) is produced at the required wavelength of 355 nm

Notes:

- Cure time could be further reduced through the addition of a reflector

Risks

#	Risk	Description	Effect	Likelihood	Severity	Importance	Prevention	Contingency	Owner
Ordinary Risks									
O1	Team Member becomes temporarily indisposed of	Team Member becomes temporarily indisposed of	Loss of man power	3	2	6	Have more than one team member working on each aspect of the project	Have another member take over responsibilities	All
O2	Team Member gone indefinitely	Team Member gone indefinitely	Loss of man power	1	2	2	Have more than one team member working on each aspect of the project	Have another member take over responsibilities	All
O3	Chosen component does not meet specification	Chosen component does not meet specification	Loss of money and time to order new part	2	2	4		Purchase different component	All
O4	Team member does not deliver promised progress	Team member does not deliver promised progress	Loss of time to make up his work	2	2	4	Assign multiple members to tasks	Get help from other members and/or guide	All
O5	Do not have proper facilities to fabricate/test	Do not have proper facilities to fabricate/test	Loss of money and time to outsource or design test	1	3	3	Create design to match facility capabilities	Outsource to a different facility	All
O6	Cost	Too expensive	Does not stay in fab@home mindset	2	2	4	Budgeting	Buy different product, revise design	Greg

Material Delivery Risks									
MD 1	Too viscous (dynamic)	Resin too viscous for effective printing	Does not stay in place before curing	2	2	4	Resin Research	Heat material to lower dynamic Viscosity	Chris, Eric
MD 2	Stream too large	Dispensed resin stream is too wide	Fails to meet design feature size	2	2	4		Print faster up too 10 mm/sec, change PSI gauge	Chris, Eric
MD 3	Stream too small	Dispensed resin stream is too narrow	Takes too long to print	2	2	4		Print slower, change PSI gauge	Chris, Eric
MD 4	Too small contact angle	Too small contact angle	Material Does not hold position on surface	1	1	1		Change material	Chris, Eric
MD 5	Too large contact angle	Too large contact angle	Material Does not hold position on surface	1	1	1		Change material, Vibrate table	Chris, Eric
MD 6	Layer thickness	Uneven droplets cause the error to compound with each layer	Part is coarse and doesn't meet schematic	1	2	2		Vibrate table, lower viscosity, change material	Chris, Eric
MD 7	Valve too large	Valve cannot dispense a small enough droplet	Cannot meet design feature spec	1	2	2	Droplet/ valve calculations	New valve/ syringe	Chris, Eric

MD 8	Cannot regulate air pressure	The pressure that controls the syringes	Too much or too little resin is dispensed when commanded to	3	2	6		Better regulator, change valve on regulator, change actuation method	Bill
MD 9	Tip is too hot	Melts the tip	Cannot continue printing until tip is replaced	1	1	1	Experiment to find how hot the print head can get before melting		Bill
MD 10	Melting point of tip is to low	Cannot lower the viscosity enough before melting	Print head clogs	1	1	1		Use valve with larger diameter, Use valve with higher ,melting point	Chris, Eric
MD 11	"fountain pen" approach to material delivery does not produce	material stream is too wide or inconsistent color	cannot reach specs	2	3	6		Implement air ejection system	Chris, Eric
MD 12	Valves clog or fail or do not come in on time	color mixing failure	cannot reach specs	2	3	6		Heat resin; use air controlling solenoid valves instead of VHS valves	Chris, Eric
MD 13	Too few motor outputs	Current motor controllers can not support additional	Loss of money to buy new controller	2	2	4		Get new motor controllers	Joe
Motion Control Risks									
MC 1	Repeatability	Ability to return to a given position within a given tolerance	High variability	1	2	2	Step size and screw pitch calculations	More accurate motor, finer thread pitch	Chris, Eric
MC 2	Too coarse	Can not get accurate enough position	Cannot meet design feature spec	1	2	2	Step size and screw pitch calculations	More accurate motor, finer thread pitch	Chris, Eric
MC 3	Pinching	Moving parts pinch or harm operator	Damage to user	1	1	1	Warning Stickers	Protective Case	Bill
Color Delivery Risks									
CD 1	Residual Color	Residual color in mixing chamber prevents accurate color	Printer does not print desired color accurately	2	2	4	Minimize chamber volume	Cleaning Cycle	Chris, Eric
CD 2	Not Vibrant	Color that is printed is not desired	Final color of part does not meet customer expectations	3	2	6	Dye research	New dyes, More dye	Chris, Eric
CD 3	Incompatible with Resin	Dye doesn't mix into resin	Color is not spread throughout part	1	3	3	Research, experiment	New dyes	Chris, Eric
CD 4	Incompatible with each other	Dyes do not mix together	Non Homogeneous	1	3	3	Research, experiment	New dyes	Chris, Eric
CD 5	Command of color	Existing software does not support any color control	Loss of time to learn software	3	2	6		Develop Control system	Joe

Curing Risks									
C 1	UV emissions	Machine emits harmful UV radiation	Damage to user	1	2	2	Comprehend levels beforehand	Protective Case, Goggles	Greg
C 2	Clogs Print head	Resin cures on or otherwise clogs print head	Print head needs to be changed/ cleaned	1	3	3	Coating on print head, print head protection	Install print head protection shroud, Lower Viscosity, Increase Tip Diameter	Chris, Eric
C 3	Bulb Fails	Bulb fails to emit required energy rate	Part does not cure or partially cures	1	2	2	Mechanical isolation	Replace bulb, improve isolation	Greg
C 4	Wrong power supply	Variation in power supply output causes incorrect	Part does not cure or partially cures	2	3	6	Power supply research, Bulb research	New power supply	Greg
C 5	Time Consuming	Critical Exposure not achieved in reasonable time	Parts take too long to print	1	2	2	Robust Design, Lighting Research	Slow down print carriage cycle time, add more lights	Greg
C 6	Not Enough Energy	Light not intense enough to achieve critical exposure	Part does not cure or partially cures	1	3	3	Robust Design, Lighting Research	Add more lights, change resin to lower critical exposure	Greg
System Integration Risks									
SI 1	Not viscous enough (static)	Resin flows from deposition point before curing	Droplets too large	1	3	3	Cure Quickly, Increase print speed, Additive in resin	Change offset of curing bulb	Chris, Eric
SI 2	Dye interference	Tint in dye interferes with the curing of the resin	Part does not cure or partially cures	2	2	4	Dye research, experimentation	Reduce dye tint	Greg
SI 3	Vibrations	Vibrations cause UV bulb to fail	Part does not cure or partially cures	1	2	2	Mechanically isolate bulb	Move bulb off print carriage, use fiber optics	Chris, Eric
SI 4	Resin Shrinkage	Material Shrinks when it is cured	Part is smaller than designed	1	1	1	Draw the part out larger than desired to compensate		Chris

Test Plan

The test strategy we have developed serves to test the ability of the Nano-Ink Deposition System. Many of the Engineering Specs leave room for variation in the ability of the system. This test plan strives to eliminate variability and ensure predictability. Various elements of the test plan serve to confirm predictions and

Structure of Test Plan

1.) What system/integration to test.

2.) What features of the system to test and what equipment is involved in the test.

3.) Which member the test is assigned to and pass fail criteria.

4.) Risks and contingencies to change structure.

Test #	Sub System	Test Description	Source
T1	Material Delivery	Test to see if heating resin is applicable/desired	
T2	Curing System	Verify the capabilities of the Curing System	ES15
T3	Material Delivery	Establish sufficient parameters to run the valve at.	ES3
T4	Color Delivery	Verifies the system can deliver multiple colors	ES2
T5	Motion Control	Ensure the Motion Control is acceptable	ES4, ES5, ES6, ES7
T6	Electronic Control	Verify control of the material and color delivery system	ES2, ES15,
T7	System	Verifies the system can print and cure a single layer of material	ES4 ES7 ES9 ES14
T8	System	Verifies the system can print and cure multiple layers	ES4 ES5
T9	System	Establishes the capabilities of the system to deliver colors	ES2 ES10 ES11
T10	System	Final printing capabilities of the system	
T11	System	Print Customer Test Part	

Test Equipment available

- CMM
- Microscope
- Power Supplies
- Oscilloscope
- Frequency Generator
- Shop Air Pressure
- Micrometer
- Stop Watch
- Fab Epoxy
- Computer

Test Equipment needed but not available

Color detection Device
High Speed Camera
USB Voltage I/O

Phases of Testing

Component/ Device (wks 2-12)

1.) Lee Micro valve testing

2.) Epoxy/Resin Testing

3.) Pressure Testing

Subsystem (wks 11-13)

1.) Material Deposition
2.) Curing System
3.) Control System

Integration (wks 13-15)

1.) Material Synchronization
2.) Curing system control

Reliability (wks 15-20)

1.) Micro valve testing for longer builds
2.) Setup and Clean-up

Customer Acceptance (wks 20-21)

1.) Develop Test Part
2.) Print Test Part for Customer

Definitions; Important Terminology; Key Words

Viscosity: the property of a fluid that resists the force tending to cause the fluid to flow

Manifold: a chamber having several outlets through which a liquid or gas is distributed or gathered

Lee Micro Valve: a small solenoid valve intended to dispense very small volumes of liquid materials quickly

Fab@Home: an inexpensive, open source 3D printer developed by Cornell University for use in the home; requires no additional hardware to operate and be commanded by free open source software off of a home computer

UV Resin: a liquid polymer capable of being cured to a solid by being exposed to UV radiation

Curing: the process of polymer cross-linking in which a resin goes from a liquid to a solid state

Motion Control System: system for moving the material delivery system to a desired location; in this system it is made up of 3 stepper motors attached to lead screws, each of which controls one axis (X,Y and Z)

Material Delivery System: system for moving controlled amounts of different types of resin from reservoirs to the deposition surface in a very precise manner

Test #1
Description:

It has been shown in preliminary testing that the resin's viscosity is too great for it to "jet" from a nozzle of small inner diameter. This test seeks to see if heating the resin will decrease it's viscosity enough for it to flow more freely from the from a small nozzle.

Start Date: Week 10 Winter Quarter **End Date: Week 11 Winter Quarter**

Assigned to: Eric Hettler

Equipment Needed:

1.) Resin
2.) Hot plate
3.) Heatable container of water
4.) Thermometer
5.) Syringe with small inner diameter tip
6.) Compressed air?

Test Plan:

Water will be heated to various temperatures using the hot plate and a container of the resin will be submerged in it until its temperature increases to that of the water. The resin will then be placed in the syringe and extruded through the small inner diameter nozzle. The force required to achieve a desired flow rate will be measured. Temperature will be increased until the desired flow is achieved or until the temperature becomes unreasonable.

Pass/Fail:

This is an analysis procedure required to determine if heating the resin is beneficial. If heating is seen to be a benefit, a resin heating system will be designed.