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Date: *3/21/25*

Re: *Finalized Testing Plan*

# Design Requirements Summary

## Engineering Requirements

|  |  |  |  |
| --- | --- | --- | --- |
| # | Requirement | Units | Targets |
| ER1 | Materials Tested | Al, SS 316L, Ti, Bronze  | One |
| ER2 | Final Print Material | Al, SS 316L, Ti, Bronze  | SS 316L |
| ER3 | Final Print Volume | mm^3 | <90x90x80 |
| ER4 | Power  | V, A | 240V, 16A |
| ER5 | Inert Gas | N, Ar, bar, purity | 2 bar Ar purity >=2.5 |
| ER6 | Young's Modulus Tested | GPa | 193 |
| ER7 | Dog Bone Size | mm | 65 |
| ER8 | Airtight Gas Supply | N/A | No audible leak |
| ER9 | Build Plate Alignment | N/A | Even material distribution |
| ER10 | Printed Part Tolerance | mm | ±0.2mm |

## Customer Requirements

|  |  |  |
| --- | --- | --- |
| # | Requirement | Description |
| CR1 | Ease of Use | Easily accessible to IDEA Lab managers, Instruction manual and supplementary instructions at hand |
| CR2 | Safety | Printer fully and properly installed, safety signs posted, PPE available, instruction manual at hand |
| CR3 | Time | Fully installed by the end of the spring 2025 semester |
| CR4 | Successful Installation | Printer fully operational, all technical issues addressed |
| CR5 | Tensile Test Results | All test specimen tested; all results analyzed |
| CR6 | Final Part and Assembly | Final part printed and assembled into greater assembly |
| CR7 | Instruction Manual | “First print” instruction manual complete with comprehensive steps and files attached |

# Top Level Testing Summary

## Test Summary Table

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment/Test | Relevant DRs | Testing Equipment Needed | Other Resources |
| EXP1 - Test Print | ER2 - Final Print Material (SS 316L)ER4 - PowerER5 - Inert GasER8 - Airtight Gas SupplyER9 - Build Plate AlignmentER10 - Printed Part Tolerance (±0.2mm)CR2 - SafetyCR4 - Successful InstallationCR6 - Final Part and AssemblyCR3 - Time | Small tubeDial gauge indicatorShimCalipers | Rail system to slide dial gauge indicator along build module |
| EXP2 - Tensile Test | ER2 - Final Print Material (SS 316L)ER6 - Young's Modulus TestedER7 - Dog Bone SizeCR5 - Tensile Test ResultsCR3 - Time | Tensile test equipmentCalipers |   |

# Detailed Testing Plans

## EXP1 – Test Print

This test has four consecutive parts. First, we will test all areas of the machine for gas leaks, then test each of our remaining three build modules which we haven’t tested for the alignment of its z-axis elevator. If no aligned build module is found, we will select a build module, measure its distance from alignment and elevate the build plate with shims as necessary. Once an aligned build plate is achieved, we will print a part and measure it against its CAD model to determine the print’s accuracy.

**EXP1.1 Gas Leak Test:**

For this test we will be using a 1” diameter copper tube to locate any potential gas leaks after installing our new non-leaking build chamber door latch. This relates to design requirements CR2 – Safety, ER5 – Inert Gas, ER8 – Airtight Gas Supply, CR3 – Time, and CR4 – Successful Installation. The procedure is as follows:

1. Open inert gas supply valve and start machine
2. Start process of making build chamber inert
3. While the oxygen is being pushed out of the build chamber, place one end of the copper tube on one ear, and comb the door of the build chamber, noting any audible gas leaks and their locations
4. Once the chamber is inert, repeat step 3
5. Using the above method for finding audible gas leaks with the copper tube, comb the entire length of the gas supply tube, starting with the tank and pressure regulator, and ending with the internal connection of the gas tube with the machine.
6. In a similar fashion listen to all parts of the inside of the machine which connect to the build chamber.
7. If leaks are found around the door, fill the gaps in the silicone door seal with rubber cement.
8. If leaks are found in any other part of the machine which may be faulty, consult Colibrium Additive for a quote, and attempt to find ways to temporarily address the problem.

The goal of this test is to find any remaining gas leaks after we install the new build chamber door latch, which was the source of our most recent leak. This will greatly reduce the cost of printing and make for a safer environment for the IDEA Lab personnel, as prints can take anywhere from 1-2 days to complete, causing an increasing displacement of oxygen in the lab if a leak is present and doors are closed.

**EXP1.2 Build Module Trials:**

For this test we will be installing each of our build modules and testing their build plate alignment with the hopes of finding one which is perfectly aligned. We used one of our four build modules for our first print and found it misaligned, so the remaining 3 will be tested here. This requires no extra equipment, just the build modules, a build plate, the metal powder, and the printer. This test relates to design requirements ER9 – Build Plate Alignment, ER10 – Printed Part Tolerance, CR3 – Time, and CR4 – Successful Installation. The procedure is as follows:

1. Place fresh build plate in untested build module
2. Place build module in extended build module arms on printer
3. Dock glove box trolley onto build module and fill with argon
4. Fill powder chamber with metal powder (not much is needed, as we are just testing for visual evenness of the first coat of powder on the build plate) and spread evenly in powder chamber
5. Push build module into the printer and make the build chamber inert
6. Do initial coating procedure of printer, looking for an even coat across the build plate with the build plate visible underneath it
7. If uneven after multiple attempts, repeat steps 1-6 for the next build module until all have been tested. If even, skip to EXP1.4
8. If all have been tested and none are aligned, proceed with EXP1.3

This test is to determine if we have any build modules with aligned z-axis elevators, which would allow us to move forward with printing and testing print tolerances. Since a field service to upgrade the build elevators is now out of our budget, we will instead perform EXP1.3 to fix the alignment ourselves if no build modules are found to be aligned in EXP1.2.

**EXP1.3 Shim Alignment Experiment**

If no aligned build modules are found, we will perform this test to align a build module by placing shims between the build plate and the build chamber elevator, raising a lowered portion of the build plate to alignment. This test will use a dial gauge indicator and shims to find misaligned sections of the build plate and correct them. This test relates to design requirements ER9 – Build Plate Alignment, CR3 – Time, and CR4 – Successful Installation. The procedure is as follows:

1. Choose build module in the best visible condition and place it in extended build module arms on printer
2. Place build plate in build chamber of build module
3. Raise the build chamber elevator so that the build plate is just above the surface of the build module
4. Mount dial gauge indicator onto build module and probe the surface of the build plate to find any lowered areas of the build plate. Use rail system if available to more easily probe the entire length of the build plate
5. Select shim with the appropriate thickness for the difference between the lower and higher build plate elevations
6. Trim shim if necessary to match the lower build plate area
7. Insert shim under build plate and probe again with dial gauge indicator. If there is any unevenness in the surface elevation of the build plate, trim shim, adjust its placement, and probe again.
8. Repeat step 7 until the build plate is as even as physically possible. Every micron counts.
9. Once an even surface is achieved, move on to EXP1.4

This test is necessary to achieve a perfectly even build plate assuming none of our build modules have aligned z-axis elevators. Any unevenness of the surface of the build plate will manifest as inconsistencies in the final print and could take the accuracy of the printer outside of our determined tolerance goals.

**EXP1.4 Test Print and Tolerance**

This test will be a print to determine the accuracy of the printer in its currently installed state. This will also inform us if changes need to be made to the pathing code we supply to the printer (such as infill and support decisions) or the print parameters we determine on the machine (such as laser wattage and speed). Aside from the necessary equipment needed to print, we will also be using calipers to ensure that the printed part’s dimensions are within 0.2mm of their expected values. The relevant design requirements for this test are ER9 – Build Plate Alignment, ER10 – Printed Part Tolerance, CR4 – Successful Installation, CR6 Final Part and Assembly, and CR3 – Time. The procedure is as follows:

1. Print part through normal procedure, steps not shown here due to extent and irrelevance to tolerancing
2. Pull build module into glove box trolley and make environment inert
3. Clean off part using brush and pressurized gas, and remove from build module and glove box trolley
4. Compare printed dimensions with expected CAD dimensions using calipers at each defining dimension
5. If there is a difference between the CAD dimensions and the print dimensions greater than 0.2mm, note on which axis the difference occurred, on which plane, and if there is any warping, discoloration, or non-adherence of layers which can account for this difference
6. Adjust the pathing code or printer print parameters in accordance with the inconsistency found, and repeat steps 1-5 with a clean build plate and adjustments made
7. Once print achieves proper tolerance, record all settings used on both the print pathing and machine

As stated above, we are looking for a tolerance of +-0.2mm to consider the machine properly installed, and the printing procedure fully fleshed out. This test is vital to ensuring that the printer is printing accurately so that we can successfully hand off the printer and instructions to the IDEA Lab for future use. This will complete the customer requirement of successful installation.

EXP2 – Tensile Testing

During this test, the strain and stress values will be measured, along with the relevant dimensions of the testing samples, to evaluate the mechanical properties of both traditionally machined and 3D-printed specimens. First, the experiment will utilize a tensile tester provided by Dr. Cioconel inside room 110, which can apply tension up to 60,000 lbf. This machine will be connected to a data acquisition (DAQ) system, most likely LabView or a similar program, to accurately record force and displacement data throughout the test. This test successfully helps the project meet ER2 - Final Print Material (SS 316L), ER6 - Young's Modulus Tested, ER7 - Dog Bone Size, and CR5 - Tensile Test Results. The procedure is as follows:

1. Insert samples into the Tensile Tester, starting with control machined samples
2. Log the amount of force and strain as more stress is applied to the part until failure.
3. Continue with each test specimen.
4. Format graphs and compare results.

Three samples from each manufacturing method—machining and additive manufacturing—will be tested to assess differences in material performance, including ultimate tensile strength, yield strength, and ductility. Each sample will be secured in the grips of the tensile tester and subjected to a controlled tensile load until failure. Additionally, necking behavior will be observed in select specimens to analyze how the material deforms under extreme stress conditions and to determine failure mechanisms. For the 3D-printed samples, particular attention will be given to layer adhesion and anisotropic behavior, while the machined samples will serve as a baseline for comparison. The equations necessary are:

$$σ=\frac{F}{A}$$

Eqn. 1

$$ε=\frac{δ}{L}$$

Eqn. 2

$$E=\frac{σ}{ε}$$

Eqn. 3

We expect the machined specimen to result in a Young’s Modulus of about 193 GPa and a yield strength of 170 MPa. As for the 3D Printed specimen, we have no reference for the results and can only hypothesize if it will be weaker or stronger.

# Specification Sheet Preparation

## CR Summary Table

|  |  |  |
| --- | --- | --- |
| Customer Requirement | CR Met? (Yes or No) | Client Acceptable (Yes or No) |
| Ease of Use |   |   |
| Safety |   |   |
| Time |   |   |
| Successful Installation |   |   |
| Tensile Test Results |   |   |
| Final Part and Assembly |   |   |
| Instruction Manual |   |   |

## ER Summary Table

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Engineering Requirement | Target | Tolerance | Measured/Calculated Value | ER met? (Yes or No) | Client Acceptable (Yes or No) |
|  |
| Materials Tested | One | N/A |   |   |   |  |
| Final Print Material | SS 316L | N/A |   |   |   |  |
| Final Print Volume | <90x90x80 | No Tolerance |   |   |   |  |
| Power  | 240V, 16A | >=240V |   |   |   |  |
| Inert Gas | 2 bar Ar purity >=2.5 | No Tolerance |   |   |   |  |
| Young's Modulus Tested | 193 | N/A |   |   |   |  |
| Dog Bone Size | 65 | +-0.1mm |   |   |   |  |
| Airtight Gas Supply | No audible leak | No Tolerance |   |   |   |  |
| Build Plate Alignment | Even material distribution | No Tolerance |   |   |   |  |
| Printed Part Tolerance | ±0.2mm | Same as Target |   |   |   |  |

# QFD

