# Theory of Operation

Document 03 | Rev C | 17 November 2026 | Status: design package. Nothing has been built or bench-tested; numbers are design targets, calculations or simulations.

## 1. Motion

A fixed bridge carries the X carriage; the bed moves in Y; Z lifts the tool plate. All three axes are lead screws on linear rails driven by stepper motors at 800 steps per millimetre. The planner turns paths into trapezoid speed profiles with corner speeds limited by a junction deviation of 0.02 mm; the stepper layer then passes axis position through a 4 ms moving average, which rounds every acceleration change and bounds jerk without a separate S-curve planner.

## 2. Tool changing

Tools hang on a four-position dock on the front of the bed carriage. The Z plate picks one up through a three-ball kinematic coupling held by magnets, so each tool returns to the same position within the coupling's repeatability. Every tool's working tip sits 22 mm in front of and 70 mm below the coupling centre, so the machine needs one offset table entry per tool, measured once by touching the calibration target.

## 3. Dispensing

A geared stepper drives the cartridge plunger. Flow is commanded as plunger travel per millimetre of path, computed from bead width and height; pressure advance leads the plunger on starts and retracts on stops. Plunger motor load is watched: a rising load means a drying tip, a falling load an empty cartridge.

## 4. Height and touch

A load cell under the tool plate detects contact. Before a job the machine touches a grid of points and builds a height map, then follows the board surface during dispensing and milling. The touch signal reaches the controller on its own wire so a stop never waits on the wireless module.

## 5. Curing, exposure and reflow

Silver ink is cured by the bed; dielectric and solder mask by 405 nm light, either the UV bar or the laser tool rastered at reduced duty. The same bed runs a reflow profile for paste. Bed temperature is controlled at 1 kHz from two sensors that must agree within 15 C.

## 6. Vision

A camera on the X carriage finds board corners and fiducials for alignment after a flip, measures a test line to set flow for a new cartridge, and compares the finished layer with the design to find breaks and bridges.

## 7. Safety chain

Lid switches, the watchdog and the stop input act in hardware: a quad AND gate holds the heater, the switched 24 V tool rail, tool PWM and the UV output off unless the watchdog reports a live processor and the lid is closed. Firmware adds limits and state checks on top but is not relied on for the cut-off.

## 8. Compute split

The controller runs motion and safety only. The carriage module serves the app over Wi-Fi, streams the camera and stores the current job. Gerber checking, toolpath planning and image analysis are meant to run in the browser; in this package they exist as Python reference code.