Vector Scan SL

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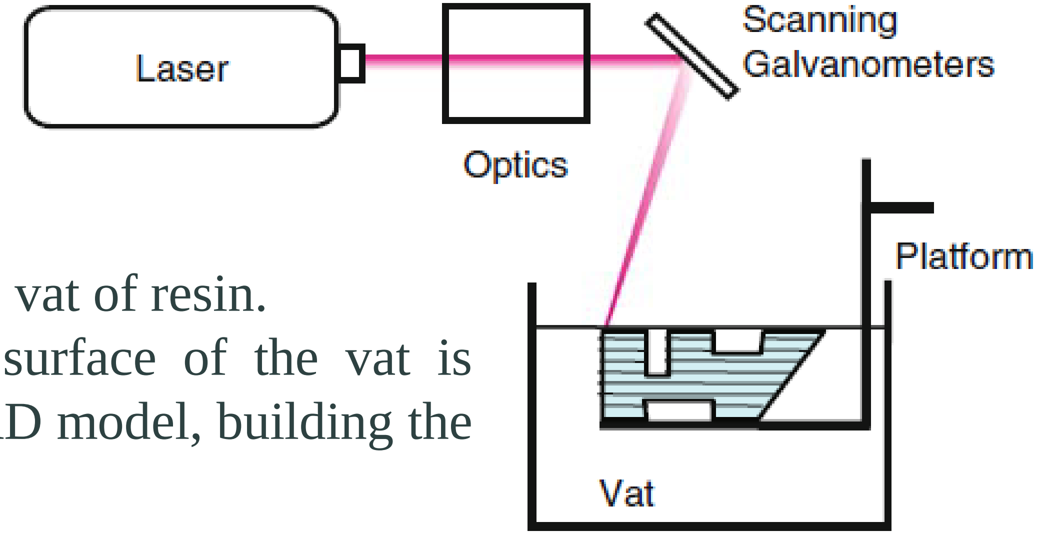
- SL creates solid parts by selectively solidifying a liquid photopolymer resin using an UV laser.
- The physical parts are manufactured by fabricating cross-sectional contours, or slices, one on top of another.

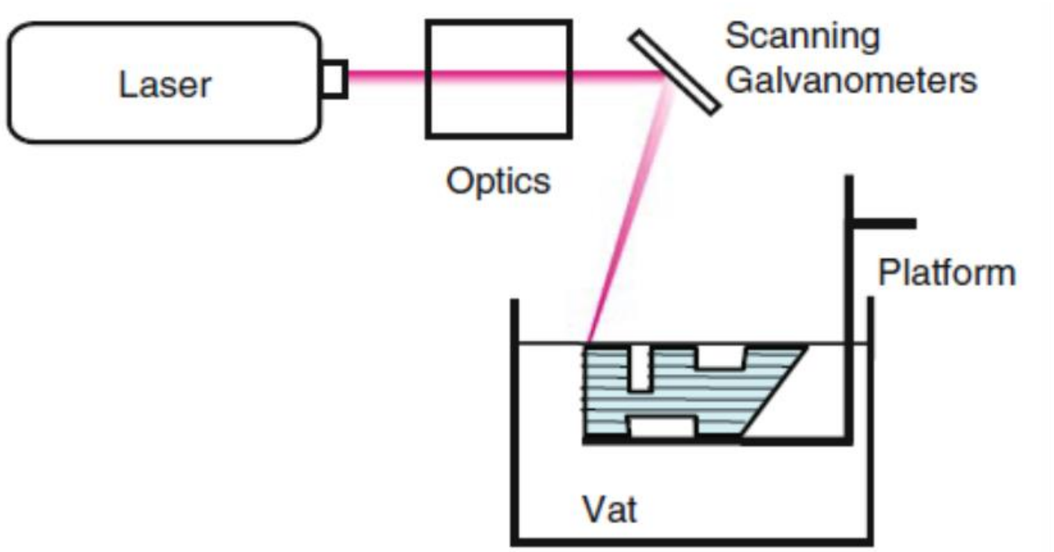


- The part being built rests on a platform that is dipped into the vat of resin.
- After each slice is created, the platform is lowered, the surface of the vat is recoated, then the laser starts to trace the next slice of the CAD model, building the prototype from the bottom up.
- The creation of the part requires a number of key steps: input data, part preparation, layer preparation, and finally laser scanning of the two-dimensional cross-sectional slices.
  1. The input data consists of a STL created from a CAD file or reverse engineering data.
  2. Part preparation is the phase at which the operator specifies support structures, to hold each cross section in place while the part builds, and provides values for machine parameters.
  3. Layer preparation is the phase in which the STL model is divided into a series of slices, as defined by the part preparation phase, and translated by software algorithms into a machine language.
  4. The laser scanning of the part is the phase that actually solidifies each slice in the SL machine.
- After building the part, the part must be cleaned, post-cured, and finished.

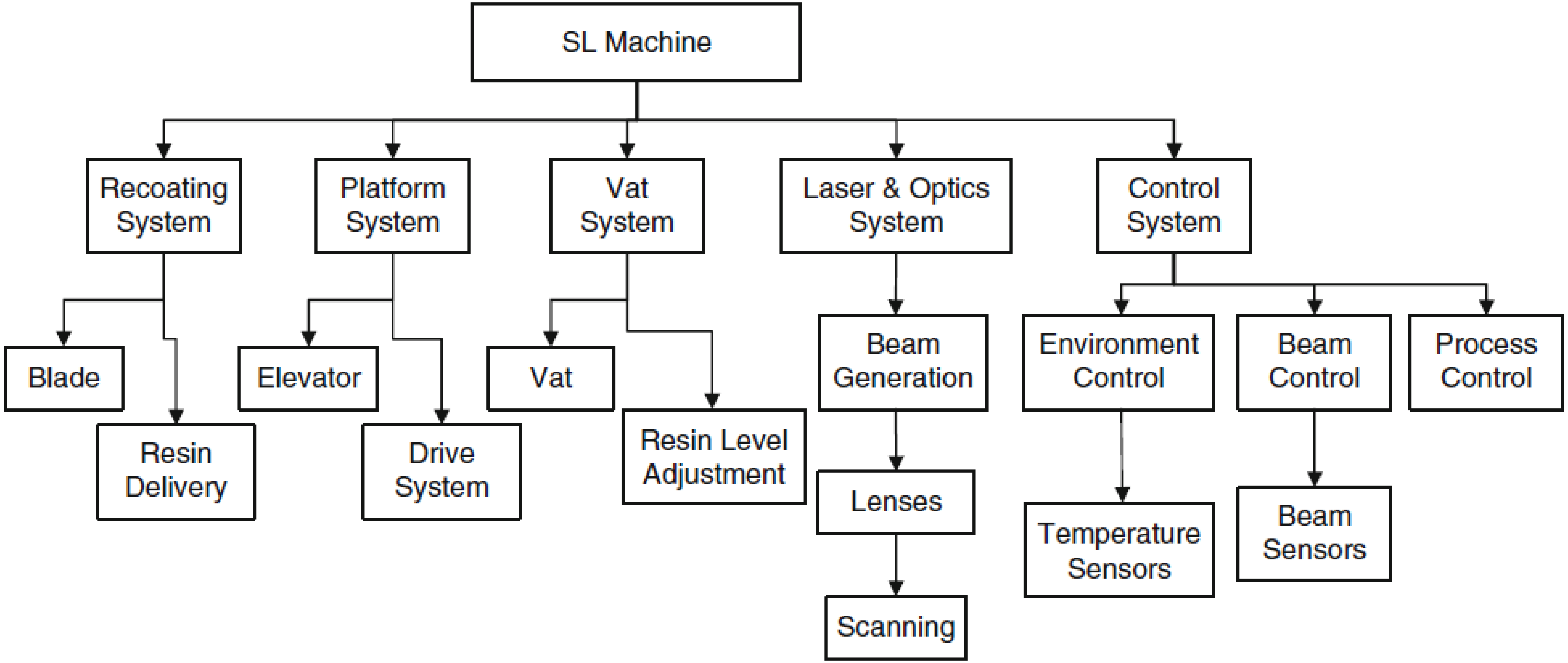
SL Machines

Main Subsystems:

- Recoating system,
- Platform system,
- Vat system,
- Laser and optics system, and
- Control System



SL Machines



SL Machine
Recoating System
Platform System
Vat System
Laser & Optics System
Control System
Blade
Resin Delivery
Elevator
Drive System
Vat
Resin Level Adjustment
Beam Generation
Lenses
Scanning
Environment Control
Temperature Sensors
Beam Control
Beam Sensors
Process Control

SL Machines

Recoating System

- Recoating is done using a shallow dip and recoater blade sweeping. The process can be described as follows:
  1. After a layer has been cured the platform dips down by a layer thickness.
  2. The recoater blade slides over the whole build depositing a new layer of resin and smoothing the surface of the vat.
- A common recoater blade type is the zephyr blade, which is a hollow blade that is filled with resin.
- A vacuum system pulls resin into the blade from the vat. As the blade translates over the vat to perform recoating, resin is deposited in regions where the previous part cross section was built.
- When the blade encounters a region in the vat without resin, the resin falls into this region since its weight is stronger than the vacuum force.
- Blade alignment is critical to avoid “blade crashes,” when the blade hits the part being built and often delaminates the previous layer.

SL Machines

Platform System

- The platform system consists of a build platform that supports the part being built and an elevator that lowers and raises the platform.
- The elevator is driven by a lead-screw.

Vat System

- The vat system is simply the vat that holds the resin, combined with a level adjustment device, and usually an automated refill capability.

Optics System

- The optics system includes a laser, focusing and adjustment optics, and two galvanometers that scan the laser beam across the surface of the vat.
- Modern SL machines have solid-state lasers that have more stable characteristics than their predecessors, various gas lasers.

SL Machines

Control System

- First, a process controller controls the sequence of machine operations. Typically, this involves executing the sequence of operations that are described in the build file that was prepared for a specific part or set of parts. Commands are sent to the various subsystems to actuate the recoating blade, to adjust resin level or changing the vat height, or to activate the beam controller. Sensors are used to detect resin height and to detect forces on the recoater blade to detect blade crashes.
- Second, the beam controller converts operation descriptions into actions that adjust beam spot size, focus depth, and scan speed, with some sensors providing feedback.
- Third, the environment controller adjusts resin vat temperature and, depending on machine model, adjusts environment temperature and humidity.

SL Resin Curing Process

- Investigation into the fundamental interactions of laser energy with photopolymer resins.

C_d = cure depth = depth of resin cure as a result of laser irradiation [mm]

D_p = depth of penetration of laser into a resin until a reduction in irradiance of $1/e$ is reached = key resin characteristic [mm]

E = exposure, possibly as a function of spatial coordinates [energy/unit area] [mJ/mm^2]

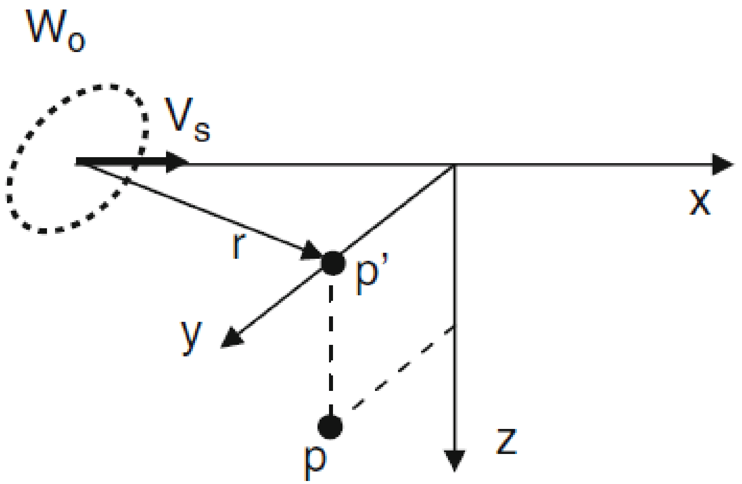
E_c = critical exposure = exposure at which resin solidification starts to occur [mJ/mm^2]

E_{max} = peak exposure of laser shining on the resin surface (center of laser spot) [mJ/mm^2]

SL Resin Curing Process - Irradiance and Exposure

the irradiance at any point x,y between $x = 0$ and $x = b$ is given by:

$$H(x,y) = \frac{2P_L}{\pi W_0^2} e^{-2x^2/W_0^2} e^{-2y^2/W_0^2}$$



SL Resin Curing Process - Irradiance and Exposure

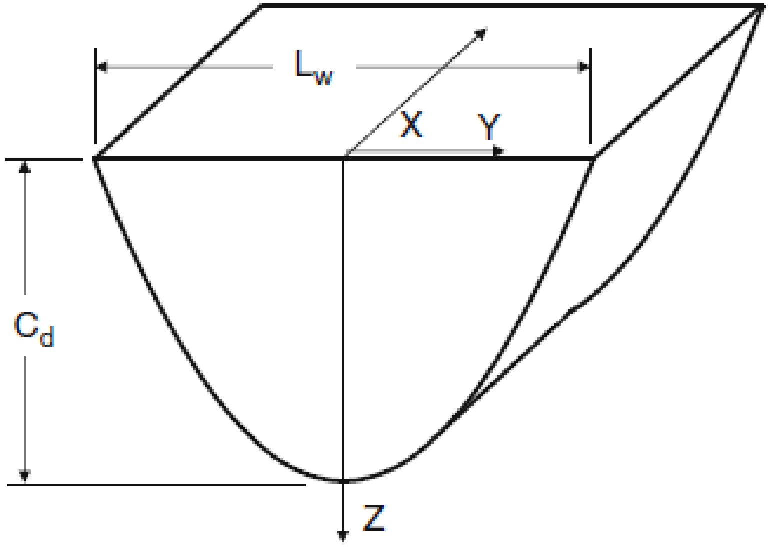
the fundamental general exposure equation:

$$E(x,y,z) = \sqrt{\frac{2}{\pi}}\frac{P_L}{W_0 V_s} e^{-2y^2/W_0^2} e^{-z/D_p}$$

SL Resin Curing Process - Laser–Resin Interaction

- The cross-sectional shape of a cured line becomes a parabola.

$$C_{\mathrm{d}} = D_{\mathrm{p}} \ln\left(\frac{E_{\max}}{E_{\mathrm{c}}}\right)$$



SL Resin Curing Process - Photospeed

- Photospeed is typically used as an intuitive approximation of SL photosensitivity.

$$V_s = \sqrt{\frac{2}{\pi}} \frac{P_L}{W_0 E_c} e^{-C_d/D_p}$$

SL Resin Curing Process - Time Scales

- On the short end of the time scale, the time it takes for a photon of laser light to traverse a photopolymer layer is about a picosecond (10^{-12} s). Photon absorption by the photoinitiator and the generation of free radicals or cations occur at about the same time frame. A measure of photopolymer reaction speed is the kinetic reaction rates, t_k, which are typically several microseconds.
- The time it takes for the laser to scan past a particular point on the resin surface is related to the size of the laser beam. This time is called the characteristic exposure time, t_e. Values of t_e are typically 50–2000 μs.