# Calculating how to squeeze the resin to the correct layer thickness

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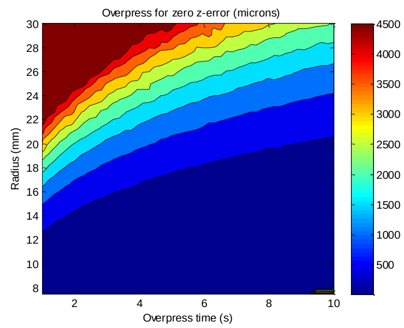
## Abstract

Errors in the layer thickness appear to be correctable by lowering the build head into the PDMS window and squeezing the resin out. The required deflections are on the order of millimeters, and add an additional 3-5 seconds per layer. These calculations are fairly fast, but the process appears to be easily described by a simple log-linear regression of the results.




## Introduction and force balance on the printer

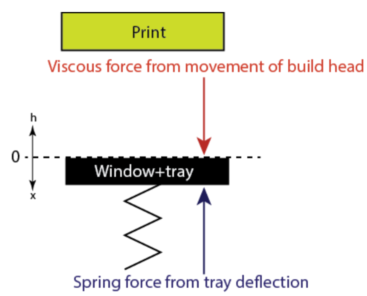



Figure 1. Diagram of the system

The deflection of the build tray platform can be described by considering two forces. The first is the viscous force resulting from the downward movement of the print and build head during the approach portion of the printing cycle. The second, the restorative force resulting from the deflection of the build tray platform as the build head approaches. The first force can be approximated via a known solution of the Reynolds equation for approximately unidirectional flows, which is itself a simplification of the Navier-Stokes equations in the absence of inertial forces. The force to separate (or compress) to rigid circular plates or radius, r, is given by,

$$F_{viscous} = \eta \frac{3\pi r^4}{2l(t)^3}\frac{dv}{dt} \qquad 1$$

where l(t) is the instantaneous separation distance, η the viscosity of the liquid, and dv/dt the relative velocity of the two plates. The second force is simply described that of a Hookean spring, with spring constant k, that is easily experimentally determined (0.0657 N/micron).

$$F_{deflection} = kx \qquad 2$$

Balancing these two forces gives,

$$\eta \frac{3\pi r^4}{2(x+h)^3}\frac{d}{dt}(x+h) = kx \qquad 3$$

where h describes the height of print above the zero force position of the tray. This equation can be rearranged as,

$$\frac{dx}{dt} = \frac{2kx}{3\eta\pi r^4}(x+h)^3 - \frac{dh}{dt} \qquad 4.$$

Numerical solutions of (4) are easily obtained, as shown in figure 2.

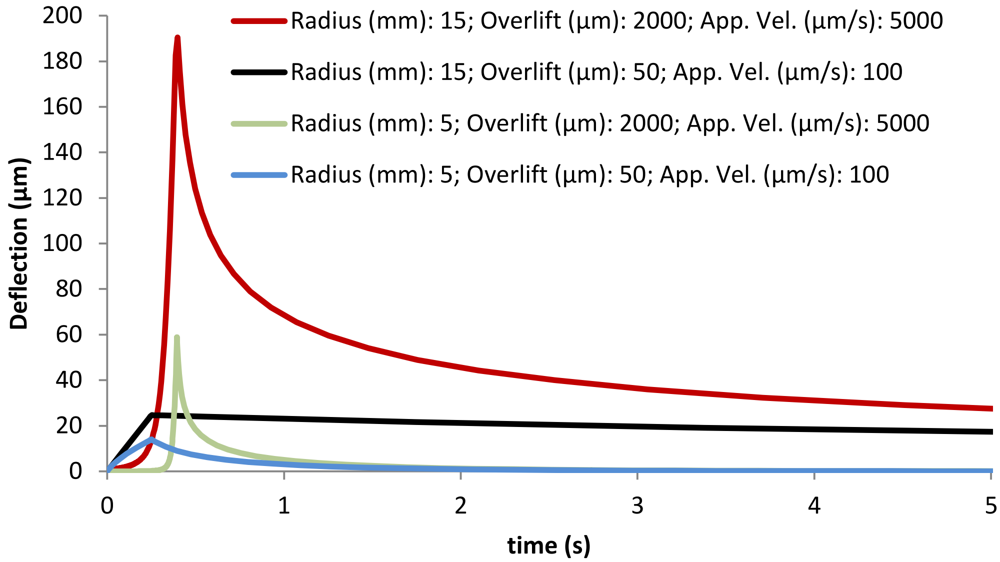



Figure 2. Solution of (4) for various conditions.

It is apparent from these solutions (and the known behavior of the printer) that substantial deviations from the layer thickness occur because the fluid does not have time to flow out from underneath the build head. This is more pronounced in viscous resins, but the cross-sectional area of the print and layer thickness plays a much larger role.

**Correcting for errors by "overpressing" the build head below the "zero' position**

By lowering the build head below the zero position the resin can be squeezed out between the print (or build head) and the PDMS window in a process that is described by (4). For these calculations the process was broken into three stages (**Figure 3**). In the first the build head approaches the layer thickness as fast as possible (5000 µm/s from a 225 µm overlift), it then moves below the next layer height (the *over press distance*) over a fixed period of time (*overpress time*), finally it returns to the next layer height over a fixed time (0.5 s). The times were defined rather than the velocity, so that the cycle would take a fixed amount of time.  An example calculation is shown in **Figure 4**.

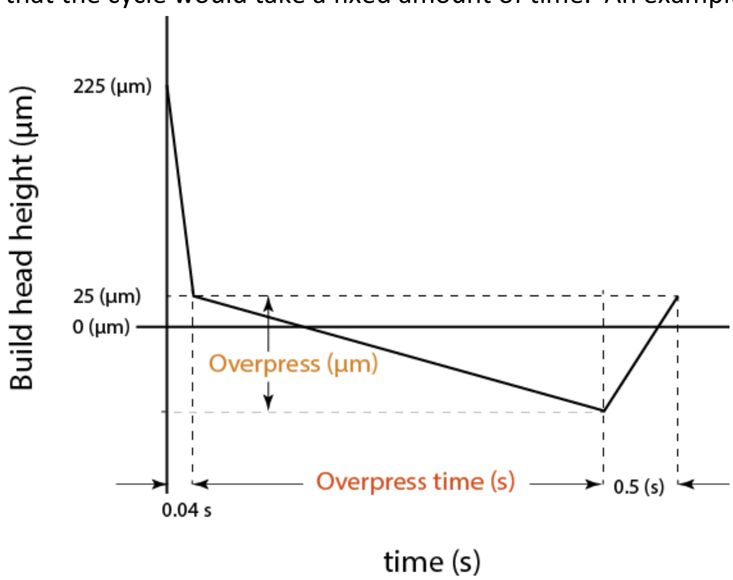



Figure 3. Description of the *overpress* cycle

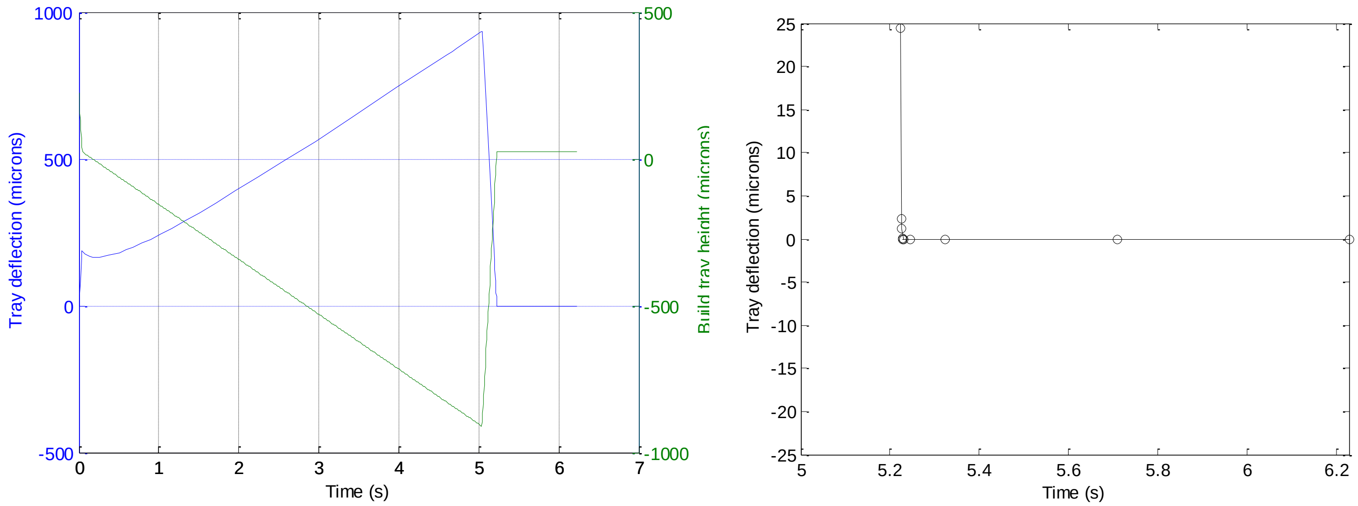



**Figure 4. For a 20 mm radius circle ad deflection of 935 µm over a 5 second period gives zero tray deflection when the build head reurns to the next layer height.**

The numerical solution to (4) can be obtained very quickly, so it is easy to calculate the final tray deflection for a variety of overpress distances (over a fixed time intervals, figure 5) and then find the zero using a bisection method as shown in figure (5).

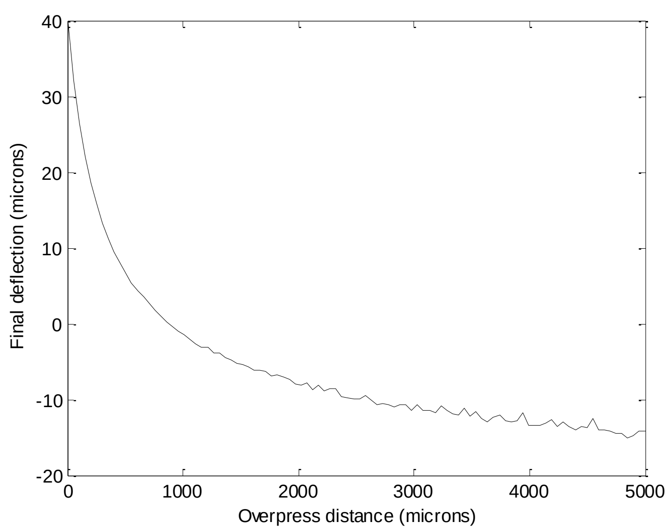



**Figure 5. Tray deflection when the build head returns to the next layer height for a range of overpress distances (20 mm circle, 5 s overpress time, 512 datapoints).**

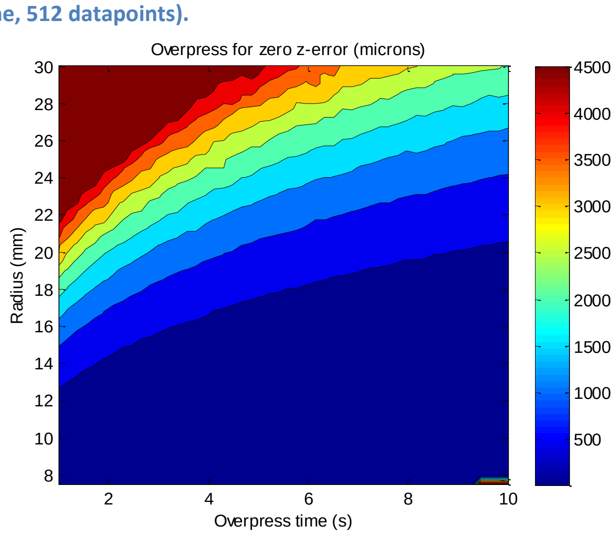



**Figure 6. Overpress (µm) required for a range of radi and overpress times.**

The data shown in figure 5 can be very well described by the following log-linear regression with an interaction term,

$$\ln(z) = a_0 + a_r \ln(r) + a_t \ln(t) + a_i \ln(r)\ln(t)$$

where z is the overpress that gives zero tray deflection, r the radius, and t the overpress time.

| | |
|---|---|
| **a0** | -5.061 |
| **ar** | 4.455315 |
| **at** | -1.79498 |
| **ai** | 0.317026 |

**Table 1. Constants for model**

To implement this into the printer one would first need to calculate a critical distance from the image slice, and then imput the likely user controllable overpress time. For full implementation a more complicated regression model would need to be obtained to account for the viscosity and layer thickness.