

# Design a Temperature controller for Direct Laser Deposition

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**Introduction**  
 Additive Manufacturing (AM) is a process of building parts layer by layer using a 3D model. Direct Laser Deposition (DLD) is a specific AM technique. It allows a laser beam to melt the surface of a metal powder bed to create the shape of a desired part. The process works by using the laser beam to heat the powder and the heat is conducted into the substrate. As the deposition progresses, the molten metal pool cools and solidifies to form the part layer by layer.



The following design focuses on a basic control loop of the system. Our study will focus on the temperature regulation.

**Output Signal**  
 The output signal is voltage. After setting a desired temperature starting from 0, the input voltage into the control system will control the voltage to the substrate that affects the temperature of the molten pool.

## Melt Pool Temperature Control

**Input Signal**  
 The input signal for the system is the temperature, which is regulated by the controller through voltage variation. To obtain real-time feedback information, we must extract the desired voltage from the current temperature of the molten pool. Two types of pyrometers can be used to measure the current temperature:

**Contact**  
 One of the pyrometer types measures temperature by detecting the thermo-electric electronic force generated by the temperature gradient at different ends, which is then converted into electrical signals for temperature measurement.

**Non-Contact**  
 The second pyrometer type uses infrared radiation to detect temperature. According to Planck's law, the energy emitted by a body can be expressed as follows:

$$E_{\lambda} = \frac{2\pi^5 k^4 T^6}{15 \hbar^3 c^2} \frac{1}{e^{\frac{hc}{\lambda k T}} - 1}$$

where  $E_{\lambda}$  is the spectral radiance of the body at wavelength  $\lambda$  and temperature  $T$ ,  $k$  is Planck's constant,  $c$  is the speed of light,  $h$  is Planck's constant, and  $\hbar$  is the reduced Planck constant. By knowing the geometry of the material ( $L$ ), we can calculate the thermal signal ( $T$ ) using the measured radiance values from the pyrometer.

## Control Parameters

The dynamic model is identified using second order state-space model with the form

$$\begin{aligned} \dot{x}(k+1) &= Ax(k) + Bu(k) \\ y(k) &= Cx(k) + Du(k) \end{aligned}$$

- $x$ : state vectors
- $y$ : output temperature
- $u$ : input driving voltage of laser power

$A$ ,  $B$ ,  $C$ , and  $D$  are the matrices defining the state space model, defined as

$$\begin{aligned} A &= \begin{bmatrix} -0.00187 & -0.01505 & 0.016227 & 0.00011625 \\ 0.01505 & 0.00187 & 0.21883 & 0.036113 \\ -0.016227 & 0.02293 & 0.33864 & -0.72384 \\ 0.00011625 & 0.02293 & -0.42702 & -1.05477 \end{bmatrix}; \\ B &= \begin{bmatrix} 0.000307 \\ -0.000307 \\ 0.02293 \\ -0.02293 \end{bmatrix}; \\ C &= \begin{bmatrix} -0.00768 & 0.26713 & -0.0872 & -0.7855 \end{bmatrix}; \\ D &= 0. \end{aligned}$$

## Control Process

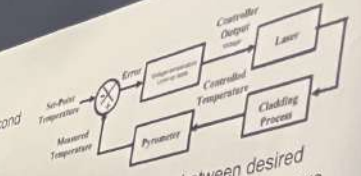
The control system design is based on a feedforward control loop. The first step is to generate a voltage-temperature lookup table using the following design diagram.



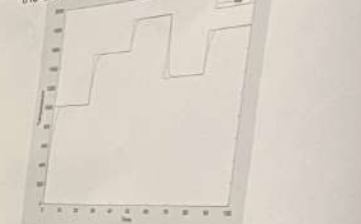
Since every voltage has its unique temperature output, when we get a temperature output, we can inversely find the voltage input.

For example, when we have 1.42V, the temperature output is 2191.2°C, vice versa.

To start with temperature controller, we first need to set the temperature we desire into the control model. The initial voltage state is set as 0. The figure below is the control diagram we build.



By getting the difference between desired temperature and measured temperature, we iteratively run the control model and settle down the device at its desired temperature.



The above figure shows how temperature desired to change and in real. We can see there will always be delay to change from one temperature to another. Code added below as reference.

```

% Parameters
A = [-0.00187 -0.01505 0.016227 0.00011625;
     0.01505 0.00187 0.21883 0.036113;
     -0.016227 0.02293 0.33864 -0.72384;
     0.00011625 0.02293 -0.42702 -1.05477];
B = [0.000307;
     -0.000307;
     0.02293;
     -0.02293];
C = [-0.00768 0.26713 -0.0872 -0.7855];
D = 0;

% Initial state
x0 = zeros(4,1);

% Reference temperature
T_ref = 2191.2;

% Voltage-temperature lookup table
% (This part would be implemented as a table or function)

% Control loop
% (This part would be implemented as a loop)
    
```

## Conclusion

DLD has a bright and wide application scenarios in the future. With feedforward control system, the DLD will self-correct and have less flaws and defects on the produced parts. This poster shows a possible method of achieving it.

Mentor  
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