Parameters setting of selective laser melting machine

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Abstract. Additive Manufacturing or Selective Laser Melting, in particular, has been used in industries in a vast number of applications since the 1980s. It has become common in various manufacturing processes, ranging from car engines, ships, and building constructions. In Additive Manufacturing applications, getting better accuracy and surface roughness as the main criteria with time efficient are challenging tasks that requires understanding of the fundamental Selective Laser Melting process. This study will investigate the relationship of process parameters and system parameters in Scanner Head Control, experimentally. Following the given result of this work, the machine operators will be able to understand the root of systems dynamics, the effects of process parameters, and speed up the initial setting with time efficiency.

1. Introduction
Additive manufacturing (AM) has become a trend in manufacturing technology in recent decades. It has developed for decades as 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), Selective Laser Melting, and Selective Laser Sintering (SLS) in many industrial applications [1, 2]. In the case of SLM, it is an Additive Manufacturing (AM) technique, in which laser power will melt powder alloys on a platform, layer by layer. This manufacturing technology has proved the potential of an existing procedure to fabricate frameworks for complex objects with flexibility, mass customization, and low material waste. This type of manufacturing also can be applied to various materials such as Fe, Ni, and Cu [3-5]. Although this technique is with many advantages, encountered problems in SLM are surface quality and shape accuracy that is related to process and motion control in terms of laser motion and system dynamics. In order to tackle these problems, some researches tried to optimize these parameters that influence processes such as scanning speed local geometry, oxygen content, and powder properties [6, 7]. During manufacturing process, the laser spot characteristics, such as spatial distribution and colour temperature, were monitored by camera to improve fabricated products [8, 9]. However, there is a gap in finding the experimental solutions for setting the procedure of process parameters based on the galvanometers systems’ behaviour which is a major issue for tuning parameters for the laser motion controller called Scanner Head Control (SHC) [10].

This study aims to find out the relationship between system dynamics and motion of galvanometer systems experimentally. It also presents an overview of SLM process and points out these compensated parameters on final fabricated commercial products. The following objectives were presented:

- Understand about SLM controller system, Laser control;
Analyze the effects of Delay parameters;
Provide a procedure for setting Delay parameters.

2. Experimental framework
In the following experiments, the motion of mirrors was identified by conducting measurements on the fabricated workpiece's marked line.

2.1. Apparatus
Since the machine with any inconsistency setting may give poor accuracy and validity of the experimental results, all hardware and software of the machine need to calibrate to ensure that the apparatus used throughout the experiments were in an optimal state and remained consistent throughout the study. Several unlisted parameters, such as air pressure, ambient temperature, and humidity, were provided by the user technical manual and kept constant during all experiments. All of the measurements were acquired using the Optical Measurement Machine (OMM) [11]. The material Titanium Alloy-Ti6Al4V samples were fabricated using an SLM-AM250 machine equipped with a fiber laser power-500W with a spot size of 50um and scanning speed of 900mm/s. The laser spot on platform was controlled by two mirrors in the galvanometer system of SHC [10].

2.2. Experimental details
Movement of laser beam and delay times of laser directly indicate on melted Ti6Al4V plate material. When laser beam moves, the heat-affected zone of the laser within a half linewidth in the radius is homogeneous. The transient and end zone, at the time laser beam powered on and off is a semicircle, as shown in figure 1. By the assumption that the linewidth keeps constant along the path, if the boundaries of starting and end zone can be identified, it implies that the center of laser spot size should be identified.

![Figure 1. Terminal geometry of a melted vector (D is the laser beam diameter).](image)

There are two parts in SHC changes when executing commands, including the mirrors - physical part and laser power - an electronic part. Since the bandwidth of electronic components is far higher than in physical parts, two kinds of delay parameters are added into SHC to compensate for the lagging in between. This is to keep laser intensity in constant along the designed path and reduce the processing time. The delay time includes Laser Delays (On/Off) and Scanner Delays (Jump/Mark/Polygon).

The designed experiments were conducted to find proper parameters based on effect zones of delay parameters. The designed path is fundamental in the construction of complex shapes. The beginning and end of each line in the designed path was involved at least one or two Delay parameter. For example, at a starting point of Mark command, the mirrors execute a Mark command right after the Jump command. It means that at starting points of Mark command involve the Jump Delay effects.
Moreover, at the transient zone, the laser power is switched from Off to On state. Therefore, the transient zone must involve Laser On Delay.

On the contrary, the motion of mirrors changes from executing a Mark command to stop in the end zones. Therefore, end zone must involve Mark Delay. Similarly, the laser power is switched from On to Off state at the end zone, which means the end zone must involve the Laser Off Delay. If a further Mark command follows a Mark command, Polygon Delay will be inserted instead of Mark Delay. Thus, the effects of Mark Delay on the end zone must change to the effects of Polygon Delay, instead.

![Figure 2](image)

**Figure 2.** Designed path; (a) dimensions (unit: mm); (b) denote zone.

The input setting of Laser and Scanner Delays were set in a large range from 20us to 590us (given in Appendix). The experimenting process was considered to show the effect of single parameters by fixing either Laser Delays or Scanner Delays. Thus, the effect of Laser and Scanner Delays were visible in different areas. The details of its effects are shown in table 3, following denotes in figure 2.

**Table 1.** Effective areas of Delay parameters.

| Zone | Effects of Delay parameters Specimen 1–9 | Specimen 10–18 |
|------|------------------------------------------|---------------|
| h1   | Laser On Delay                          | Jump Delay    |
| h2   | Polygon Delay                           | Polygon Delay |
| h4   | Laser Off Delay                         | Mark Delay    |
| h6   | Laser On Delay                          | Jump Delay    |

All of the 1–9 experiments, by using fixed Scanner Delays, including Jump and Mark Delays, the Laser Delays caused the topology at each zone at the beginning of each Mark command (zone h1, 4, and 6). These experiments, from No.10–18, were accompanied by using vary Scanner Delays (Jump, Mark and Polygon), and fixed Laser Delays. The measurements were conducted at zone h2, h4 and h6, following denote in figure 2(b).

**3. Results and Discussions**

**3.1. Effects of Laser Delays**

The differences in the obtained distances value of d1 and d4 are clearly visible and result from Laser Delay values’ varied settings. The value of d1 was increased with a longer value of Laser On Delays. The value of d4 decreased with a longer value of Laser Off Delays. Figure 3 shows the relationship between Laser On Delay and distance d1. Since the designed distance of d1 is 5mm, the Laser On Delay needs to set equal to 173us. Similarly, the Laser Off Delay requires to be 450us.
3.2. Effects of Scanner Delays

The effect of Scanner Delays was obtained from concept number 9 to 18, changing its values and using fixed Laser Delays in figure 2. The Mark Delay was defined as the distance d4. The Jump Delay, the effect zones were divided into horizon and vertical. In figure 5 and 6, there are significant changes in both vertical and horizontal direction in the zone h1. With the Jump Delay smaller than 100us, the errors are about 0.25mm in both directions, making a large contour error in total. The errors tend to be in steady states when Jump Delay set larger than 200us. This can explain that when Jump Delays are longer than the systems’ settling time, the error caused by this Delay parameter becomes a single value.

The Mark Delay effects were visible at the zone h4, and the distance d4 was used to evaluate the Mark Delay because in this zone is at the end of Mark commands. Following the indicating trend in figure 7, when the value set larger than 150us, the distance d4 tends to keep constant values. This means that the motion part needs more than 150us to be settling after executing Mark commands.

The Polygon Delay was validated in the corner errors because, at the corner zone h2, there are two consecutive Mark commands. Figure 9 shows the un-sharps and burn-in effects at the corner. The corner errors tend to a steady-state value with the setting of Polygon Delay of 160us in figure 8.
Figure 7. Effects of Mark Delays at zone h4.

Figure 8. Corner errors with variant Polygon Delay values at zone h2.

Figure 9. Polygon Delay; (a) un-sharp with low value; and (b) burn-in effects at the h2 zone with high value.

4. Conclusions
The purpose of these analysing methods experimentally is to understand the SLM system and the effects of the Delay process parameters. In these experiments, the movement of mirrors was identified basing on melted vectors on materials. However, the uncertainty of determining boundaries of melted vectors caused uncertainty in measurement results. Also, experimenting with Ti6Al4V, some disturbances caused unreasonable and bias data resulting from Laser Delays. The reason could be listed:

- The experiments were focused on laser spot size and compensated parameters;
- The engineer might input wrong or mark the sample cause to singular data;
- The particle materials, and other environment conditions were not suitable.

Table 2: Obtained parameter thought out experiments.

| Parameters     | Obtained value(us) |
|----------------|--------------------|
| Laser On Delay | 168–173            |
| Laser Off Delay| 450–460            |
| Jump Delay     | 200                |
| Mark Delay     | 150                |
| Polygon Delay  | 100–160            |
By applying in a varied setting, obtained results demonstrate the relationship between the effects of Delay parameters and changes in related measurement as expected utility theory. Thus, finding an experimental procedure based on the fabricated prototype is a feasible scheme as following steps:

Step 1: Provide a well-designed path which should include:
- A Jump command to Mark command to involve Laser On and Jump Delay;
- An endpoint of Mark command to involve Laser Off and Mark Delay;
- Two consecutive Mark command to involve Polygon Delay.

Step 2: Setup the machine and manufacture one by one with these parameters in the ranging of Predicted value +/- n*(step change). (n=0…4; step change = 20us).

Step 3: Measure these fabricated products.

Step 4: Use curve fitting for Laser Delays and plot these values of Scanner Delays.

Step 5: Evaluate the measurement results.

5. Future work
Although this study presented the galvanometer's motion, other factors such as absorption and absorption rate of material, inert gas, and humidity of environment and particle size need to be taken into consideration to get a better performance in SLM machine. Further research on observation for transient response in the starting and end zones will be required, specifically in evaluating the lagging in motion and laser control. Thus, setting up peripheral equipment such as High-Speed Camera for supporting to do systems identification are needed for fundamental research.

Appendix: Range of setting Delay parameters
In the Scanner Head Control, there are two specifications dynamic range in concern which are Step response time and tracking error (unit: time). Since the *Step command* can be understood as a Jump command with a big change, Jump/Mark Delay must be smaller than Step response time. If Jump/Mark Delay set equal to Step response time, these effects of Jump/Mark Delay will not visible on fabricated products. Range of setting for Laser Delay was according to the recommendation from technical manual of SHC. In the model intelliSCAN® III 20, Step response time and Tracking error are 700us and 320us, respectively. From the definition of the manufacturer [10]:
- Step response time is the time interval required to execute a jump over a specified distance;
- Tracking error is the time interval between the set and actual positions when traversing a vector.

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