Control of Parameters for Additive Layer Manufacturing using Laser Consolidation

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Abstract

Additive Layer Manufacturing (ALM) is a blanket term which describes processes which enable the direct fabrication of parts through an additive rather than a subtractive process such as milling. This paper looks at the control systems necessary for Laser Consolidation (LC), a powder fed based ALM process which aims to manufacture net-shaped parts directly in one step with little or no finishing. The paper investigates the LC process and examines the possible impact of a number of variables within the system including laser power, powder flow and system movement speed.

We define the term Additive Layer Manufacturing (ALM) as a blanket term which describes processes which enable the direct fabrication of parts through an additive rather than a subtractive process. ALM covers processes such as Rapid Prototyping (RP), Rapid Manufacturing (RM), Solid Freeform Fabrication (SFF) and Direct Metal Deposition (DMD) amongst others. ALM technologies can be considered in two base classes, bed based or fed (or head) based. Both classes take a layer-by-layer approach to fabrication and often start with a Computer Aided Design (CAD) file being sliced into a stack of layers by a virtual slicing plane within some software package. The intersections between the virtual plane and the CAD model describe the perimeter of the part at a particular height away from the build substrate or bed. This process is common to almost all ALM systems [1].

The key difference between bed and fed build processes is that the bed based approach requires at least enough powder or liquid to completely encapsulate the part being manufactured whereas fed based techniques usually only add material as needed. Examples of powder bed based system include Selective Laser Sintering (SLS), Selective Laser Melting (SLM) and, for liquid bed based systems, Stereo Lithography (SLA). Fed systems include Laser Consolidation (LC) and Filament Deposition Modelling (FDM) amongst others.

ALM systems also basically sub-divide into two other categories: metallic and polymeric. Polymer based systems have existed for longer than metallic systems primarily due to the evolution of the technology associated with melting polymers and metals with powerful lasers. Rapid Prototyping (RP) was the first use of ALM, whereby models or prototypes were manufactured using an additive technology. The term “rapid” was used because the process was comparatively fast compared with traditional hand manufacture of prototypes. However, RP is a misnomer – the process has never been rapid, and often takes days or hours rather than minutes or seconds. RP in recent years has looked at reducing the time taken to manufacture prototypes and has continually increased the accuracy and surface quality of components produced.

Post cursor to RP was Rapid Manufacturing (RM), a term intended to connect with the roots created by RP but which was comparatively much slower even than RP [2]. One of the reasons that RM is still unpopular as a manufacturing technique is that the process is far from rapid and often leads to a sense of disappointment [3].

Laser Consolidation is a metallic powder fed ALM technology which aims to make net-shape parts in one step [4]. Processes such as LC represent a new frontier in ALM in which sheet-like metallic components can be manufactured to a high degree of accuracy. Powder fed systems such as LC offer promising advantages over bed based systems: parts are metallurgically sound, have high strength and ductility and powder supplies can be changed, theoretically at any time during the build, eventually leading to graded parts [5]. Of particular interest for LC is the ease of which scale-up could be applied. Because the LC process fundamentally simply melts a metal powder with a laser beam, by adding more laser energy and more powder, larger parts could be manufactured at the same rate as smaller parts, thus scale-up becomes straightforward.

The anisotropic nature of all current ALM systems is a drawback from mainstream acceptance, but understanding the process will help to alleviate this apprehension. Currently, most ALM system do not implement closed loop feedback and control, often leading to unexplained build failures or uncontrolled material characteristics in the parts produced. This is particularly true of powder-fed systems such as LC, partly due to their relative immaturity when compared with certain RP systems.

Here, we consider the major variables responsible for affecting both the success of part fabrication and the mechanical quality of the parts produced.

Laser Consolidation is effectively a coupling of three core technologies: an Nd:YAG laser delivered via fibre; an industrial standard powder feeder unit and a motion control system (see figure 1). The equipment is configured such that a laser beam melts metal powder sprayed into the beam as a motion control system moves the substrate and any previously deposited material underneath the head assembly. If the process is completed at the appropriate rate then a smooth fine wall is created. By changing direction with the motion control system walls of different directions can be created, one attached to the other. By moving two or more axes at once smooth curves can be created.

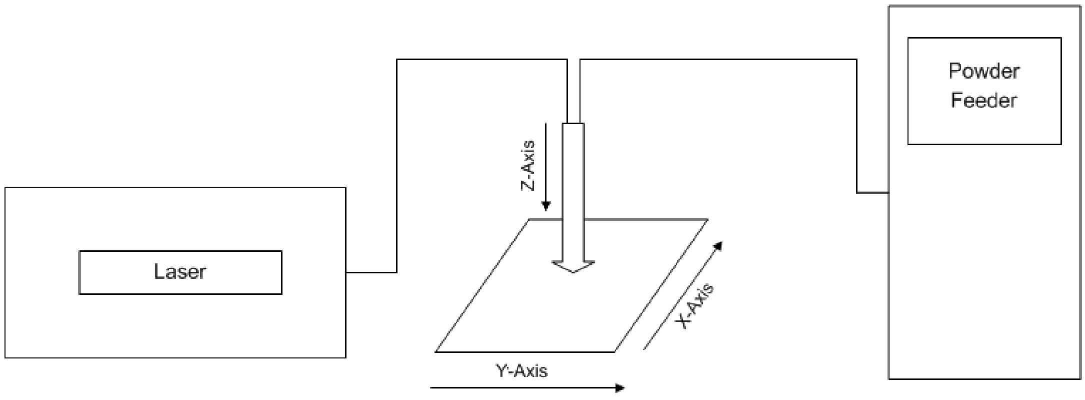

Figure 1 - LC Process Diagram

A critical aspect of LC is that sufficient energy is imparted upon the powder by the laser in a given time to enable it to melt without it being vaporised. If insufficient energy is supplied then the powder will not fully melt and either the part will fail to build or the mechanical properties of the part will be lower. If too much energy is applied then the build powder is wasted, the part may fail to build and mechanical properties are variable. Either of these results is unsatisfactory.

A secondary critical component to successful LC building is that the laser head unit should move away from the substrate or previously added material at the correct rate so that new powder being deposited is added at the focal point of the laser coincident with the top of the previous surface. If the rate of build up is too fast or step up height in the Z direction is too low then wall thickness increases due to the divergent nature of the laser beam and average energy across the surface is lower. This may eventually cause build failure. If step up height is too high or build up is too slow then the previously built sections will effectively move away from the laser head as it steps up causing build failure to occur due to energy density reduction.

It can be seen that a number of variables affect the build quality, accuracy and mechanical properties of the parts fabricated using LC. Critical variables have been identified through experimentation and include pulse energy, pulse duration, pulse frequency, motion system speed, mass of powder flow per unit time and carrier gas flow per unit time.

This paper aims to illustrate how the important variables can be monitored and recorded in order to understand their effect on both success and quality of the build. System control will be discussed with particular attention paid to the modification of the build parameters during build time to improve the mechanical properties of the parts produced.

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