THE INFLUENCE OF A DYNAMICALLY OPTIMIZED GALVANO BASED LASER SCANNER ON THE TOTAL SCAN TIME OF SLM PARTS

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Abstract

Most commercially available Selective Laser Melting (SLM) machines use galvano based laser scanner deflection systems. This paper describes the influence of the dynamical optimization of such galvano based laser scanner on the total scan time. The system identification of a galvano laser scanner was performed in combination with the development and implementation of an optimal 'Input Shaper'. Tests were performed on lattice structured SLM parts. The process time was hereby compared, with and without the use of the optimal 'Input Shaper'. Significant scan time reduction was observed when using the optimal 'Input Shaper'.

Introduction

Selective Laser Melting (SLM) is an Additive Manufacturing technique which enables the production of complex functional metallic parts with good mechanical properties. A schematic set-up of a typical SLM machine is shown Figure 1. In the SLM process, first, a thin layer of metal powder is deposited on a build platform by means of a powder coating system. After depositing, the powder layer is melted selectively according to a predefined scanning pattern, by a laser source [1] and a laser deflection system. After scanning a layer, the build platform moves down over a fixed distance equal to the thickness of one powder layer (in SLM typically 20 to 40 µm) and a new layer is deposited and scanned. The sequence of depositing and scanning is repeated until the part(s) is (are) fully built.

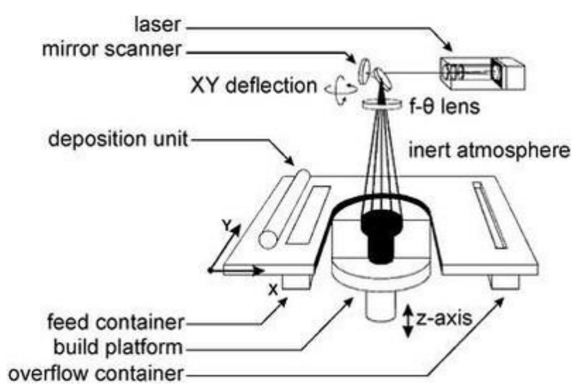

Figure 1: Schematic overview of SLM process

In recent years, the SLM technology has made an enormous progress in machine construction, production speed and part quality. Since material properties of SLM parts are nowadays comparable to the properties of the corresponding bulk material [2, 3], applications of the process can be found in domains like the medical sector [4], in tool-making industries [5–8], machine construction, aerospace, etc. However, for an even larger breakthrough of SLM in industries, which demands high quality parts and low production time and thus lower cost, the SLM process must be further time optimized.

Most commercial SLM machines available today are equipped with a galvano based laser deflection systems (galvano scanner) to deflect the laser according to the predefined scanning pattern. Throughout this paper it will be shown that the dynamical optimization of the galvano scanner plays a vital role in the reduction of the total process time.

Experimental Setup

The dynamical optimization was performed on an in-house developed SLM machine (LM-Q). This machine is fully controlled by the industrial NI-PXIe-1082 system in combination with the NI-PXI-7853R FPGA card from National Instruments. The LM-Q machine is equipped with a 300W-1064nm fiber laser and a ScanLab HurryScan25 galvano scanner.

National Instruments LabVIEW in combination with the LM-Q PXI controller was used for the dynamical measurements on the ScanLab HurryScan25 galvano scanner.

Mathworks Matlab was used for the system identification of the galvano scanner and the development of the optimal 'Input Shaper'.

Results and discussion

When scanning a SLM part, the machine controller sends a series of vectors to the galvano scanner. In essence only two types of vectors are used, namely 'jump-vectors' and 'scan-vectors'. When executing a jump-vector, the mirrors will move as fast as possible to the new coordinate without laser power, whereas when executing a scan-vector, the mirrors will move to the new coordinate with a predefined scan speed and laser power. The desired scan pattern is determined by the combination of jump- and scan-vectors.

Modern galvano scanners are designed with an optimized PID control loop to guarantee correct movement of the mirrors. This PID control loop is specifically designed for the physical properties of the galvano motors and mirrors (damping, inertia,…). However, even with the implementation of such a PID control loop, the position of the mirrors will suffer from oscillations due to the high dynamical excitation of a (fast) jump-vector. Figure 2 shows the dynamic effect of a jump-vector. The real position follows the desired position after a specific (acceleration) time. At the end of the jump-vector, the oscillations are clearly visible. To compensate for this unwanted effect a fixed delay (jump-delay) must be used (typically 750µs to 1ms) until the oscillations die out. Executing a new vector is only possible after this 'dead time'. This jump-delay results in huge time loss, mainly when manufacturing lattice structures containing a lot of very short scan vectors and where the total scan time is dominated by jump-vectors/jump-delays.

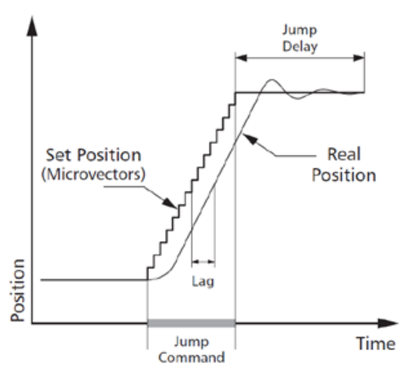

Figure 2: Jump-vector response [9]

A better solution is the use of a 'preshaping' method where all vectors are transformed in such a way that the system vibrations are kept to a minimum [10]. This can be achieved by the development of an 'Optimal Input Shaper'. When implemented, the Input Shaper will transform all the vectors before sending them to the galvano scanner. Figure 3 shows a schematic overview of the control setup. The development of the 'Input Shaper' on the LM-Q SLM machine will be further explained in the next four sections.

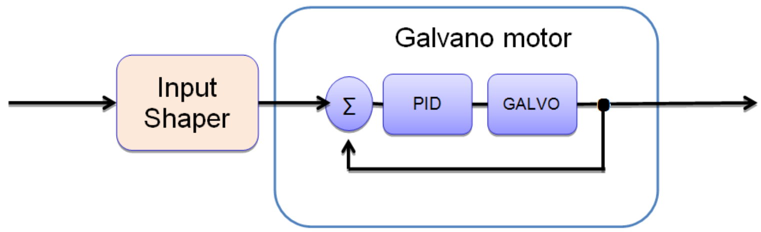

Figure 3: Schematic control overview

1. System Identification

The dynamic behavior of the galvano scanner was obtained by exciting and recording of the actual position of one of the galvano motors with a chirp signal. The excitation chirp signal has a start frequency of 10Hz and a stop frequency of 2kHz. The amplitude was set to 100bit with a measurement period of 1s. The system model of the galvano motor was estimated with the response behavior on the chirp signal and a 'non-linear least squares' system estimator.

As a result of the 'non-linear least squares' system estimation, the following model was obtained:

$$galvano\ motor\ model = \frac{1.242e11}{s^3 + 9517s^2 + 5.773e7s + 1.272e11}$$

Figure 4 shows the Bode plot of the measured system and the estimated model.

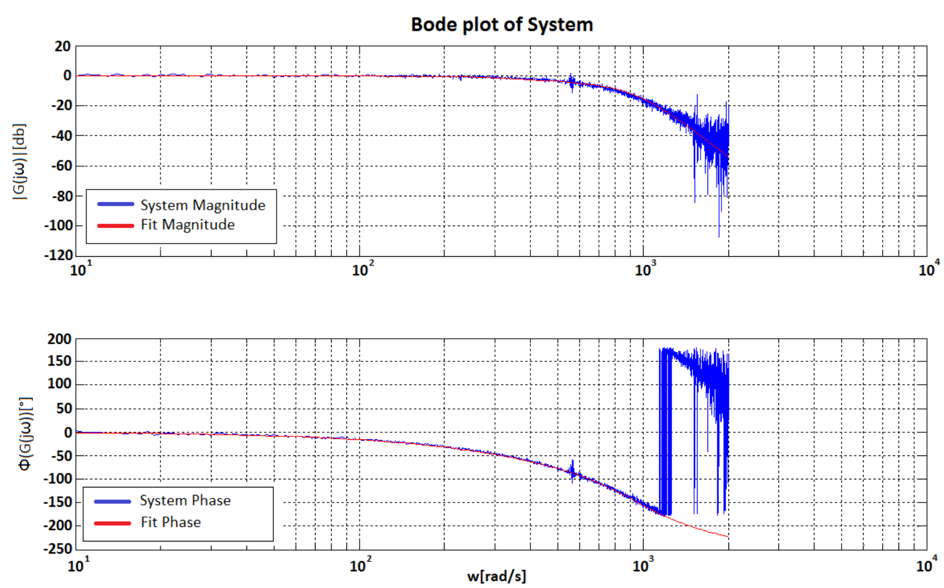

Figure 4: Bode plot of estimated galvanoscanner system

2. Optimal 'Input Shaper'

The system model of the galvano motor is further used in the development of the Input Shaper. The Input Shaper is developed by inverting the system model of the galvano motor. In addition, four extra poles are placed at 3000rad/s (6 times the cutoff frequency) for system stability. After this transformation the following Input Shaper was obtained:

$$Input\ shaper(continuous) = \frac{3.99e17s^3 + 3.797e21s^2 + 2.303e25s + 5.075e28}{1.272e11s^4 + 1.279e16s^3 + 4.82e20s^2 + 8.076e24s + 5.075e28}$$

$$Inpus\ shaper(discrete) = \frac{19.61z^3 - 56.99z^2 + 55.26z - 17.88}{z^4 - 3.111z^3 + 3.63z^2 - 1.882z + 0.3659}\ [fs = 1e-5]$$

Figure 5 shows the Bode plot of the galvano motor system model, the inverted galvano motor system model and the obtained Input Shaper with four added poles for system stability.

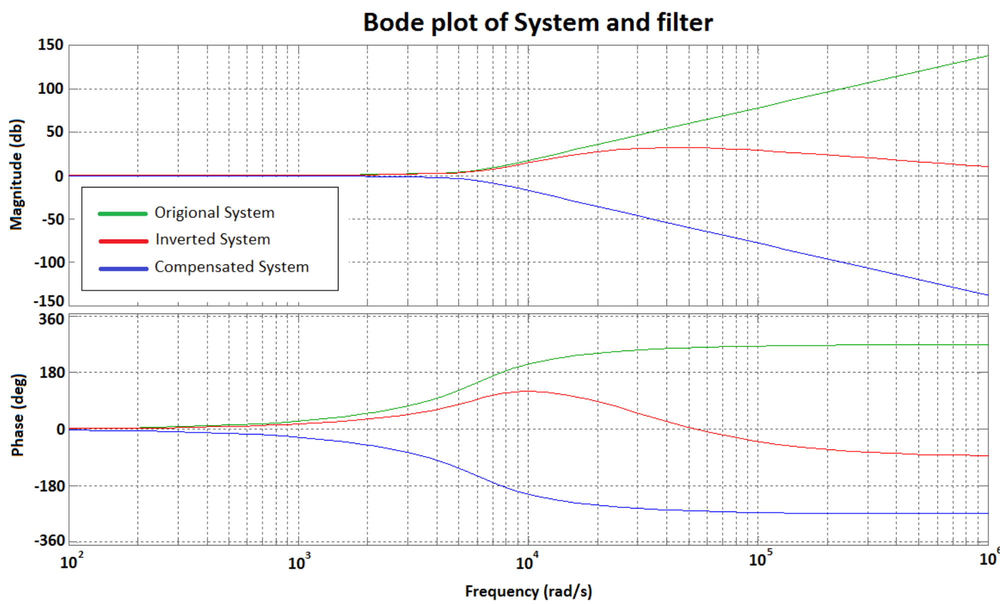

Figure 5: Bode plot of estimated galvanoscanner system, inverse of galvanoscanner system, designed input shaper

3. Validation

After the implementation of the Input Shaper, the system was validated with and without activating the Input Shaper. Figure 6 shows the response behavior (starred green line) of the galvano motor on a jump-vector (green line). When the Input Shaper is activated the jump-vector is transformed by the Input Shaper and becomes a transformed jump-vector (blue line). The response behavior on the transformed jump-vector is represented by the starred blue line. When comparing the two response behaviors, it can be noticed that both the position lag and the settling time have reduced by a factor two. Due to the reduction in position lag the jump delay can also be reduced by factor two.

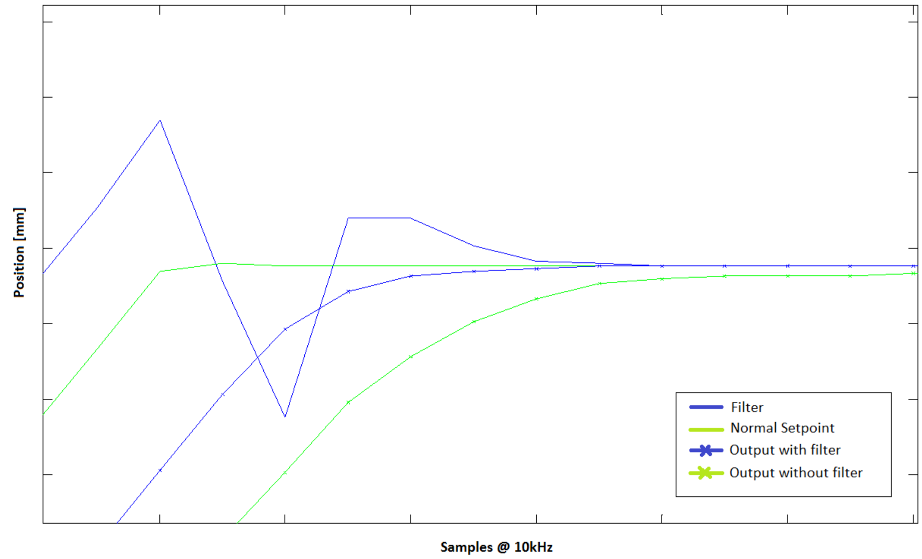

Figure 6: Position validation of the Input Shaper

Figure 7 portrays the representation of the speed response of the galvano motor with and without the activation of the Input Shaper. The blue line represents the velocity profile when the ‘Input Shaper’ is activated; the red line represents the velocity profile when the ‘Input Shaper’ is not activated. When the Input Shaper is activated, the nominal speed is achieved 25% faster.

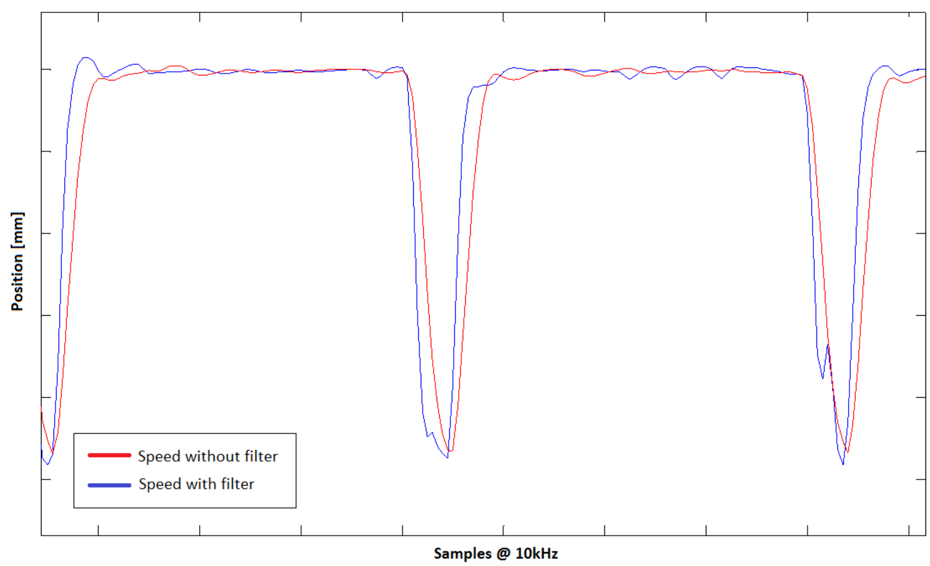

Figure 7: Speed validation of the Input Shaper

4. Test case

As test case, a lattice structured ‘Stanford Bunny’ [11] with open pores, a strut thickness of 250µm and a volume fraction of 5% was produced: see Figure 8. Two jobs were executed, one with and one without activation of the ‘Input Shaper’. The jump-delay was reduced from 750µs to 250µs. During these jobs, the actual position of the galvano motor was logged and the total scan time was calculated. The implementation of the ‘Input Shaper’ results in a total scan time reduction of 10% for this lattice structured bunny, from 4686 to 4219 sec.

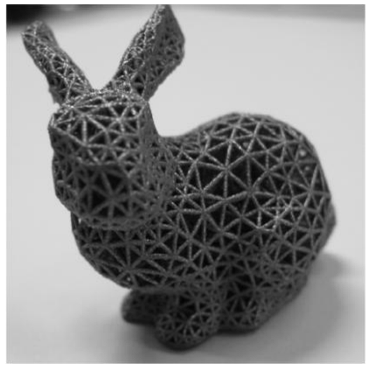

Figure 8: Test case - Porous ‘Stanford Bunny’ [scale 1:1]

Conclusion

The galvano scanner of KU Leuven’s LM-Q SLM machine was dynamically optimized. This was done by the development and implementation of an optimal ‘Input Shaper’ based on the system identification of the galvano motors. Due to the higher dynamics, nominal speed can be achieved twice as fast; furthermore the ‘position lag’ is reduced by 50%. The greatest benefit of the optimal ‘Input Shaper’ is noted when manufacturing lattice structured parts. In the test case of the ‘Stanford Bunny’ total scanning time was reduced by 10% from 4686 sec to 4219 sec.

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