Joint Special Interest Group meeting between euspen and ASPE
Advancing Precision in Additive Manufacturing
KU Leuven, Belgium, September 2023
www.euspen.eu

Legacy laser powder bed fusion systems and obsolescence: Upgrading control systems

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Abstract
The Additive Manufacturing (AM) market has experienced substantial growth, accompanied by a parallel increase in the number of Laser Powder Bed Fusion (LPBF) systems. This rapid growth has fostered rapid technology advances and with that rapid obsolescence, especially on the digital side of these systems. Thus, industrial LPBF systems are in the risk of being decommissioned solely from effects linked to legacy control systems, limiting their potential utility and integration into modern manufacturing infrastructures. Nevertheless, these legacy systems often possess high-performing specialized hardware, which still retains substantial longevity. To address this challenge, this paper proposes an innovative approach - the development of a unified PBF systems controller as part of the Open Additive Initiative. By updating the control system, this paper suggests the possibility of reintegrating legacy machines into current manufacturing systems, thereby reducing the economic and environmental burdens associated with purchasing new machines.

Open Source, Laser Powder Bed Fusion, Additive Manufacturing, System Control

1. Introduction

The Additive Manufacturing (AM) market has experienced rapid growth over the past decade. From 2021 to 2022, the revenue attributed to AM services and products increased by 17%[1]. Similarly, the sales of industrial Laser Powder Bed Fusion (LPBF) systems have also witnessed a significant rise. However, due to the proprietary nature of most industrial LPBF systems, legacy machines that fall outside of service agreements hold little to no value for their owners.

These legacy systems have become obsolete primarily because of their proprietary legacy operating systems. Consequently, they cannot be accessed, updated, or integrated into modern manufacturing facilities, nor can they contribute to state-of-the-art research infrastructure. As a result, system owners who wish to retain LPBF capabilities find themselves compelled to purchase new LPBF systems. Nonetheless, the legacy systems often include specialized hardware that still offers substantial longevity and performance comparable to their modern-day counterparts.

To address this issue, the Open Additive Manufacturing Initiative at the Technical University of Denmark (DTU) has developed a unified systems controller. This controller provides an alternative to the obsolescence of legacy AM systems.

2. Market

The evolution of Additive Manufacturing (AM) into viable means of industrial manufacturing has led to a substantial increase in market revenue. Particularly, the market for metal AM systems has shown a significant growth since 2002. Recent data from 2022 to 2023 indicates a 27.2% increase in the number of machines sold [1].

The rising number of machine sales suggests that the potential of AM is being realized. However, the entry cost for metal AM remains substantial, with an average machine price of 410,000 EUR in 2022 [1]. As a result, this technology is still primarily accessible to high-end manufacturers or specialized AM solution providers. As AM becomes more accessible as a manufacturing technology, the number of viable use cases increases.

To fully harness the potential of any AM technology, machinist operators or part designers, who may have expertise in conventional subtractive manufacturing, require proper training and a significant effort to understand the possibilities of developing parts layer by layer[2]. This learning curve can be quite steep. Consequently, end-users who lack the economic capacity and trained personnel may be excluded from metal AM.

Recently, machine providers have emerged, offering more economically viable products. Backed by larger market-relevant partners, companies such as One Click Metal GmbH are able to enter a relatively unrealised market - the industrial low-end metal AM machine market.

3. Legacy Systems and Obsolescence

The machines that have already been sold, as well as many of the currently shipped systems, are proprietary, which imposes limitations imposed by the vendors. This restrictive approach allows vendors to maintain strict control over both the machines and the market. Considering the qualitative challenges that still persist in Laser Powder Bed Fusion (LPBF), this strict control over parameters and feedstock enables some degree of consistency in part production.

The constrained machine setting also presents a major challenge. When faced with general requirements such as freely choosing feedstock, servicing one's own machines, or repairing a broken machine, these operations are often reserved and qualified by the vendor, tightly coupled to a service agreement.

The general technological advancements, including more cost-efficient computational power, IoT-enabled devices, and Industry 4.0, are propelling the technology forward at a rapid pace. Industrial AM is still considered a niche and relatively immature manufacturing technology, which allows for certain constraints that would not be accepted in conventional manufacturing. AM is an inherently cyber-physical manufacturing technology and can greatly benefit from the latest technological achievements.

This also means that even relatively recent systems can swiftly transition into legacy systems, some even becoming obsolete. The obsolescence is primarily caused by the deprecation of controller systems, software, and interfaces, while the machine-specific hardware such as lasers, scanners, motors, and pumps often remain fully adequate. Therefore, the main hindrance for these legacy systems lies in the control framework. Machine providers have also been observed to engage in new yearly releases, aiming to push newer systems to customers.

Figure 1. Unified Systems Controller

4. Unified PBF Systems Controller

The unified systems controller, displayed in figure 1 [3], developed as part of the Open Additive Manufacturing Initiative at DTU, is scheduled to be released to the public by 1st of January 2024. This controller is specifically designed for Laser Powder Bed Fusion (LPBF) systems, with a tailored interfaces that accommodate the control of the typical subsystems in an LPBF machine. It allows for control of lasing (trigger and power), scanning (XY2-100), PID regulated gas flow (VFD pump control and flow sensor input), atmosphere (valves and oxygen sensors), beam expander (TTL), and motor control (via external servo or stepper motor drivers).

Currently, the unified systems controller is installed in the AM research group at DTU (Technical University of Denmark) in three open architecture LPBF systems. One of these systems is configured for polymer AM as an open architecture Selective Laser Sintering (SLS) system [4]. The other two systems are both bespoke metal AM machines. The first generation of the LPBF system aimed to provide in-line process monitoring and serve as a proof of concept for enabling LPBF manufacturing and research based entirely on bespoke open-source solutions. The second generation, has been developed with the knowledge gained from the first iteration, incorporating a strong focus on systems engineering and modularization. This system currently serves as the primary tool for daily metal AM manufacturing of end-use components and for research purposes, delivering robust and high-quality performance [5].

5. Assessing Retrofit Potential for Obsolete Equipment

The Danish Technical Institute (DTI) has been an early adopter of metal AM and has utilized a Realizer 250 system for research and production purposes for many years, displayed in figure 2. This system now falls into the legacy category and is considered obsolete. DTI offered the non-operational machine for diagnostics and potential revitalization. Unfortunately, the machine's control framework was nonfunctioning as the controller unit, a DOS workstation PC, had crashed, rendering the system inoperable. Due to the legacy status of the system, there was no service agreement in place, and the vendor did not offer a repair program. As a result, the machine currently holds no value and will be fully decommissioned. DTI's alternative option is to purchase a new system and dispose of the old one.

The impact of a system malfunction would not have been as severe if the system were not proprietary. Repairing this system would require significant reengineering efforts to restore the DOS computer and the required software. The system relies on black-boxed electronics. Since the hardware is used but still functional, revitalizing the system could make sense both economically and environmentally. The hypothesis is that by retrofitting the legacy system with the open-source unified systems controller, the system could be reinstated into production or used as a research tool. The unified systems controller is designed to directly interface with various hardware components, making it plausible to dismantle the wire harness and connect it to the unified systems controller. Nevertheless, before proceeding with the retrofitting process, thorough due diligence is necessary to ensure the feasibility and viability of the operation.

Figure 2. Legacy LPBF system, Realizer 250

5.1. System Diagnostics

The Realizer 250 is an early one-laser system. The laser is an IPG fiber laser which is mounted in conjunction with a beam collimator and is guided through a beam expander into a Cambridge Technology (CT) analog galvanometer scanner system. The laser beam is then focused through an ftheta scan lens. With a build volume of 250 x 250 x 300 mm, the system utilizes a top-mounted container to supply powder, which is deposited into the recoater unit. The recoater unit distributes the powder as it passes over the powder bed. The recoater, powder dosing mechanism, and the z-stage are all controlled by stepper motors, with absolute position information obtained from positional end stop switches. Additionally, the z-stage is equipped with a Heidenhain linear encoder. In the current configuration, the positional switches are daisy-chained to provide feedback if any limit position is reached during motor-controlled movement, thereby requiring only two controller inputs. Furthermore, the gas flow is regulated using a VFD (Variable Frequency Drive), and the oxygen content is monitored by an oxygen sensor.

The CT galvanometer (model 6240M) is operated using a custom proprietary digital-to-analog interface, which necessitates a demodulation circuitry combined with a PD feedback regulator.

5.2. Controller Compatibility Analysis

The open-source nature of the unified systems controller allows for flexibility and customization to meet the specific requirements of the Realizer 250 machine configuration.

The total number of stepper motors in the system is 4, which includes the z-stage, recoater, and 2 dosing motors. This falls within the capabilities of the unified systems controller, as it currently supports up to 6 dedicated motor control outputs. Additionally, the controller firmware already implements support for VFD control and oxygen sensor inputs.

While utilizing the existing scanner system is possible, it would be an arduous task. It would require the development and implementation of bespoke circuitry. An alternative approach is to replace the galvanometer with a modern one that conforms to digital scanner protocols. Current-day scanner systems generate the necessary galvanometer control voltages internally within the scanner unit, allowing for fully digital interfacing that does not necessitate a dedicated feedback circuit as it is the case for closed loop analogy control. Adequate cost-efficient industrial scanner systems are readily available, and the state-of-the-art LBPF system. The second-generation open architecture LPBF system at DTU utilize a Sunny Galvo (SG) (S9320D) digital scanner system. This scanner system make use of the XY2-100 scanner protocol, which is the most common protocol for industrial galvanometers. Thus, the recommendation is to upgrade the galvanometer system of the Realizer 250 to an equivalent system. Such an upgrade with alter the specifications of the Realizer 250 as shown in table 1. This table provides a comparison of key specifications and shows that the SG digital scanner system performs similarly and, in some cases, better than the stock CT galvanometers.

Table 1 Specifications of the CT 6240M and the SG S9320D

Specification	CT 6240M	SG S9320D
Control Mode	Analog(Proprietary)	Digital (XY2-100)
Aperture [mm]	12	20
Small Step Response Time [ms]	<0.35	<0.4
Scanning Angle [°]	+/- 15	+/- 12.5
Linearity	>99.5%	>99.9%
Repeatability [µrad]	<15	<8
Scale Drift [ppm/°C]	<50	<50
Zero Drift [µRad/°C]	<25	<15

6. Conclusion

The obsolescence of legacy LPBF systems poses a significant problem for owners of these machines, as the rapid advancement of technology and proprietary nature of these systems makes them unfit for integration into modern manufacturing infrastructures. However, the idea of scrapping these systems seems economically and environmentally wasteful, given that their hardware components, such as lasers, scanners, motors, and pumps, often remain functional and retain considerable longevity.

This paper presents an approach towards solving this problem with the development of a unified systems controller by the Open Additive Manufacturing Initiative at DTU. The flexibility and adaptability of this open-source controller allow it to be retrofitted onto legacy machines, potentially revitalizing them for integration into current manufacturing systems and thus extending their functional lives. As seen in the case of the Realizer 250, the controller can cater to the machine's needs with some modifications.

This upgrade could not only reduce economic and environmental burdens but also foster greater inclusivity by making AM technology more accessible. The open-source nature of the controller might also encourage more transparency and freedom, breaking down the proprietary barriers currently seen in the AM industry.

It is important to note that such a process should be carefully considered and carried out after comprehensive diagnostics, viability- and compatibility analyses. Although challenges may arise in some areas, such as the need for bespoke circuitry for specific components, the overall benefits and potential for extending the lifespan of these machines make the development of the unified systems controller a significant advancement in addressing the issue of obsolescence in LPBF systems.

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