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External temperature and power consumption monitoring in an Open Architecture Polymer Laser Powder Bed Fusion

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Abstract

This paper presents a study on the power monitoring of a heating system in an Open Architecture Polymer Laser Powder Bed Fusion (LPBF) system. Our findings demonstrate the effectiveness of our power monitoring approach in providing valuable insights into the energy consumption of the heating system, which can inform the development of more efficient and sustainable additive manufacturing techniques.

The laser chamber heating system consists of six different heating elements, each controlled by a dedicated PID controller. An Industrial Internet of Things (IIOT) system is employed to monitor the power consumption of the heating elements and the corresponding temperature readings obtained from the respective PID controllers. The data is visualized and presented on an interactive dashboard accessible online, allowing real-time process monitoring. This study underscores the importance of power monitoring in additive manufacturing and highlights the potential benefits of utilizing IIOT systems for this purpose.

In-process measurement, monitoring, selective laser sintering (SLS)

1. Introduction

The Open Architecture Polymer Laser Powder Bed Fusion (LPBF) system, developed at the Technical University of Denmark (DTU) under the project “The Open AM Initiative”, has been thoroughly evaluated for its functionality and efficiency. This work focuses on analyzing the system's components, operation, and power consumption monitoring to enhance the understanding and optimization of the LPBF process.

The Open Architecture LPBF system is a technology used for Additive Manufacturing (AM). The system's operation requires the preheating of the powder bed chamber to 180°C to prepare the powder for laser scanning. Once the powder is heated, the laser raises the temperature beyond the melting point, causing the material to fuse and form the desired object [1]. The LPBF system uses six different heating systems, including ceramic concave heaters that heat the top of the powder bed and five additional heaters that heat the build plate and the sides of the build chamber. The thermal control system comprises a thermocouple to monitor the five heaters and a pyrometer to monitor the temperature of the top of the powder bed [2]. The thermal monitoring devices are connected to a proportional integral derivative (PID) controller to maintain a stable temperature profile and ensure optimal operation of the LPBF system.

Monitoring the power consumption of the LPBF system is crucial in maintaining optimal performance and identifying any inefficiencies. The system utilizes up to 4 kW of power, and the gathering of power consumption data over time enables the analysis of heating patterns and helps to identify the need for predictive maintenance algorithms. Power consumption data is collected and analyzed to determine the energy consumption of the system. The monitoring process detects any anomalies that may arise and enables the system operator to take corrective measures if necessary. By continuously monitoring the power consumption of the LPBF system, researchers can gain insights into the system's performance and optimize its operation to achieve the best results.

2. Methods & Materials

The LPBF system requires monitoring of power consumption to ensure optimal performance. To achieve this, the current values are converted to a 4-20 mA closed-loop signal using six Hobut CT132TRAN50A-4/20mA current transducers. Each transducer is connected to the respective heater's power supply. The six heaters consist of ceramic heaters located on the top, as well as individual heaters for the powder bed, front, back, right, and left sides of the heating chamber. The choice of the 4-20 mA closed-loop protocol over the 0-5V voltage option is based on its superior resistance to electrical noise [3]. This is particularly crucial considering the presence of numerous subsystems in the machine that may interfere with the 0-5 V voltage signal. Additionally, the 4-20 mA signal is less prone to deterioration over longer distances.

The current values of the LPBF system are periodically recorded and stored in the cloud, allowing researchers to analyze power consumption patterns. Temperature values are collected from the PID controllers via their Modbus RTU connection and presented alongside the current values. This enables researchers to correlate the results with power consumption and examine the heating patterns of the LPBF system over time, facilitating the detection of anomalies and monitoring of heater condition. It is important to note that the Modbus RTU ability to have separate addresses allows for all PIDs to communicate with the data acquisition device through the same physical medium without interference. Additionally, the installation of the STEGO CSS 014 sensor in the build chamber enables monitoring of chamber temperature and humidity. The sensor utilizes the 4-20 mA closed-loop protocol, one line for humidity that provides the humidity in percentage and the other that is able to provide temperature values from -40°C to 60°C. These measurements provide valuable data for analyzing both air humidity values and chamber temperature in relation to the printing process.

The data acquisition device utilized in this experimental setup is the 4ZeroBox by Zerynth, an IIOT device. This device is equipped with an ESP32 chipset, renowned for its exceptional performance, low power consumption, and versatility, making it an ideal platform for various wireless communication and data processing requirements in scientific applications. In the present study, Wi-Fi communication was established within the DTU laboratory, enabling connectivity with the LPBF machine. The current transducers and STEGO CSS 014 sensor were connected to the analog input ports of the 4ZeroBox, and the Modbus RTU was established by using the robust RS485 protocol connection. The setup could be seen in Figure 1.

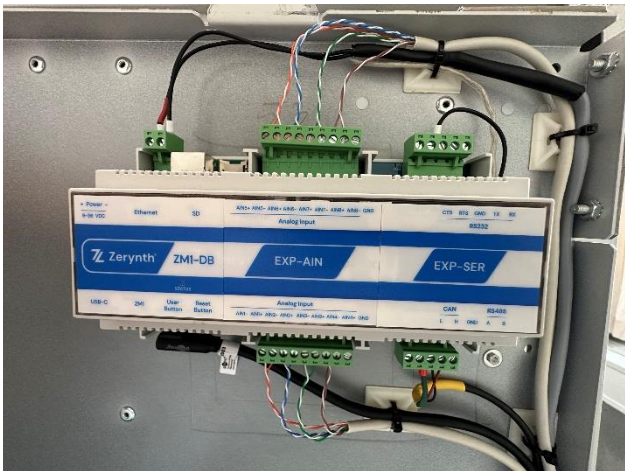

Figure 1. Data acquisition device 4ZeroBox

The acquired data is transmitted to the Cloud using a WiFi connection, where it is aggregated and visualized through a Grafana-powered dashboard. This comprehensive data visualization provides a structured presentation of all collected values, facilitating operators in gaining insights and monitoring the heating process more effectively. The real-time monitoring capability offered by the dashboard enables operators to promptly implement corrective actions, ensuring optimal operation of the LPBF system. Implementation of the dashboard had an added benefit of monitoring the printing process remotely, especially bearing in mind that it can last for several hours depending on the printing object.

3. Results

In this section, we present the findings and outcomes of our study using the Open Architecture LPBF system. The results encompass the analysis of power consumption patterns, examination of heating patterns over time, and monitoring of chamber temperature and humidity.

During the powder bed preparation, the temperature of the powder bed needs to be elevated to a predetermined level. The machine operator can select the appropriate PID controller for each heater, enabling them to activate the heaters until the desired temperature is achieved. Figure 2 illustrates the temperature readings during the heating stage of the process. The results reveal distinct heating patterns in different regions of the powder chamber.

Figure 2. Dashboard with the temperature readings during the powder bed heating up.

The data visualization also offers valuable insights into the temperature readings during the chamber cooldown process. This enables us to establish correlations between cooling patterns and the mechanical properties of the printed object. By analyzing these relationships, we can gain a deeper understanding of the cooling behavior and its impact on the final printed object.

Figure 3. Dashboard view with the temperature readings during a cooldown process.

The readings obtained from the installed humidity and temperature sensor (Figure 4) in the powder chamber provide valuable insights for the operator to assess the impact of these factors on the printing process. This information is particularly advantageous when considering variations in weather conditions across different seasons. Furthermore, it enables comparisons between different machine locations. Although currently being developed in the lab, the significance of this data becomes even more apparent when the machine is deployed in various environments. Therefore, understanding these effects and their potential variations becomes crucial for ensuring consistent and reliable printing outcomes.

Figure 4. Dashboard with the humidity and temperature reading of the build chamber.

The acquired data can be correlated with the power consumption of each heater, as depicted in Figure 5. By comparing these patterns with the temperature readings shown in Figure 2, it becomes evident that the heaters operate with a 100% duty cycle during the temperature ramp-up phase, followed by periodic heating cycles. The cooling effect observed can be attributed to two factors: the natural cooling of the powder and the recoating process involved in the printing procedure, which plays a significant role in the overall cooling process.

Figure 5. Dashboard with the power consumption during the powder bed heating up.

The availability of power consumption data allows the operator to assess the overall power usage of the machine. The dashboard can be customized to display hourly or daily consumption, providing a detailed understanding of power usage for specific printing jobs. This information proves valuable in monitoring the consumption associated with individual printed objects and gaining insights into the associated costs. An illustration of daily power consumption is presented in Figure 6, demonstrating an example of the collected data.

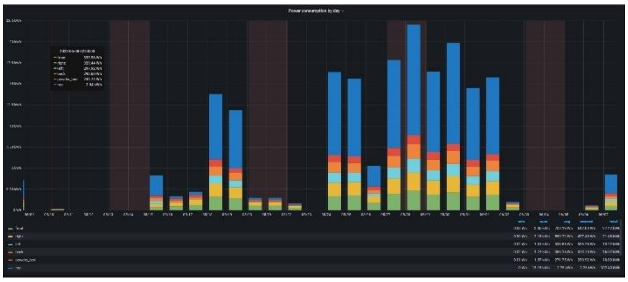

Figure 6. Dashboard with the daily power consumption.

4. Conclusion

The Open Architecture LPBF system, developed at the Technical University of Denmark, has been evaluated for its functionality and efficiency. The objective of this study is monitoring the system's power consumption and its correlation with temperature and humidity variations during the printing process. The data acquisition device, 4ZeroBox by Zerynth, facilitated the collection and transmission of data to the cloud, where a Grafana-powered dashboard visualized the information.

The results revealed distinct heating and cooling patterns in different regions of the powder chamber, providing valuable insights for optimizing the printing process. Additionally, the collected data enabled the assessment of power usage, aiding in cost analysis and monitoring the consumption associated with individual printed objects. Understanding these relationships and variations is crucial for ensuring consistent and reliable printing outcomes, particularly when the system is deployed in different environments.

Moreover, the collected data holds potential for the development of supplementary algorithms and the creation of a predictive maintenance solution. This solution would facilitate continuous monitoring of the heater condition, thereby ensuring optimal performance. Future research will concentrate on enhancing the quality control of the final print. By leveraging the collected data, a more comprehensive understanding of the entire process can be achieved, leading to improved quality and evaluation of print quality.

References

[1] S. Kumar, “10.05 - selective laser sintering/melting,” in Comprehensive Materials Processing, S. Hashmi, G. F. Batalha, C. J. Van Tyne, and B. Yilbas, Eds., Oxford: Elsevier, 2014, pp. 93–134, ISBN: 978-0-08-096533-8. DOI: https://doi.org/10.1016/B978-0-08-096532-1.01003-7.

[2] Budden, Christian L., Aakil R. Lalwani, and David B. Pedersen. "Chamber Heat Calibration by Emissivity Measurements in an Open Source SLS System." 2022 Summer Topical Meeting: Advancing Precision in Additive Manufacturing. 2022.

[3] Obinna, O., Application of High-Voltage, Precision, Low-Power Max9943/Max9944 Operational Amplifier in Industrial Process Control Using±20ma OR 4-20ma Current-Loop Systems. International Journal of Advanced Engineering, Management and Science, 2(9), p.239652.