AN IOT-BASED ELECTRIC CURRENT ASSISTED SINTERING SYSTEM CONTROL

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Abstract

Electric Current Assisted Sintering (ECAS) systems offer an efficient method for creating sintered materials. ECAS systems are complex systems that need both thermal and electrical models coupled with each other. It is crucial to monitor and document electrical and thermal variables such as temperature, current, voltage, power, and energy consumption with respect to time in an ECAS system throughout the sample production process. It is also important to model or obtain the electrical container model of the system, which has a significant determining effect on all operating characteristics. The electrical parameters of the container can be utilized to design autonomous ECAS systems that provide precise and higher-quality operation characteristics. The Internet of Things (IoT) and Industry 4.0 are contemporary solutions in the context of autonomous material production. They enable seamless connectivity and real-time data exchange and allow machines to work autonomously. This integration of IoT collectively with ECAS systems can enhance production efficiency, reduce downtime, and minimize production errors. IoT integration can create smarter, and more responsive ECAS systems ensuring the reliability and consistency of material production processes. In this study, an IoT-based ECAS system design approach that systematically measures electrical and thermal quantities during the sintering process and can be used to produce the correct container characteristics and to analyze the sintering regime is proposed. An algorithm that enables the determination of the container resistance and temperature online and offline by directly measuring input and output current and voltage waveforms and processing experimental data has been presented. The proposed design can be used to produce high-quality ECAS systems.

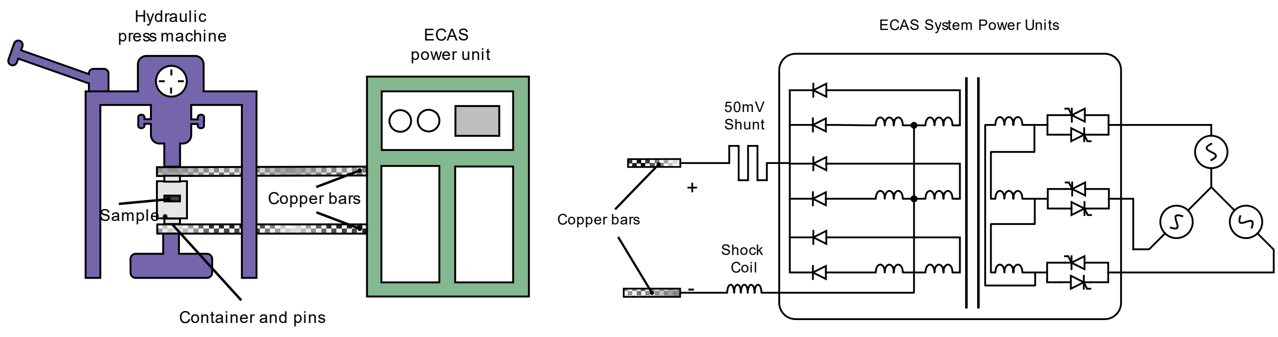
Keywords: Sintering, Industry 4.0, IoT-based material production, ECAS, container characteristics

1. INTRODUCTION

Electric Current Assisted Sintering (ECAS) systems use electric current for the sintering of composite, ceramics, metal, and intermetallic materials at high temperatures and very short production times [1]–[4]. In the ECAS method, combining electric current and mechanical pressure properly, the material that is dust or compacted gets sintered [5]–[9]. The primary purpose of using electric current is to provide the electrical energy needed for resistance-based heat in the ECAS container for sintering [1]. The current density and the current waveform are important parameters for analysis and controlling the sintering process [1], [2], [8]. Resistive sintering methods can use constant DC, AC, pulsed DC, and pulsed DC+DC current waveforms [1]–[3]. A non-linear relationship exists between the container current and the heat transfer because of the mutual dependency of the electrical resistance on temperature and thermal conductivity on temperature and mechanical pressure [1]–[3]. That's why the current and the voltage waveforms of an ECAS system beside the container temperature should be monitored. Industry 4.0, also known as the fourth industrial revolution, refers to a concept that encompasses advanced automation systems, data exchange, and manufacturing technologies [10]. Industry 4.0 also includes the Internet of Things (IoT), online services, and cyber-physical systems [11]. In the future, it is expected that most of the residential and industrial devices are to be connected to the net [12]. An IoT-based PDCS system has been examined and it is suggested that the data acquired by IoT can be used to make a sintering process database in [13]. An ECAS system is a complex system due to mixed thermal and electrical dynamics and that's why it is difficult to model it [1], [2], [14]. The container resistance and thermal circuit of an ECAS system is temperature dependent Data on the current, voltage, and temperature of the ECAS system is needed to make better container and thermal circuit models of such a system [13]. Monitoring the current, voltage, and temperature of such a system can be done using IoT. To the best of our knowledge, it has not been examined how to design an IoT-based ECAS system in the literature yet. In this study, first, an ECAS system topology used is introduced, how some of the IoT integrated circuits and sensors usable for controlling AC and DC loads operate is explained, and then how to turn the ECAS system into an IoT-based ECAS system using the circuit components is shown and told in detail. Such an ECAS system can be used to make a database for the ECAS system and the data can be processed to determine its equivalent circuit parameters by directly measuring. The paper is structured as follows. In the second section, the ECAS system examined is introduced. In the third section, the IoT chips and the sensors usable for ECAS control are presented. In the fourth section, the electrical circuit schema of the ECAS system is given and explained. The paper is finished with a conclusion.

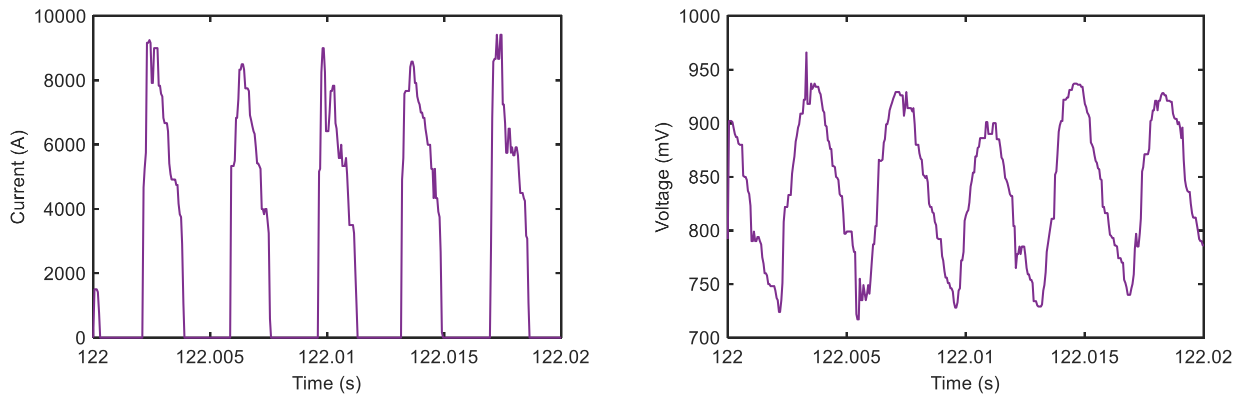
2. ON THE ECAS SYSTEM EXAMINED

The topology of an ECAS system is given in **Figure 1.a.** ECAS systems may have power electronics units to control the sintering current, which provides the necessary heat for sample production. The electrical circuit of the power electronics units of the ECAS system examined is shown in Figure **1.b.** The ECAS system uses a Pulse DC electric current during its operation. The power transformer of the ECAS is rated at 60 kVA. The ECAS system has two power electronics units: a thyristor-based AC chopper at the input used to control the effective voltage values of the delta-connected primary windings of the three-phase transformer and the uncontrolled rectifier connected to the interleaved windings of the transformer to obtain the pulsed DC current to heat the ECAS container. The control system triggers the thyristors of the AC chopper to supply the necessary sintering current adjusted manually by the system's operator [15]. Thousands of ampers are made to flow through the container to produce the sintered sample placed therein. Such a current is hard and expensive to measure. The shape of the container current indicates that the rectifier runs in the discontinuous conduction mode. The input current and voltage of one of the phases of the ECAS system are given in **Figure 2.** The input current of the system is lower since the input voltage of the ECAS system is higher. That's why the input current of the ECAS system is easier to measure and it is easier to find an AC sensor to measure a current whose amplitude is less than 100 Amps as done in [13] due to the economic and availability issues of the sensors. The AC input current measured results in a loss of accuracy. Perhaps, the power electronics simulations can be employed to estimate the DC output power or the average ECAS container current based on the measured input current and voltage, and the triggering angle. However, the DC output current can also be measured using a shunt resistor as shown in **Figure 1.b.** The temperature of the ECAS container during a sintering process is measured with an infrared temperature meter. Its temperature can be as high as 1000 °C.



a) b)

Figure 1 a) The principle block diagram ECAS system during the sintering process and b) The electrical circuit of the ECAS system



a) b)

Figure 2 The output waveforms of the ECAS system: a) the current and b) the voltage of the container

3. AN IOT-BASED ECAS SYSTEM DESIGN

In this section, the IoT-based ECAS system design and its operation algorithm are presented. The principle block diagram of the IoT-based ECAS system is given in **Figure 3.** The DC current, the AC phase current, and voltages of the ECAS system and its container temperature are to be controlled and monitored. The rms current and voltage values of the ECAS system are monitored with the current and voltage sensors given in the previous section. Also, the temperature of the ECAS container placed in front of the container is monitored with a non-contact Infrared IR Temperature Sensor Module placed at a distance of 30 cm. The relay module shown in **Figure 3** is used to turn on and turn off the output of the ECAS system. The ECAS system can also be turned on or turned off by putting a condition in the microcontroller program such as "Start the ECAS system, if the operator pushes the start button and the mechanical system is locked, and, if the container temperature reaches 900 °C, turn it off.".

The microcontroller board is chosen for its sensor compatibility, flexibility in setting general input and output pins, and price advantages. A system-on-chip implementation could also be considered for the solution, but these features of the microcontroller-based realization made it a more suitable choice for this purpose. The relay module used is selected with enough current-carrying ability to control the internal controller unit of the ECAS system to trigger the thyristors of the AC chopper at the desired angles. Combining these circuit elements and microcontroller board measures not only current, voltage, and temperature but also transfers data to a remote PC via an ethernet module. A cheap off-the-shelf current sensor is chosen to be able to carry current high enough to measure the ECAS input current. It measures the input current via a clamp mechanism and has 2 pins and one additional pin for ground can be used with a microcontroller board. Such a sensor can be used to measure AC load currents up to 100 A. A voltage-divider and op-amp-based voltage sensing module can be used for the measurement of the AC voltages on the input side. The voltage across the shunt resistor is also read using two of the ADC inputs of the microcontroller board and subtracting them. The DC output current can be calculated from it. A non-contact Infrared IR Temperature Sensor Module is used for temperature measurements. It produces an analog voltage level at its output proportionally to the measured temperature. This signal is measured at an ADC input of the microcontroller board and transferred to the corresponding temperature value. An essential component for IoT applications is the Ethernet Network module. With this module, the microprocessor card can connect to the internet and is prepared to transfer measured data to a PC or the cloud.

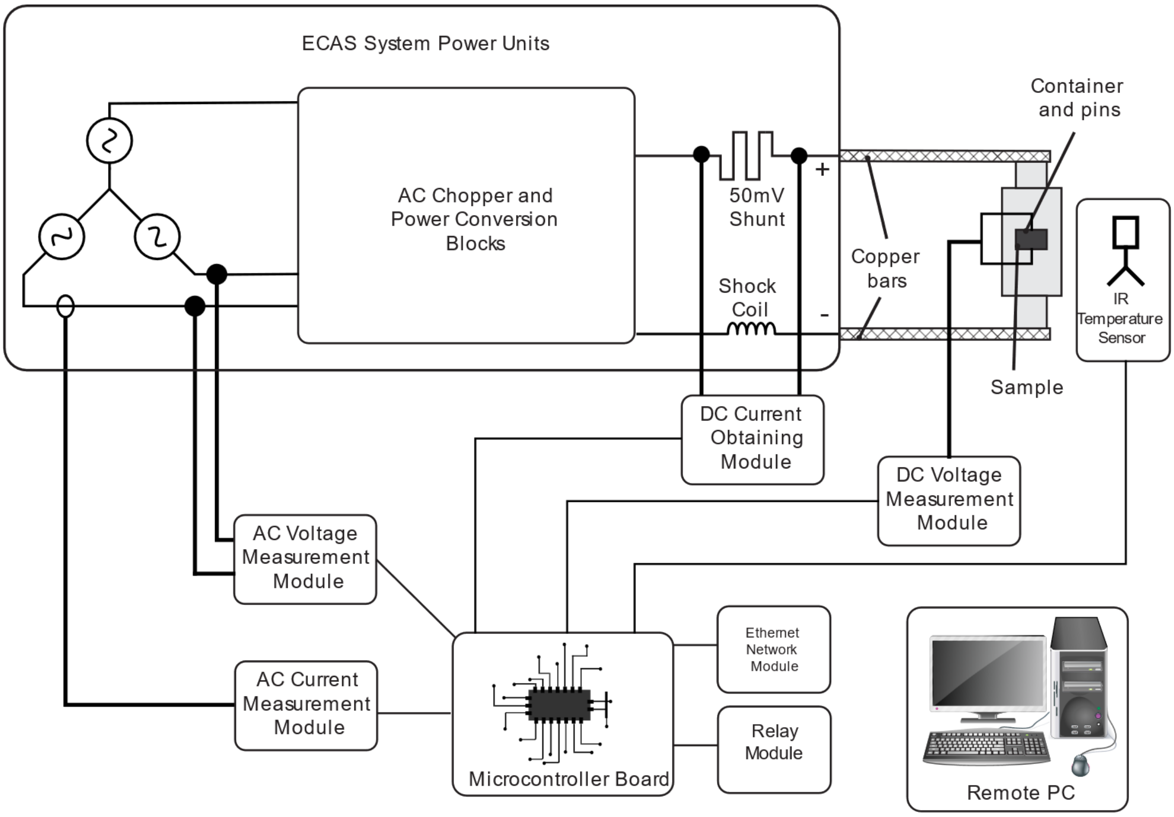


Figure 3 The IoT-based ECAS system schematic.

Such a system can calculate the electrical parameters of the ECAS container not only online but also offline. The heat produced in the container depends on the electrical power dissipated which is given as

$$P = (i_{container})^2 R_{container} \tag{1}$$

That's why it is important to measure the container current that can be measured using the voltage across the shunt resistor by the microcontroller as

$$i_{container} = \frac{v_{shunt}}{R_{shunt}} \tag{2}$$

Where v_{shunt} and R_{shunt} are the shunt resistor voltage and resistance, respectively. The container resistance $R_{container}$ which can be monitored by connecting the IoT-based ECAS system to a PC can be calculated using the measured voltage across the copper bars of the ECAS system $v_{container}$ and the container current $i_{container}$ as

$$R_{container} = \frac{v_{container}}{i_{container}} \tag{3}$$

Since the container resistance is temperature-dependent, it is important to monitor the container resistance. It defines also the dissipated power or thermal dynamics. The calculated container resistance and temperature values as a function of time can be recorded whether internally or at the connected PC. The temperature dependency of the container can be found experimentally and be monitored online. The container resistance and temperature can be monitored using the simple algorithm given in **Figure 4.** After measuring, calculating, and recording the ECAS variables, the algorithm sends them to the PC through the ethernet connection. Further examination of the acquired data may give more information about the thermal dynamics and efficiency of the IoT-based ECAS system.

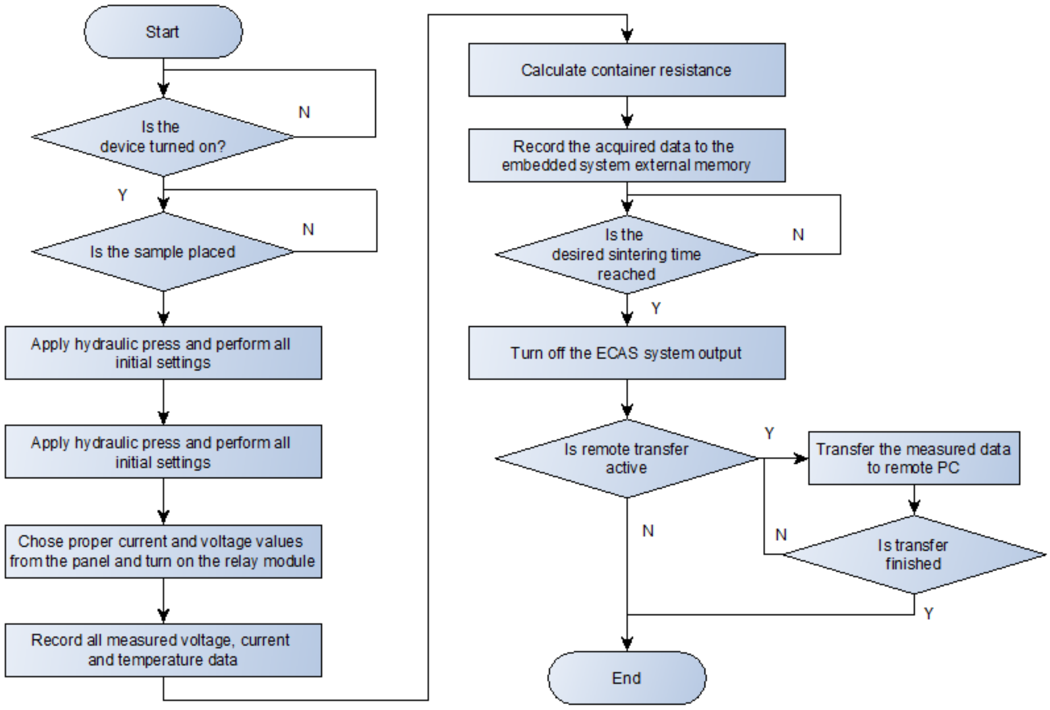


Figure 4 The flowchart of the IoT-based ECAS system code.

4. CONCLUSION

In this paper, an IoT-based ECAS system is performed. It uses cheap sensors to monitor and control the ECAS system. Such a system can be used to model the ECAS system electrical circuit better by online monitoring and calculation of its container resistance. Also, the ECAS system estimates the container power well since this one calculates the output power by measuring the container voltage and current instead of calculating the input power by measuring the phase current and voltage. A database can be made for container resistance as a function of the container temperature measured. The suggested ECAS system design can be used to make better-performing ECAS systems in the future. Such a system can also be monitored by a PC to see whether it operates without a failure or not.

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