2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33179

A Capstone Experience Through the Development of a Powder Compaction System During COVID-19 Pandemic

Dr. Byul Hur, Texas A&M University

Dr. B. Hur received his B.S. degree in Electronics Engineering from Yonsei University, in Seoul, Korea, in 2000, and his M.S. and Ph.D. degrees in Electrical and Computer Engineering from the University of Florida, Gainesville, FL, USA, in 2007 and 2011, respectively. In 2017, he joined the faculty of Texas A&M University, College Station, TX. USA, where he is currently an Assistant Professor. He worked as a postdoctoral associate from 2011 to 2016 at the University Florida previously. His research interests include Mixed-signal/RF circuit design and testing, measurement automation, environmental & biomedical data measurement, and educational robotics development.

Dr. Chao Ma, Texas A&M University

Dr. Chao Ma received his B.E. degree from Tsinghua University in 2010, M.S. degree from University of Wisconsin–Madison in 2012, and Ph.D. degree from University of California, Los Angeles in 2015, all in Mechanical Engineering. He was a senior mechanical engineer at Cymer (an ASML company) from 2015 to 2016. He is currently an assistant professor at Texas A&M University. His teaching interests are manufacturing processes and product design. His research interests include additive manufacturing, laser manufacturing, and metal matrix nanocomposites.

Mr. Brey C. Caraway, Texas A&M University
Jorge I. Roa, Texas A&M University
Alejandro X. Trejos, Texas A&M University
Pauline Davila, Texas A&M University

A Capstone Experience through the Development of a Powder Compaction System during COVID-19 Pandemic

Abstract

A powder compaction system can be useful to various manufacturing technologies. In order to create a powder compaction system, a four-student capstone team is formed with two faculty advisors. This team started their capstone as usual. However, in the middle of the first semester of the capstone (Spring 2020), the team has experienced imposed restrictions due to COVID-19. Restrictions due to COVID-19 were still active in the second semester (Fall 2020). The team could complete the capstone project in Fall 2020 during COVID-19 pandemic. In this paper, the powder compaction system is introduced. The details of the block diagrams and fabricated prototype device are presented. Testing and verifications are shown, and the capstone evaluation is presented.

I. Introduction

A powder compaction system can be useful to various manufacturing technologies, such as powder metallurgy [1] and additive manufacturing [2-5]. In powder metallurgy, a powder compaction system can be used to tune green density before sintering [1]. In additive manufacturing (e.g., powder bed fusion and binder jetting) [2-5], a powder compaction system can be used to improve powder bed density. In order to develop a powder compaction system, a capstone team with four senior students was formed. The capstone was carried out for Spring 2020 and Fall 2020. Two faculty members advised this capstone team.

This team has designed a uniaxial compaction system. This compaction system is capable of controlling the vertical compaction of a powder bed. To ensure precision, the system is equipped with a force sensor to monitor the applied force during compaction. The system includes a user interface that controls and displays the compaction force. However, in the middle of Spring 2020, there was a major interruption to the progress in this capstone project due to COVID-19. The mode of operation in managing this capstone team has been changed. This capstone project was successfully completed in Fall 2020, when they were still in a COVID-19 crisis. In this paper, a custom designed compaction system is introduced. And, the impact on the capstone project is presented. The tests and verifications of the prototype device are presented. The capstone project evaluation is presented.

II. Capstone Project on Powder Compaction System

The conceptual block diagram of the powder compaction system is shown in Figure 1. The mechanical structure is shown on the left side. The force of the compaction is generated by a NEMA 23 stepper motor [6]. A Schneider MDrive NEMA 23 is adopted for the stepper motor. This is controlled by Modbus TCP protocol [7]. Raspberry 4 model B is used as a main controller for this compaction system, and it can control the stepper motor. For safety, an emergency stop button was implemented. It can shut down the power to the stepper motor immediately. A load cell is used to measure the applied force [8], and an optical switch is used to set a limit for the motor position. These components are connected to the interface PCB (Printed

Circuit Board). This PCB can be mounted on the Raspberry Pi board using the 40 pin headers. A motor can display the status and the measurement. Moreover, a touch screen interface has been used to provide easy access to the system.

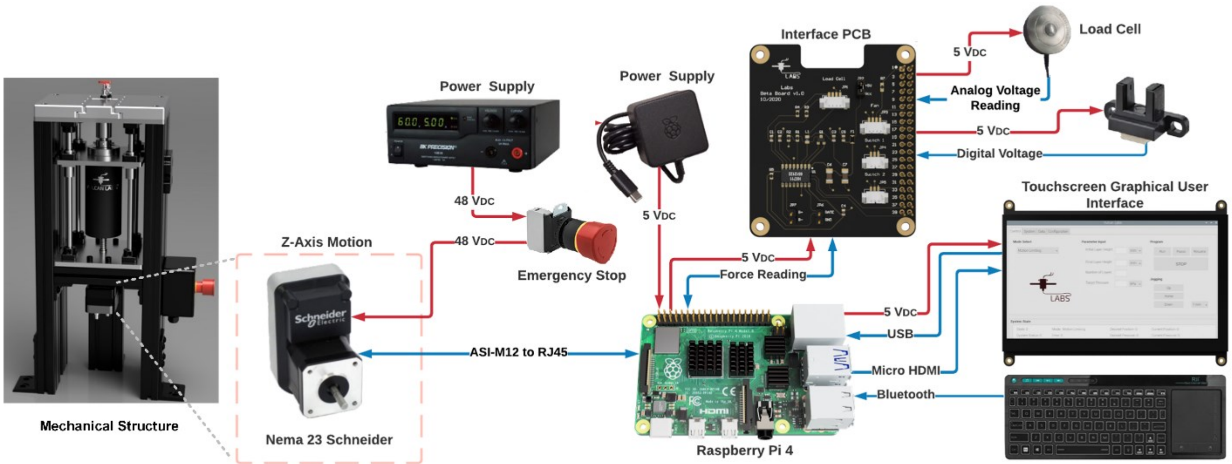

Figure 1. Conceptual Block Diagram of a powder compaction system

The functional block diagram shown in Figure 2. This diagram shows details of the connections to the part and device names. An interface PCB is shown on the right side. This is a custom PCB that includes a 12-bit ADC (Analog and Digital Converter) IC (Integrated Circuit) and interface circuits to the load cell. This PCB also includes the headers and circuits for optical switch sensors.

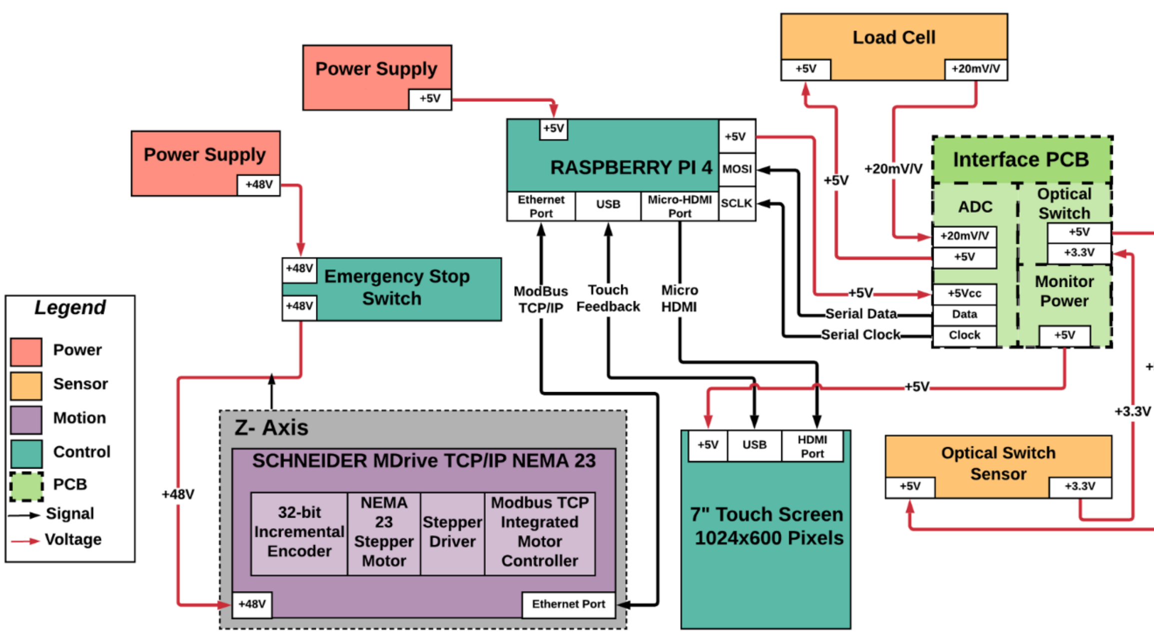

Figure 2. Functional Block Diagram of the powder compaction system

An electronic enclosure was designed, and it was fabricated by 3D printers. This enclosure integrates a majority of the electronics parts. A Raspberry Pi 4 board may get hot when the system is in operation. For this reason, a fan was included to reduce this heat.

III. Project Schedule and Impact due to COVID 19

The total number of the undergraduate students who have worked on this capstone project was four. Two of them had already worked on the similar theme with one of the advisors (Dr. C. Ma) before the beginning of this capstone project. Thus, they had prior knowledge and experience on this topic before the capstone project. By the addition of the two more members as well as one more advisor (Dr. B. Hur), this team was formed, and they started the capstone project in the semester of Spring 2020. Compared to other typical Capstone projects, this team was in a relevantly very good position because they already understood the technical challenges and background for this given project. Thus, this capstone experience could have been a smooth journey. However, in the middle of Spring break, Texas A&M University has imposed restrictions due to COVID-19 [9,10]. They have prevented the students from coming to the campus. It made them change the mode of operation of this capstone team. The weekly capstone meetings were held remotely via an online conference platform such as Zoom. The team was unsure of many things including the uncertainty of when to end the limited operation. The team kept going and it ended up in the limited mode from the point of Spring break until all the way through the end of the project in Fall semester.

This uncertainty and limited mode of operation have impacted the team significantly in many aspects. In spite of these challenges, the team could keep moving forward. Fortunately, this team had prior knowledge and experiences relevant to this project. It helped this team make progress and complete the project at the end. However, due to the unexpected and drastic changes in the mode of operation, the project scope change was inevitable. Initially, it was planned to implement 2-axis movements. This means the loaded powder can be leveled by a scrapper. Given this mode of operation, this scope has been revisited, and lifted the requirement of powder leveling. Thus, this decision made the project focus on the compaction of the powder. Overall, the project was delivered as it was planned. The journey was not smooth as it was initially hoped for, however, the team could complete this project successfully despite the COVID-19 restrictions.

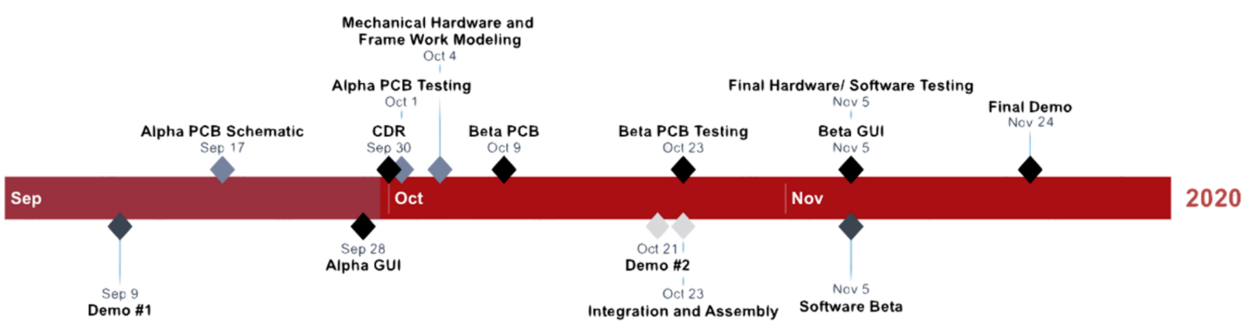

Figure 3. Project schedule (September ~ November of 2020)

The project schedule from September through November of 2020 is shown in Figure 3. This is a similar schedule compared to the prior capstone schedule before the restrictions. This capstone team worked hard to make this possible, and most of the schedules were kept as they were. They showed their final demonstrations on Nov. 24, 2020.

III. Prototype fabrication, Tests and Verifications

This powder compaction system has been built and the photo is shown in Figure 4. In the center, it shows the mechanical structure of the system. There is a piston in this mechanical structure. This piston is connected to a cylinder chamber to the upper side of the piston. The compaction is processed in this chamber. The force of the compaction generated by the NEMA 23 stepper motor is connected to the piston and located in the bottom of the picture. The power for this stepper motor is provided by a separate power supply shown on the lower right side. A heavy-duty emergency switch button is attached to the right side of the mechanical structure.

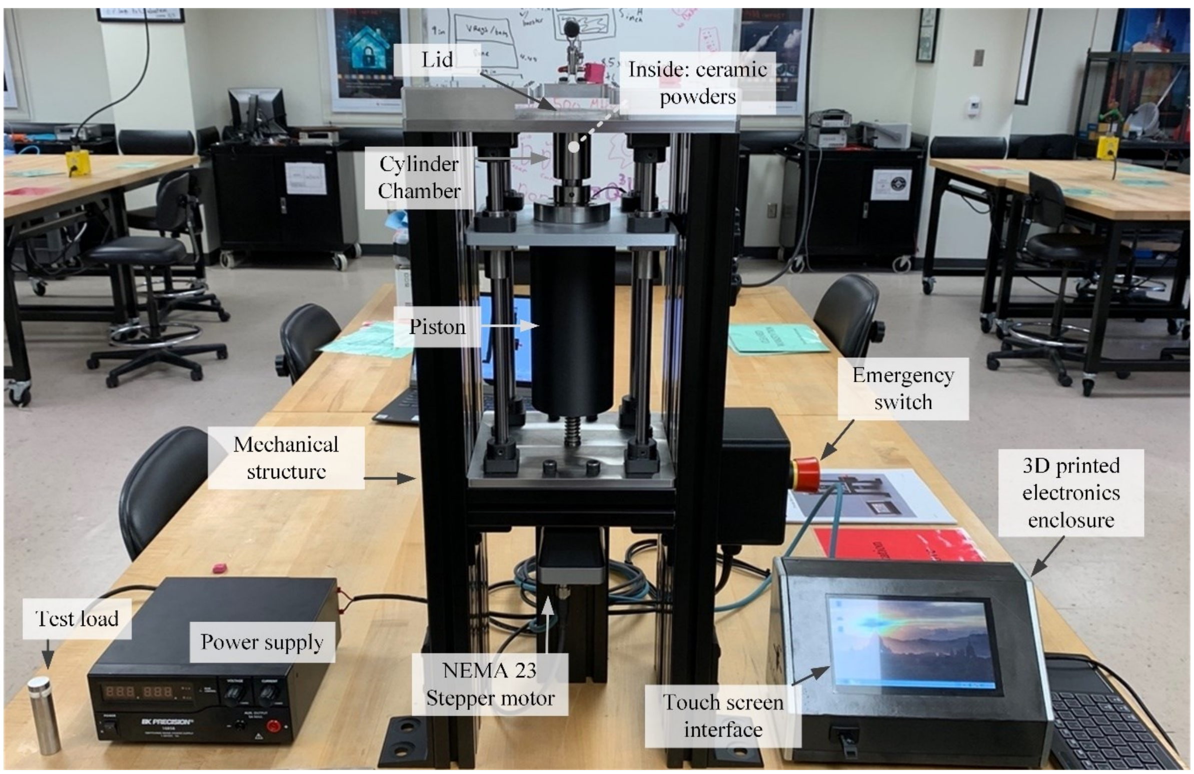

Figure 4. A photo of the fabricated powder compaction system

On the lower right side of Figure 4, there is an electronics enclosure. As it was described in the previous section, it is a custom designed enclosure, and it is fabricated using 3D printers. This enclosure contains a majority of the electronics. specifically, including Raspberry Pi 4 board, the interface PCB, and monitor. This system supports a touch screen, and the GUI (Graphical User Interface) program provides the touch screen access.

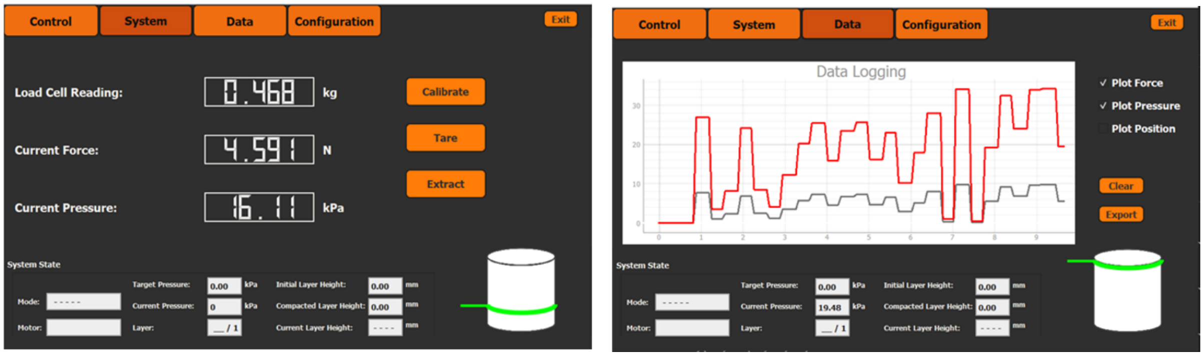

Figure 5. Testing of powder compaction system. The screens on the left and right show force measurements and data logging, respectively.

Various functions of this system have been tested and verified. The screenshots of tests and measurements are shown in Figure 5. On the left side, it shows the measurement of the applied force. Given this senor data, a controlled compaction pressure was implemented. The measured data was stored. The screen on the right side shows the data logging. The measured data during the testing can be retrieved and analyzed.

Students were required to participate and show their final demonstration to the stakeholders. A photo that was taken during the final demonstration is shown in Figure 6. Meetings for all members were held remotely only over Zoom after the Spring break until this day of the Final demonstration. For the final presentation, it was decided to meet in person and conduct a demonstration. Due to the COVID-19 restrictions, all members needed to wear masks and kept a social distance as it can be seen in the picture. The compaction system was shown in the center of Figure 6. Students were presenting the compactions system to the stakeholders and audiences. After this final demonstration, this project was successfully concluded.

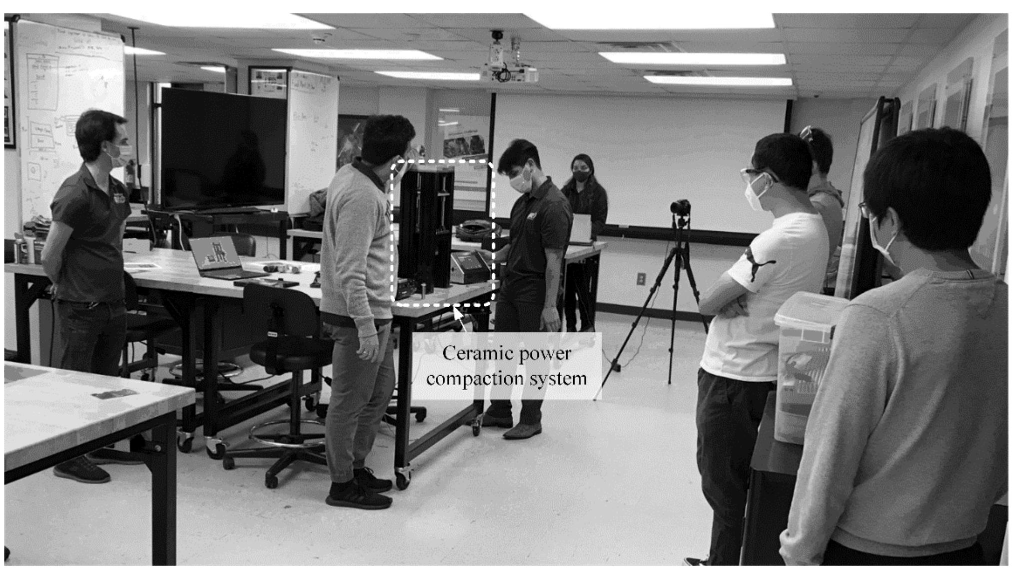

Figure 6. A photo taken during the final demonstration.

IV. Capstone Project Evaluations

The post capstone evaluation was performed after the completion of the two-semester capstone courses. The on-line anonymous survey invitations were sent to all the four students who were in this Vulcan capstone team. The questions in the on-line survey were shown as follows:

1. Did this Capstone project enhance your learning about relevant technical skill sets?

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	N/A
5	4	3	2	1	0

2. Did this Capstone project enhance your learning about working in a team environment?

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	N/A
5	4	3	2	1	0

3. Due to COVID-19, you had experienced the partial lockdown during your first semester and the limited mode of operation during your second semester. Which of two semesters have affected you more?

First semester (Partial lockdown)	Second semester (Limited mode)	Similar	N/A

4. Briefly state the impact on your capstone experience due to COVID-19.

5. Do you think this capstone project has been beneficial to your current or future career?

Strongly agree	Agree	Neutral	Disagree	Strongly disagree	N/A
5	4	3	2	1	0

This survey was created and conducted using Qualtrics. This was a voluntary survey asking a couple of questions related to the educational impact and their feedback about their capstone experience. "Anonymize responses" option in Qualtrics was used. This option was described as "Don't record respondents' IP Address, location data, and contact info." from Qualtrics. The summary of this post Capstone survey results is shown in Table 1. All the students have participated in the survey. From their feedback, students have shown positive responses toward their capstone project related to the technical skills (Q1, Average: 4.75) and teamwork (Q2, Average: 4.5).

Table 1. The post capstone survey results for Vulcan capstone team

Survey participation rate	100% (4/4)
1. Did this Capstone project enhance your learning about relevant technical skill sets?	4.75 (Average)

2. Did this Capstone project enhance your learning about working in a team environment?	4.50 (Average)
3. Due to COVID-19, you had experienced the partial lockdown during your first semester and the limited mode of operation during your second semester. Which of two semesters have affected you more? *Summary of the selected answers:* ** 75%, Second semester (Limited mode) * 25%, Similar*	
4. Briefly state the impact on your capstone experience due to COVID-19. *Summary of the selected answers:* ** The limited mode of operation during the second semester made collaborating, building, and housing our components very difficult. * It made manufacturing parts, acquiring tools, and having access very challenging.* ** Expectations and ability to perform tasks had to be adjusted, and new ways of achieving completion had to be exercised.* ** Hands-on collaboration between team members was limited and affected.*	
5. Do you think this capstone project has been beneficial to your current or future career?	4.50 (Average)

From the results of the survey, the COVID-19 affected this capstone team. It is particularly the second semester (Q3, 75%). In their first semester, there was a lock-down situation in the middle of the semester due to the COVID-19. It suddenly forced them to change the mode of remote operation. In their second semester, there was no sudden drastic change, but they were demanded to maintain the limited mode of operation. It was asked to briefly state the impact due to the COVID-19. It can be summarized that the students have experienced difficulty in collaborations due to the limitation as well as in accessing tools or components to build the prototype. The team had to adjust the project scope to make this project feasible given the circumstances due the COVID-19. The progress of determining this change was not simple. All team members with all stakeholders including faculty advisors had discussed it for an extended period in their early second semester. It was resolved by the minimal scope change while maintaining to meet the original intent and goal of the project. During the second semester, the regular meetings were forced to be held remotely. Students could work together at the school, but there were regulations and limitations related to the COVID-19. In this project, the only chance to gather and meet all members in the second semester was the final presentation as shown in the picture in the previous section. This Vulcan labs capstone team students were able to overcome many challenges due to the COVID-19 during their capstone experience. They were able to successfully complete their capstone project.

For the question related to the impact on their career, students showed positive responses (Q5, Average: 4.5). The impact and the success of this capstone project can be also observed in students' post graduate status. Two of them have joined our own master's program. They have been working on the relevant theme or have been applying relevant skill sets [11,12]. Engineering Technology in Texas A&M University created a Master of Science in Engineer Technology in 2018. Having our own undergraduate students joined in our graduate school in Engineering Technology is a desirable direction for students and the department.

V. Conclusion

This research and development of a powder compaction system has been carried out via a capstone project from Spring of 2020 to Fall of 2020. However, there was a significant change of operation in the middle of Spring 2020 due to COVID-19. There were related impacts and actions to adjust to the changes. Although it was a struggle, this team was capable of delivering this project, and completed the capstone project successfully. This capstone experience and effort were described in this paper. The testing and verifications were carried out. They were shown during the final presentation. The capstone evaluation related to this project was presented and discussed. At the time of writing this article, we are still in the middle of the COVID-19 crisis. However, as the several semesters have passed, it seems instructors and students have been adjusted to the circumstances at some level. Authors plan to continue to conduct research on this topic of the powder compaction system as well as to continue to teach students for their success.

Acknowledgements

Thank Dr. Garth V. Crosby and Prof. Shane Dickson for teaching students through capstone courses.

References

[1] Randall M. German, 2005. Powder Metallurgy and Particulate Materials Processing, Metal Powder Industries Federation.

[2] Gibson, I., Rosen, D., Stucker, B., & Khorasani, M. (2014). Additive manufacturing technologies (Vol. 17, p. 195). New York: Springer.

[3] Bourell, D., Kruth, J.P., Leu, M., Levy, G., Rosen, D., Beese, A.M. and Clare, A., 2017. Materials for additive manufacturing. CIRP Annals, 66(2), pp.659-681.

[4] Du, W., Ren, X., Pei, Z., & Ma, C. (2020). Ceramic binder jetting additive manufacturing: a literature review on density. Journal of Manufacturing Science and Engineering, 142(4).

[5] Graybill, B., Li, M., Malawey, D., Ma, C., Alvarado-Orozco, J., and Martinez-Franco, E., 2018. Additive manufacturing of nickel-based superalloys. The ASME International Manufacturing Science and Engineering Conference, College Station, TX, U.S.

[6] Spencer, O. O., Yusuf, O. T., & Tofade, T. C. (2018). Additive manufacturing technology development: a trajectory towards Industrial Revolution. Am. J. Mech. Ind. Eng, 3(5), 80-90.

[7] Sunny, S. N. A., Liu, X. F., & Shahriar, M. R. (2018). Communication method for manufacturing services in a cyber–physical manufacturing cloud. International Journal of Computer Integrated Manufacturing, 31(7), 636-652.

[8] Khanuja, S. S. (1996). Origin and control of anisotropy in three dimensional printing of structural ceramics (Doctoral dissertation, Massachusetts Institute of Technology).

[9] Eyles, A., Gibbons, S., & Montebruno Bondi, P. (2020). Covid-19 school shutdowns: What will they do to our children's education?

[10] Azevedo, J. P., Hasan, A., Goldemberg, D., Iqbal, S. A., & Geven, K. (2020). Simulating the potential impacts of COVID-19 school closures on schooling and learning outcomes: A set of global estimates. The World Bank. shutdowns: What will they do to our children's education?

[11] Zhan, W., Hur, B., & Ryoo, B. Y. (2020). A Control Systems Course Project Serving as a Bridge to A Capstone Course and Research Projects. In 2020 ASEE Annual Conference & Exposition.

[12] Hur, B., Malawey, D., Morgan, J. A., Song, X., & Langari, R. (2020). Open-source Embedded Linux Mobile Robot Platform for Mechatronics Engineering and IoT Education. Journal of Management & Engineering Integration, 13(2), 34-44.