Creating a CNC Machine from a Manual Drill Press

(Technical Paper)

The Implications in Design of Rapid 3D Design and Manufacturing

(STS Paper)

A Thesis Prospectus Submitted to the
Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia
In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science, School of Engineering

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Spring, 2021

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Technical Topic

The purpose of this Capstone Project is to provide the University of Virginia's Mechanical Engineering Department the means to machine metal quickly with ease and precision. This goal will be achieved through the conversion of a model PM 727-V Precision Matthews Mill into a CNC mill, or computer numerical controlled machine. This Precision Matthews Mill uses a moving, vertically-aligned drill bit that can be raised and lowered to cut various materials, but most notably different types of metals. The mill also contains a mount that can be moved in the X, Y and Z directions by manually rotating knobs on each respective end, with an accuracy of 0.001" on both the X and Y axes. (precisionmatthews.com, 2019). The drill bit has different gears that can be manually switched to achieve varying levels of spindle speed to safely manipulate different materials. By converting this manual mill into a CNC mill, we will incorporate servo-motors into the machine's design that will autonomously control all of the machine's motion, eliminating the need for a manual operator and automating precision (Pahk, 2001). Initially the team will disassemble the manual mill by taking apart the hand cranks from all axes and the motor with its spindle from the Z-axis. The lead screws, which are long threaded fasteners responsible for moving the machine's mount in each axis upon rotation of each respective axis's knob, will be removed from the machine. These now empty carriages for the three lead screws will be replaced with ball screws, which are far more precise than lead screws due to their ability to diminish backlash as a result of their ball bearings. Due to reduced gap size between gear teeth, these ball screws are able to decrease backlash, ultimately allowing the CNC machine to attain accuracy levels up to 0.00025" during operation. The team will then design mounts for the servo-motors so they can be positioned in a manner that allows them to turn the ball screws, and all of these motors will be interconnected via an Ethernet Smoothstepper. The

Ethernet Smoothstepper operates as the brain of the machine, using an ethernet connection to communicate with all three servo-motors to pilot the ball screws, in turn moving the machine's spindle and base. The servo-motor's encoders also relay feedback to the Smoothstepper so that it continuously knows the positions of all motors in real time, enabling the mount to simultaneously move on all three axes. The Smoothstepper will operate via Mach3 software, sending step and direction pulses to the servo-motors (Warfield, 2020). Lastly, the machine will be integrated with limit switches that will alert the servo-motors when they have rotated too far in a certain direction, endangering a ball screw from becoming unthreaded and falling out of the machine. One limit switch will be placed on each end of the three ball screws for a total of six. The conversion will utilize the University of Virginia's Mechanical Engineering Department, Automation4Less, Amazon and McMaster-Carr as part suppliers, in addition to online resources materials explaining conversion instructions and disassembly including: video guides posted on Youtube, Github, Heavymetalcnc.com and Precisionmatthews.com.

STS Topic

I was a summer 2018 engineering intern at Cadence Inc, a contract manufacturing company that mass produces advanced products, technologies, and services to companies worldwide (https://www.cadenceinc.com/, 2020). I had access to highly-valued 3D printing and CNC machining equipment, allowing me to witness how beneficial these machines are by saving time and money. 3D designs were created, printed and brought to life as functioning prototypes within hours.

By contrast, in summer 2020 I interned at Rivanna Medical, a small biomedical company that did not provide access to a 3D printer. The design work was virtually identical, but once a 3D design was finalized, I compared different outsourcing 3D printing companies' lead times and costs to discover the best option. This time-consuming process included researching costs of shipping, materials, and material performances. At Cadence, the only manufacturing expense was material cost, which tended to be a few dollars per project. At Rivanna, even small prototypes could cost upwards of $200. Because I was creating multiple prototypes, this was significantly expensive. More importantly, contracted parts could take more than two weeks to arrive. In 3D design there is often a fit or function problem that the CAD model does not reveal; edits must be performed to make a fully-functional prototype. It wasn’t uncommon to wait weeks for delivery, only to learn the prototype didn’t work as expected. In contrast, if my Cadence design did not function properly, I would simply edit my 3D model and have a fixed prototype within hours.

Innovation and design are suppressed without immediate 3D printing capabilities because a designer is hampered from creating different iterations of a design in a short timeframe. In-house print ability supports engineers in constructing original designs and technologies by easily generating prototypes. If 3D printing is unavailable, artificers will design more conservatively because there is greater risk while waiting on a third-party manufacturer to create a prototype that may or may not work. Without these turnover times, a more relaxed environment exists where more time can be spent finalizing the product. This stimulates creativity, allowing product architects the ability to rapidly implement changes and test multiple physical models. Engineers are also provided additional time to consider secondary design factors such as safety, durability, and diversification products for alternate uses. Typically, when an engineer goes through the initial iterations of a product, there is one main feature intended at the design’s core. With each iteration, the design goal is stretched to include cost, time and quality (Sobek, 2003). 3D printers permit product design to reach the satisfactory point in a shorter time period, improving the overall manufacturing process with greater efficiency. Engineers then have more time to invest on seemingly less important details.

3D printers have a significant impact on a product’s lifecycle, allowing a complete prototype to be created within hours; it isn’t necessary to have engineers discuss intentions with manufacturers. Engineers can simply send the manufacturer a prototype rather than manufacturing products based solely from a CAD model, increasing sustainability. No longer must design engineers invest millions of dollars and countless hours building molds, machining parts, and creating expensive assembly processes in the hopes that their original design is adequate. With 3D printing, engineers can rapidly prototype ideas, eliminating concepts that don’t work well while improving promising ideas. Alternatively, this “3D print and iterate” concept could create an engineering environment lacking attention to detailed tolerance, stress points, and force vectors that are not illuminated in a 3D model. This could be devastating in real-world production. For example, printing a 3D small-scale model of a bridge or building might be great visual confirmation of stability, without yielding critical information regarding wind-shear, earthquake resilience, or thermodynamic forces.

3D printing is not a one-size-fits-all solution, highlighted by Kostakis and Papachristou; they reference Winners’ idea that widespread adoption of certain technologies cannot automatically produce a better world. Some technologies require appropriate social environments to be structured in a certain way for them to meet their potential (Kostakis, 2013). They suggest this may be the reason attempts for more autonomous forms of production based on novel technologies has been so common in recent decades. They emphasize that design manufacturing optimization focuses on three essential aspects: design modularization, customer intuition, and cost-efficiency. Focusing on these aspects, engineers better understand the needs and performance of products, and more practical, inexpensive changes can be implemented into designs with each iteration.

Grigoriadis acknowledges the possibility that rapid advancements in additive manufacturing can lead to a decrease in distributive innovation, proving it difficult for small companies to compete in quickly saturating and high performing markets (Grigoriadis, 2017). Furthermore, it causes quicker product obsolescence. When frequent prototype changes are implemented, new products and technologies follow. For example, a two-year-old version of Apple’s iPhone is often considered archaic. This produces vast waste because the population is regularly upgrading its technology while disposing of the old. However, this environment encourages engineers to think more innovatively. The expectations 3D printing has brought upon designers puts pressure on them to reveal new designs far more frequently than in the past. The most obvious examples are cell phones and smart watches, which now essentially have a 12-month lifecycle. Companies mass producing technologies such as cars, cellphones and computers release multiple products annually, gaining a competitive edge. Additionally, 3D printing tends to lower the costs of development because of its ability to avoid fees from contracting out prototypes within R&D. This creates product design entry barriers, sparking greater competition. Unfortunately, this can also result in companies easily and inexpensively replicating products, undercutting the innovator’s design and market leadership. For example, Ping golf clubs, Bluetooth earbuds, and even computer processors have all been victimized by copycats using CAD tools and 3D printing to enter the market in a disruptive way.

Lastly, another potential 3D printing drawback is that it can put large company infrastructures at risk of employee layoffs. Autonomous production can jeopardize jobs, reducing the number of engineers and manufacturing laborers needed to perform the same amount of work.

Next Steps

Various sources will be examined in order to highlight all the change within the technology and history of 3D printers, specifically what it was like to design prior to their existence and what has changed. 3D printing and CNC milling will be explained during their evolution focusing on periods of major development, allowing readers to become familiar with how a well-known machine has larger socio-technological impacts than one might think. Particularly, a rich repository of engineers with 3D printing real-world experience will be found and their thoughts and opinions on how the technology affects their jobs will be analyzed. There will be a focus on how this technology impacts their real-life experience and how it has changed over the years. It will show that not only does 3D printing change the design process as a whole, but it also causes engineers’ thought processes to change as a whole. Contextualization of this material will create a sense of interconnectedness between all of the feelings towards 3D printing capabilities in order to aid readers in their comprehension that was framed in the introduction of this thesis.

References

Kostakis, V., Paparachristou, M. (2013). Telematics and Informatics. *Commons-based peer production and digital fabrication: The case of a RepRap-based, Lego-built 3D printing-milling machine*. Elsevier. https://d1b10bmlvqabco.cloudfront.net/paste/jcj65k72m3q44b/7f8d2e0ff19fbdadec9a10a6f2246be15e0c47ba40c9762b51cc04ee8c19de1d/STS_Telematics_and_Informatics_Article.pdf

Grigoriadis, K. (2017). *Computational and Conceptual Blends: The Epistemology of Designing with Functionally Graded Materials*. Royal College of Art.

https://d1b10bmlvqabco.cloudfront.net/paste/jcj65k72m3q44b/74d18d2b9b957ec986813f50af3d712a23618f4c0280e2ed08ba22e30c8e4e8b/STS_Computational_and_Conceptual_Blends_Article_Split.pdf

Greenhalgh, Scott. (2016). *The effects of 3D printing in design thinking and design education*. Journal of Engineering, Design and Technology. Research Gate. https://www.researchgate.net/publication/310510419_The_effects_of_3D_printing_in_design_thinking_and_design_education

Reichental, A. (2018). *How 3D printing is revolutionizing healthcare as we know it*. Tech Crunch. https://techcrunch.com/2018/04/05/bioprinted-organs-skin-and-drugs-how-3d-printing-is-revolutionizing-healthcare-as-we-know-it/

Brown, MacKenzie. (2019). *How 3D Printing is Changing Product Design and Manufacturing*. Cad Crowd.

https://www.cadcrowd.com/blog/how-3d-printing-is-changing-product-design-and-manufacturing/

D’Aveni, Richard. (2015). *The 3-D Printing Revolution*. Harvard Business Law. https://hbr.org/2015/05/the-3-d-printing-revolutionA

Hand, Aaron. (2019). *How 3D Printing Is Changing Production Models*. Automation World. https://www.automationworld.com/products/software/article/13320073/how-3d-printing-is-changing-production-models

Upputuri, Raja. (2014). *3D Printing – Boon or bane for employment*. Think3D. https://www.think3d.in/3d-printing-boon-or-bane-for-employment/#:~:text=Job%20Creation%3A%20Definitely%20millions%20of%20jobs%20will%20be,living%20and%20a%20better%20quality%20of%20living%20worldwide

Erickson, Steve. (2013). *5 ways 3D printing is affecting the design industry*. 99 Designs. https://99designs.com/blog/design-other/5-ways-3d-printing-is-affecting-the-design-industry/#:~:text=Thanks%20to%20the%20accessibility%20and,production%20is%20becoming%20more%20efficient

Warfield, B. (2020, October 23). *What is CNC Machining and CNC Machines? [2020 Easy Guide]*. CNCCookbook. https://www.cnccookbook.com/what-is-cnc-machining-and-cnc-machines/.

PM-727V Milling Machine. Precision Matthews Machinery Co PM727V Milling Machine Comments. (2019). https://www.precisionmatthews.com/shop/pm-727v/.

About Cadence. (2020). Cadence. https://www.cadence.com/en_US/home/company.html

Sobek, Durward. (2003). Iteration in engineering design: Inherent and unavoidable or product of choices made?. *Montana State University*. https://www.researchgate.net/publication/240066660_Iteration_in_engineering_design_Inherent_and_unavoidable_or_product_of_choices_made

Pahk, H., Lee, D. S., Park, J. (2001). *International Journal of Machine Tools and Manufacture*. Ultra precision positioning system for servo motor-piezo actuator using the dual servo loop and digital filter implementation. Elsevier.

https://www.journals.elsevier.com/international-journal-of-machine-tools-and-manufacture

The End of Speed Constrains in Industrial 3D printing. (2019). ttps://xponentialworks.com/the-end-of-speed-constraints-in-industrial-3d- printing/