Hands-on activity demonstrating different in-process measurement methods

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Abstract. Purdue Polytechnic Columbus is one of ten statewide extensions of Purdue University and is located about an hour south of Indianapolis in an economic region dominated by manufacturing. Just less than 40% of the workforce in this 10 county region is directly employed by the manufacturing industry. The primary employer in the region is diesel-engine manufacturer Cummins, Inc. but there are many others including Toyota, Honda, Faurecia, NTN Driveshaft, Valeo, and Aisin. Most of the manufacturing industry is related to automobile production. Purdue Polytechnic Columbus is unique among higher education institutions due to a partnership with diesel-engine manufacturer Cummins Inc. that has led to an environmentally-controlled metrology lab located within the university facility. This puts Purdue Polytechnic Columbus in a unique position to develop and offer training and education programs targeted to local industry and local education institutions. There have been many recent reports of shortages of trained metrology personnel. As a university, Purdue Polytechnic Columbus has developed many programs to engage young people in the STEM disciplines to foster interest in manufacturing and engineering careers. This work attempts to develop a hands-on activity that emphasizes the importance of measurement within the broader context of assembly-line manufacturing. Participants create multiple assembly lines to produce a simple fixture, utilizing various measurement tools to increase quality and improve efficiency. The last effort employs go/no-go gauges to illustrate the value of those tools in manufacturing to improve quality and efficiency.

1 Introduction

In 2005, a white paper sponsored by the National Conference on Standards and Laboratories International (NCSLI), discussing the need to refocus on training and education, identified two key issues facing the industry:

- “There is a critical ongoing loss of metrology expertise (in the US)” [1]
- “The changing demographics in science, technology, and engineering, (aging staff, retirements, loss of military personnel, lack of interest in these careers, smaller next generation, higher pay and glamour in other fields) along with the lack of a clear career path in metrology, is causing a shortage of qualified staff that will worsen” [1]

Additionally, this shortage of trained measurement personnel has been highlighted internationally by Wilcox [2] who, in a 2014 article, stated

- “In metrology there is a dearth of measurement professionals at all levels. Metrology has been neglected when compared to other key industrial skills. The tool room and skilled manual machinist have all but disappeared. The traditional pipeline has dried up and not been replaced. This lack of skilled measurement people is recognized by most manufacturing companies, from inspectors to site metrologists”

In 2012, Purdue Polytechnic Columbus earned the opportunity to manage an environmentally-controlled metrology lab as a result of a collaborative effort with a local manufacturer, which is detailed in a paper by Stahley et al. [3]. This opportunity marked the beginning of a focused effort for Purdue Polytechnic Columbus in metrology. By the spring of 2019, the Purdue Polytechnic Precision Measurement Center was listed as a “core facility” at Purdue University and included a calibrated coordinate measuring machine (Zeiss Duramax), a calibrated Instron tensile test machine, a surface finish tester, a roundness tester, various standards such as gauge blocks and mass standards, a force measurement machine, an impact tester, and numerous analog and digital hand measurement tools to support internal and external measurement activities. As knowledge and experience in metrology increased, there has been a comparable increase in awareness that a shortage of measurement expertise and metrology professionals is approaching and that this appears to be an international problem. With the expected retirement of a large number of measurement professionals and the lack of young people interested in measurement as a career, this presents a critical problem. Data indicate there will be a shortage in engineers and technologists as well as STEM professionals in general in the coming years.

2 K-12 and Teacher Education Outreach Initiatives

There are initiatives at the K-12 level to address this coming crisis. Mostly they include efforts to educate young people about what metrology is (it’s not meteorology) and to inform them about rewarding careers in metrology. Gentry [4] worked together with colleagues from the National Conference of Standards Laboratories International (NCSLI) to create and market a DVD entitled “Find a Cool Career in Metrology”. The DVD and subsequent website (www.metrologycareers.com) allow those interested to explore what metrology is, the various types of metrology (physical, chemical, electrical, legal, dimensional etc.), and interviews with current metrologists. Additional features include learning about the International System of Units (SI), World Metrology Day, and measurements in sports. This outstanding resource was made available to interested professionals to use in the Metrology Ambassador program sponsored by NCSLI that could be used in outreach efforts to K-12 students. Many other tools are available through NCSLI to promote metrology to the younger generation and includes kits that may be checked out for use in an outreach event.

Another effort to promote metrology through outreach was supported by the US Navy. Fishell, et al. [5] reported in 2012 of efforts “to attempt the educate students and faculty about the importance and basics of metrology to the world around us.” In particular, they wanted to reach out to the “earliest stages of the engineering pipeline which begins in grade school.” Their effort began with providing tours to local schools of laboratory facilities at the Naval Surface Warfare Center in Corona which included a demonstration of watching a steel bar expand as it is slowly heated. The growth of the bar was measured with a dial indicator so that students could see the bar expand ever so slightly with increasing temperature. Other laboratory demonstrations that utilized measurement equipment were also included in the tours. The paper reported that “having metrology explained early in the

educational system provides at least an awareness of measurement science and its importance in our lives” [5]. One difficulty cited was the inability to do a longitudinal study to track those students participating in the outreach events due to various privacy laws and regulations to discover if they had eventually chosen to study STEM and/or metrology.

In a more recent work, Gentry [6] summarized the outreach activity within the NIST Office of Weights and Measures (OWM) division. Since 2011, the OWM division has supported over 130 outreach events and have reached over 28,000 students, parents, and teachers. The audience at these events often was quite different, ranging from classrooms of students to teachers participating in a professional development activity. In any case, content is adjusted for the proper audience. OWM staff have also partnered with Science and Technology Education Partnership (STEP) and participated in their annual conference by offering a teacher professional development program including a hands-on metric estimation activity and by distributing SI resources and other publications to parents and students promoting metrology.

It is difficult to measure the effectiveness of these efforts. As mentioned, longitudinal studies to track the participants are challenging due to privacy laws involving minors. However, engaging young people with hands-on activities that involve measurement and manufacturing appears to be the best approach for attracting them to

Figure 1. This shows all the parts utilized in the activity completely assembled. Participants are asked to create the assembly from the individual parts.

relevant and rewarding careers in metrology. Consequently, this paper details an outreach effort utilizing parts created by additive manufacturing, digital and analog measuring tools, and a simple assembly fixture to illustrate a basic manufacturing assembly line with various measurement features. Digital calipers, digital micrometers, Vernier calipers, and go/no-go gauges are introduced and utilized in the hands-on activity. Gauge blocks are also discussed as tools to calibrate the various dimensional measurement instruments.

3 The Assembly

Figure 1 displays the complete assembled construction utilized in the activity. The two plates – upper and lower - are identical parts. The four required orange supporting pins are also identical and the larger black center pin fits in the larger holes in the plates. The 0.25-inch bolts and accompanying nuts are purchased from an online retailer and are cheaper to buy than to 3D print. Additionally, while threads can be 3D printed, the process is rather problematic and often requires additional work to make them operational. Figures 2-4 are individual part drawings of the 3 parts which are 3D printed for the assembly – the end plate, center pin and support pin. Of particular interest for this activity, are the dimensions of the holes in the plate and their corresponding tolerances, and the dimensions of the 2 pins along with their tolerances. The participants, who are grouped in teams of 5, are asked to construct 5 of the assemblies as quick as possible, including “finger” tightening the fasteners.

Figure 2. Drawing of the End Plate for the Fixture assembly.

Figure 3. Drawing of the Center Pin.

Figure 4. Drawing of the Support Pin.

4 End Plate

The end plate basically has three different size holes as shown in Figure 2 with limit dimensions to indicate maximum and minimum sizes. Two examples of 3D printed plates are displayed in Figure 5 with clearly different size holes. The advantage of 3D printing parts for this type of activity is that variations from the nominal size plate are simple using the CAD program and then the 3D printer is utilized to produce the variations. Additionally, the different materials used for the additive manufacturing likely have different shrink rates as the material cools, creating yet another variable in the process. However, in terms of education and training, additional variables are beneficial since most manufacturing operations are impacted by many variables that affect dimensions, quality, and functionality.

Also shown in Figure 5 are the go/no-go gauges for the end plates. The dimensions of the gauges are set by the tolerances associated with those hole dimensions. Red and green tape are used to indicate the “go” and “no-go” sizes of the gauges.

Figure 5. Examples of 3D printed end plates and the corresponding go/no-go gauges utilized to confirm dimensions of the three holes.

5 Support and Center Pins

Figure 6. The center pin and the support pins shown in the partial assemblies.

The support and center pins are also 3D printed for the assembly. They are shown in the partial assemblies of Figure 6. Again, the nominal size pins are detailed in Figures 3 and 4 but many variations of both pins are created using the CAD program and the tolerances indicated on the drawings. The pins are then printed using additive manufacturing.

Similarly for the pins, go/no-go gauges are produced as well. Designed in the CAD program using the corresponding tolerances, they are shown in Figure 7.

Figure 7. Go/No-Go gauges created using additive manufacturing with reference to the appropriate tolerances for the center and support pins.

6 The Activity

Utilizing the 3D printed parts described, participants in the activity are challenged to produce 5 copies of the assembly under different conditions.

1. The end plates, center pins, support pins, and fasteners are distributed randomly to the various teams of participants. Without any additional tools, the teams are to construct 5 of the assemblies as quickly as possible. As the teams work, they discover that not all of the pins fit in their proper hole on the plates. As experienced with a class in a local high school, participants became frustrated as the inability to know if a part would actually fit slowed the process and created a confused and haphazard environment. Most teams successfully completed the 5 assemblies in about 12 minutes.
2. Again, the various materials are distributed randomly but for this trial, the teams are provided digital calipers and digital micrometers to use in their efforts to construct the 5 assemblies. The teams were not given specific instructions on how to use the measurement tools. They could choose to use them anywhere in the assembly process or not at all. Typically, teams used the tools to measure the diameter of either the support pins or the center pins. Very few teams used the tools to measure the diameter of the holes in the plates. Figure 8 demonstrates a participant using a digital caliper to measure the diameter of a pin. There is also a discussion at this point about training required to properly utilize the digital

Figure 8. A student participant using a set of digital calipers to measure the diameter of the support pin.

calipers. Most student participants automatically assume that with digital tools that no training is required. They learn, however, especially with calipers, that the measurements can vary based on the pressure applied to the instrument in pressing on the part being measured. The digital micrometers, with a ratchet mechanism, are quite good at achieving a constant instrument-part contact pressure but calipers are more of a challenge. These issues are discussed at the end of that part of the exercise. Interestingly, the time to produce the 5 parts did not really decrease but several participants remarked that the “quality” of the final parts is better. While the tools didn’t speed up the process appreciably, they did all the assembly-line personnel to create better parts.

3. The final assembly line simulation begins with a detailed description of go/no-go gauges including how they are produced and dimensioned, and how they are used to simplify the production process, especially with untrained production associates. The terms “maximum material condition” and “least material condition” are introduced to further clarify how the go/no-go gauges are created and how they relate to details in the part drawings. After learning how to use the gauges, the teams are once again instructed to construct 5 of the completed assemblies. The process for this simulation was much smoother. All three participating teams completed the 5 assemblies in less than 6 minutes. Figure 9 shows a participant using a set of go/no-go gauges to determine acceptability of the end plate.

Figure 9. A student participant using the go/no-go gauges to determine if the end plate meets specifications to continue in the manufacturing process.

7 Conclusions

This work details the development and evolution of a simple manufacturing assembly operation using 3D printed parts and purchased fasteners. Different modes of in-process measurement are demonstrated during the process to help educate young people about manufacturing, measurement, and 3D printing. The objective is to provide an engaging and interesting activity for pre-college youth to discover the role of measurement in the manufacturing process and to encourage them to consider careers in manufacturing and specifically metrology. There is a demonstrated need both now and in the near future for measurement professionals in manufacturing enterprises and many organizations are embracing outreach activities to educate and encourage young people to pursue measurement as a career. This humble work provides an additional activity for that purpose using simple tools and parts that are made using additive manufacturing, including dimensions that could be easily duplicated and used elsewhere.

8 References

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