A New Approach to Teaching Manufacturing Processes Laboratories

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Abstract

The manufacturing processes laboratory taught in the Padnos School of Engineering at Grand Valley State University has been modified to focus on part and process design. Machining, injection molding and lost foam casting have been taught using the new approach. First, students design a part for a specific process. Then the required tooling is designed and fabricated. When it is appropriate, process parameters are determined using designed experiments. Finally, the parts are produced and inspected. Inspection results are compared to the original design intent. Discrepancies between inspection results and the design are investigated. The new approach has forced students to demonstrate a deeper understanding of the manufacturing processes and the relationship between part design and manufacturing process design. Another advantage of this approach is that students have an opportunity to apply design of experiments knowledge to concrete problems. Other advantages and challenges of this approach will be presented.

I. Background

The Padnos School of Engineering is a four-year ABET accredited engineering school offering engineering degrees in mechanical, electrical, manufacturing, and computer engineering. The curriculum emphasizes design while preparing students for careers in industry. All students are required to complete three four-month cooperative education experiences before graduation. A four-credit manufacturing processes class is offered to junior level mechanical and manufacturing engineering students. The class consists of three hours of lecture and three hours of laboratory work each week. In the past, the laboratory experience has consisted of traditional laboratory exercises and tours of local industry. In the laboratory students gathered data and then compared the data to theoretical predictions. Unfortunately, this approach lacked relevance to students with industrial experience. On the other hand the tours of local industry were very relevant to the students. Interesting manufacturing facilities and knowledgeable tour guides are easy to find in the Grand Rapids area. But the faculty has grown concerned that too many tours result in students retaining little information while they passively trudge through factories.

Fortunately, a new laboratory building and changes to the first year curriculum enabled fundamental changes in the laboratory portion of the manufacturing processes course. In the summer of 2001 construction of The Fred M. Keller Engineering Laboratory building was completed. The two story, 30,000 square-foot building was built to support the Padnos School of Engineering's practice orientated, hands-on, design and build centered curriculum. The 7 million dollars required to erect and equip the building was donated by local industry and other private sources. The metal processing lab moved from cramp quarters on the sixth floor of an office building to a large space designed for machine tool instruction. Modern equipment, most significantly a CNC turning center and CNC milling center, was purchased. A new plastics processing lab was created and equipped with a small pneumatic injection molding machine. At the same time, students who had completed the revamped engineering graphics course were now eligible to take the manufacturing processes course. The engineering graphics class had been changed to emphasize design and manufacturing. Students who completed the new course are comfortable designing and manufacturing parts using computer aided design (CAD) software, computer aided manufacturing software (CAM) software and small 3-axis CNC mills.[1]

II. Goals of the New Approach

The following goals for the new lab exercises were formulated:

1. Students should apply CAD and CAM skills acquired earlier.
2. Students must apply knowledge of specific manufacturing processes.
3. Students must apply design of experiments (DOE) knowledge to plan and execute experiments to determine optimal process settings.
4. Students must solve the practical manufacturing problems that arise.

To meet these goals a generalized or idealized lab procedure was developed. Under the ideal procedure, teams of students designed a part to meet functional and geometrical specifications. The design of the part was optimized for production using the manufacturing process under consideration. Next Students designed the manufacturing process to produce the part. Tooling was designed and fabricated by the students. Design of experiments was then employed to optimize the process parameters. Finally, parts were evaluated to determine conformance to original specifications.

III. Description of the Laboratory Exercises

Machining, injection molding and casting laboratory exercises are described below. To start the machining exercise students were presented with the assembly of a small 3-axis CNC milling machine. The assembly drawing is shown in figure 1. Pairs of students were assigned to each distinct part.

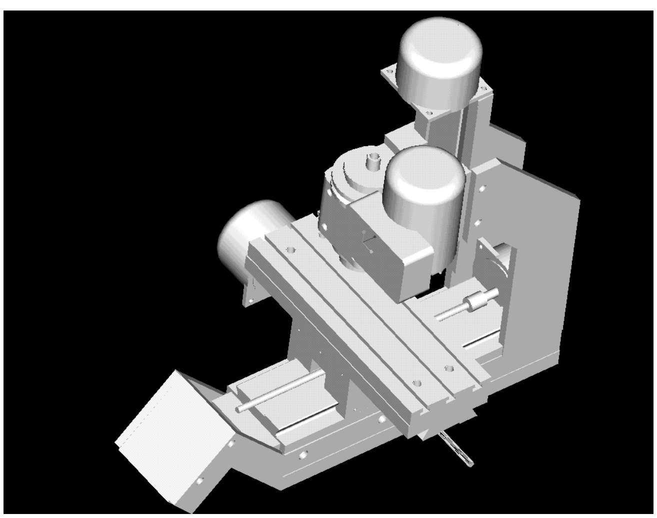

Figure 1. Assembly drawing of a Small CNC milling machine.

A description of the project deliverables and their due dates was presented. The first deliverable was a detailed print of the assigned part. Dimensions, tolerances, datums and geometric dimensions and tolerancing call outs were required. Students assigned to mating parts were required to review and approve each other's prints.

Next students formulated process and inspection plans for each part. The process plan included the following information:

1. Machines required to manufacture the part.
2. The tooling and fixturing required for each machine.
3. The process parameters for each machine.
4. The part program if a CNC machine was used.

Design of experiments (DOE) was often employed to optimize process parameters. For instance students specified strict surface roughness criteria for some parts. DOE was employed to minimize cutting time while still satisfying the surface roughness criteria. Inspection plans were also required for each part. These plans detailed the equipment and methods that would be used to inspect each dimension and GD&T call out on the print. Part details that could not be inspected had to be modified or redesigned. The process and inspection plans forced students to think through or design the entire manufacturing and inspection process before any chips were produced.

Finally, students produced the parts, inspected the parts and attempted to assemble the mill. Problems encountered in assembly evoked mature and sometimes animated discussions about dimensioning, tolerancing and metrology. The instructor believed that these charged discussions were the highlight of the course. Designs were modified and parts were reworked to enable successful completion of the project. The finished assembly is shown in figure 2.

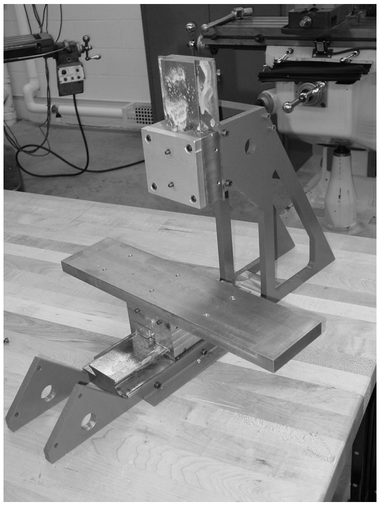

Figure 2. Mechanical parts of CNC mill assembled.

The machining exercise was a semester long project. Two lab periods were devoted to work on the project. Students completed the project by working outside of assigned laboratory time. All deliverables were graded during the semester and at the end of the semester. This enabled students to receive timely feedback, ignited discussions about difficult topics and deepened student understanding. These discussions were a valuable addition to the class.

Injection molding was the next process investigated. The students were introduced to a small pneumatic injection molding machine. Pairs of students were challenged to design a simple part to be manufactured using the machine. Students designed and manufactured mold inserts to produce their parts. The inserts were manufactured from aluminum stock using either manual or CNC machines. DOE techniques were used to minimize part cycle time while ensuring the parts produced met specifications. Parts were produced and inspected. Discrepancies between the part design and the inspection results had to be explained. A typical part and mold insert are shown in figure 3.

Figure 3. A simple part and the mold insert.

The injection molding exercise required two lab periods to complete. The deliverables for the exercise included the following:

1. A dimensioned and toleranced part print.
2. A dimensioned and toleranced mold insert print.
3. Documentation of the process optimization process.
4. Part inspection results.
5. Discussion of discrepancies between the part design and the inspection results.

Again, student's hands-on experience designing and manufacturing parts and tooling for the injection molding process enhanced their understanding of the process.

Lost foam casting was the last process investigated with the new approach. Teams of students were challenged to redesign machined parts from the CNC mill project as cast parts. They were encouraged to take advantage of the design freedom afforded by the casting process to reduce the weight of the parts, the machining time required for each part and the number of parts. Students designed the parts as well as the patterns required to cast the parts. Engineers from Betz Industries of Grand Rapids, Michigan reviewed the part and the pattern designs. Students produced the foam patterns for promising designs and Betz Industries poured the castings. The cast parts were inspected and compared to the original design.

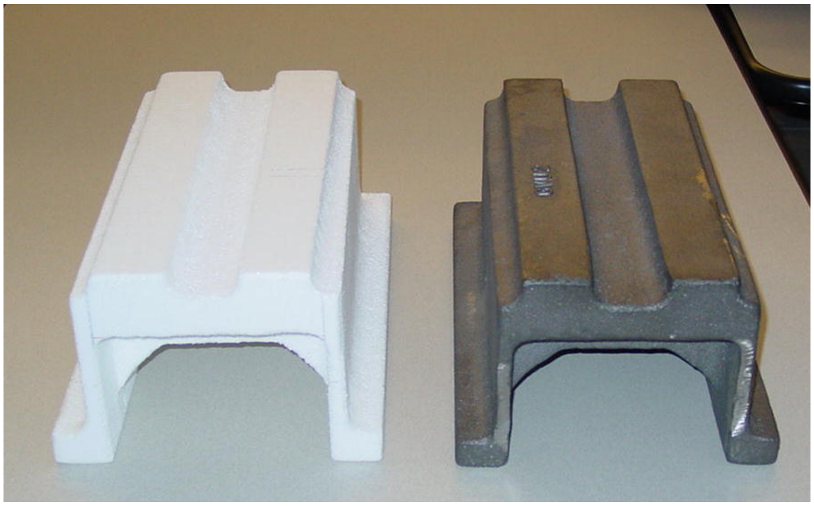

Figure 4. Foam pattern and cast part.

The deliverables for this project included:

1. Dimensioned and toleranced prints for the cast part, the pattern and the finished machined part.
2. Inspection results for the cast part.
3. Discussion of discrepancies between the part design and the inspection results.

This exercise gave students practical experience designing and manufacturing cast parts. They also obtained valuable feedback about their designs from the engineers at Betz Corporation. Difficulties with this lab included fitting into the foundry's production schedule, not having sufficient time to machine the cast parts and the inability to produce a part for each team.

IV. Discussion and Future Directions.

The strengths and weaknesses of this approach to teaching manufacturing processes lab are listed below.

Strengths:

1. The practical experience of designing and manufacturing parts fostered a more mature understanding of each process.
2. The approach reinforces important topics from previous courses including design of experiments, engineering graphics and CAD/CAM.
3. Students gained experience solving practical manufacturing, tooling and metrology problems.

Weaknesses:

1. Increased faculty and student time was required to complete exercises.
2. Students required liberal access to manufacturing and metrology equipment.
3. Tool breakage and machine break down occurred and had to be dealt with in a timely manner.

Student, faculty and industrial feedback have all been positive. The faculty would like to expand the approach to other manufacturing processes. Thought has been given to having all parts designed and manufactured be a part of a larger product. Other refinements under consideration include combining the casting and machining exercises to produce parts that are cast and then machined to final dimensions.

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References

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John Farris is currently an assistant Professor in the Padnos School of Engineering at Grand Valley State University (GVSU). He earned his Bachelors and Masters degrees at Lehigh University and his Doctorate at the University of Rhode Island. He has 6 years of college engineering teaching experience as well as 3 years of industrial design experience. His teaching interests lie in the first year design, design for manufacture and assembly, interdisciplinary design and kinematics.

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