Putting Around -- An Interdisciplinary Manufacturing Project

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Abstract

Innovative, interdisciplinary laboratory exercises are difficult to develop and successfully execute. This paper describes a joint manufacturing engineering/mechanical engineering project to design and machine the head of a golf putter. The project spanned two terms. The project involved two separate courses, one in manufacturing engineering and another in mechanical engineering. Only one student in the first term was a member of both classes. In the manufacturing engineering course, teams were assigned so that manufacturing and mechanical engineers worked together. A questionnaire on specific engineering knowledge was used to assist in team assignments.

Introduction

Much has been said and written about the desirability of interdisciplinary, team based projects for undergraduate engineers. This paper does not repeat these points, rather describes the implementation of such a project.

Manufacturing Engineering and Mechanical Engineering at Kettering University (formerly GMI Engineering & Management Institute) are separate academic programs and are not part of the same department. Manufacturing Engineering is in the Department of Industrial and Manufacturing Engineering and Business. Mechanical Engineering is a stand-alone department. As with all Kettering University programs, students in both Manufacturing Engineering and Mechanical Engineering have cooperative education positions beginning in the freshman year.

The purpose of the Manufacturing Engineering Program is to produce an engineer capable of taking a product design and subsequently designing the manufacturing system required to put the design into production and monitor the quality of the output. The Manufacturing Engineering program employs hands-on laboratories using only industrial grade equipment. Students are taught both analytical and statistical methods associated with manufacturing.

The purpose of the Mechanical Engineering Program is to produce an engineer with excellent abilities to perform design and analysis of physical objects and systems of objects. Specialties within the program include automotive, medical, and polymer products. There is also a manufacturing track within Mechanical Engineering. In this track students take three Manufacturing Engineering courses, but the emphasis remains on product design and computational analysis of manufacturing processes.

It is with this background that one of the Mechanical Engineering faculty members approached me with the concept of producing a golf putter. This engineer had extensive experience with the design of golf equipment and has since left Kettering University to direct development and testing for a major golf equipment manufacturer.

2. Design Phase

In the first term, a mechanical engineering faculty member and several students designed the putter head using IDEAS. The basic putter design is shown in Figure 1. The design specified the material to be stainless steel. 304 stainless steel was chosen, because it is already in use in golf equipment.

When the project came to me, I was teaching my senior level course in Material removal Processes. Because the teaching schedule for the course had recently been changed, the class had only 12

Figure 1: Kettering Putter

students. This was ideal for a high intensity project, because the teams would remain within my span of control and only a single laboratory session needed to be scheduled with the course. A finished prototype needed to be presented to the President of the University in 6 weeks. This project would require focused effort by both faculty members and the students.

Students enrolled in the course were a mixture of manufacturing and mechanical engineers. Most had coop positions in manufacturing companies. The first step in assigning teams was to survey the students' knowledge and other attributes. This was performed with a questionnaire. The questions are listed in Table 1.

Table 1: Student Questionnaire
Free hours on Tuesdays:
Free hours on Wednesdays:
Mark the classes below you have taken or are now taking: ☐ MfgE 384 Numerically Controlled Systems <i>[manual NC programming]</i> ☐ MfgE 480 Computer-Aided Manufacturing <i>[includes MasterCAM]</i> ☐ IE 430 Quality Assurance ☐ ME 102 Engineering Graphics ☐ ME 212 Intro to 2-D CAD ☐ ME 315 Computer-Aided Engineering
Do you currently work in a plant which performs machining? ☐ Yes ☐ No Have you done manual machining (other than in ManPro class) ☐ Yes ☐ No Have you done any CNC machining (other than in an MfgE class)? ☐ Yes ☐ No Do you play golf? ☐ Yes ☐ No Are you in town most weekends? ☐ Yes ☐ No Do you have evening classes or an evening job? ☐ Yes ☐ No

Each group was assigned 1 manufacturing engineer and 3 mechanical engineers. Students with knowledge of MasterCAM were assigned as available. There were four basic tasks which needed to be accomplished. These were: Programming, Fixtures, Presentation Stand, and Reporting. A competition was held between the groups first for programming. Each group submitted a plan for how they would program the part. This included a process plan for cutting and the required tooling. Tools had to be drawn from the existing inventory. The winning team from that competition began work immediately. The remaining two groups competed for design of holding fixtures. Of particular concern was a fixture to hold the workpiece for the final 4 degree loft on the putting face. The teams submitted preliminary sketches for their fixtures. The preliminary fixtures designs were required to be coordinated with the process plan of the Programming Team. Once the winner was declared, the team began work immediately. The remaining team began work on both the presentation stand and the reporting.

3. Development Phase

The approach of the Programming Team was to write a series of numerical control (NC) programs to accomplish the machining. Simple features, such as drilled holes, the central pocket, and final 4 degree

loft, were programmed directly on the controller of the Haas VF-E vertical machining center (15 hp, 20 tool carousel, and DNC capability). Complex features, such as the ridges with a 21 degree slope and the perimeter, were programmed using MasterCAM. The process plan for cutting the putter head is shown in Table 2. To speed the programming, the designers were asked for IGES files of the putter. These files were imported into MasterCAM and these formed the basis for generating the NC codes. As is usually the case with the transition between design and manufacture, the Programming group negotiated several design concerns with the designers, as well as getting clarification on several design requirements, which were not well documented in the drawings.

The Fixture Team negotiated with the Programming Team on several points in the process plan. The original process plan would have required three fixtures and four fixture changes. This was reduced to two fixtures, one change of fixture, and one movement of the stock in the first fixture. The final process plan is shown in Table 2. The fixtures are shown in Figure 2. The first fixture is used for all operations, except the final four degree loft. The final loft is cut using the second fixture. Through this redesign of the process plan it became possible to produce multiple units with Fixture 1 and then change to Fixture 2. The units could then be finished on Fixture 2 and sent to sand blasting.

Table 2: Process Plan for Cutting Putter Head	
1. Mount Fixture 1 in vise.	11. Remove stock.
2. Insert stock until it stops.	12. Mount Fixture 2.
3. Tighten vise.	13. Insert stock into fixture 2.
4. Run program: Putter 1 to drill shaft hole	14. Tighten vise.
5. Remove stock and turn 90° counterclockwise.	15. Run Putter 6 to cut final 4° loft.
6. Tighten vise.	16. Remove finish cut putter.
7. Run Putter 2 to rough cut shape.	17. Debur as needed.
8. Run Putter 3 to cut 21° lofts.	18. Tape putting face.
9. Run Putter 4 to finish cut shape	19. Sandblast to matte finish.
10. Run Putter 5 to cut 1° loft.	20. Remove tape.

The next step in the project was to produce Fixture 1. Both fixtures were machined from 2"x2"x6" machinable aluminum vise jaws. It was produced first, because it was easiest to produce and was needed to begin testing the programming. Many iterations of the programming followed, including further negotiations with the designers as limitations of the tooling became apparent. A total of 6 test units in machining wax were required to complete programming of the VMC. Design work and fabrication were completed on Fixture 2 in the fifth week of the project. Prior to completing fixture 2

the four degree loft was set using an angle vise.

Figure 2: Fixture 1 and Fixture 2

In the fifth week of the project the presentation stand was machined from oak stock. Early in the sixth week of the project two stainless steel prototypes were cut. Adjustments were made in the machining parameters as a result. Over the last two days of Week 6 (the last week of classes for the term) and the following weekend 6 finished prototypes were produced. The machining time for these prototypes was 5 hours per unit.

On Tuesday of finals week a prototype putter was presented by the class to the President of Kettering University, an avid golfer. He was very pleased and interested in the project and the putter. So much so that he placed an order for 40 units to be presented to members of the Board of Trustees.

4. Production

I taught the Material Removal Processes course again in the very next term. The term began the week after the President received his putter. The goal was now clear: reduce the processing time to a point where 40 putters could be produced during the term. At this point the students also wanted putters. There were now 18 students in the class, again a mix of manufacturing engineers and mechanical engineers. The putter total needed was then 70, if putters were produced for all current and prior students in the class.

Teams again were constructed along the lines of 1 manufacturing engineer and 3 mechanical engineers per team. The four teams were: Parameters, Tooling, Fixtures, and Monitoring. Unlike the previous term, there was no competition held between the teams. A simple goal was established: 1 hour of machining per putter (Commercial milled putters require about 30 minutes of machining time.) This was achieved.

The Parameters Team was responsible for speeds, feeds, depths of cut, and appropriate alterations to the programming. The Tooling Team was responsible for reviewing performance of the cutting tools

used for the prototypes and specification of new tools as needed. The Fixtures team had to review and redesign the four degree loft holding fixture. The four degree fixture was failing by the end of prototype production. The Monitoring Team was tasked to develop a tool monitoring regime using the Montronix force measuring system (three dimensional forces and spindle power). The Monitoring Team was also responsible for the final report.

It was quickly apparent to the Parameters Team that the NC programs, particularly the ones generated by MasterCAM, were not efficient. This primarily involved multiple passes at low depths of cut. The chosen tooling was capable of deeper cuts at higher feeds. The MasterCAM files were manually edited to reduce redundancy and improve parameters. The greatest single improvement from editing these files was in perimeter cutting. The perimeter cut time was reduced from one hour to 10 minutes.

The Tooling Team made several changes which drastically improved feed and speed. These included selecting shorter, stronger tools for increased feed and suggesting changes to the Parameters Team on speeds to reduce tool wear. The greatest single contribution by the tooling team to the reduction of cutting time was to specify an endmill with a 21 degree loft for cutting the lofted surfaces on the back of the putter. Previously, the cut was performed by multiple passes of a ball nose end mill. This reduced cutting time from approximately 30 minutes to 3 minutes. Three test pieces were produced in wax.

The Fixtures Team had the major task of designing a new fixture to hold the workpiece for the final four degree loft. The fixture needed to accomplish both the holding function and allow for higher feeds and greater depths of cut. To do this the team had to change the direction of the clamping force. The original fixture clamped the workpiece in the direction of the feed, as is generally considered best. The problem was that there was insufficient clamping area available to allow for high feeds or depths of cut. This led to both long machining times and degradation of the fixture. Far greater area was available if the putter was clamped perpendicular to the feed. The new design, shown in Figure 3, was produced by running the putter machining programs in such a way that a negative of most of the profile was created on one jaw. The opposite jaw was machined to meet the angle on the opposite side of the putter. Clamping was then great enough to allow for substantially more rapid machining, reducing the cutting time from 30 minutes to 10 minutes. The new fixture did not noticeably degrade in production.

The Monitoring Team collected data on the cutting forces. They were not able to establish the necessary parameters for tool monitoring. This was due primarily to unfamiliarity with the Montronix system and tool monitoring in general. There was simply not enough time available to master the operation of the system. Therefore, they concentrated on the final report.

Production began with 3 weeks remaining in the term. Students were scheduled during both day and evening hours to run the machines. A minimum of two students in the Advanced Machining Laboratory were required for safety reasons. Production of the actual putter heads was estimated to require about 80 hours, including both machining time and operations such as fixture changes, cleaning the machine, sand blasting, and incidental finishing operations. A major change was made mid-way through the production run. This was that sand blasting was performed prior to machining of the final four degree loft. This eliminated the need to mask the putting surface with tape. This saved probably 5 minutes per

putter.

A total of 70 putter heads were produced by the class. Shafts and grips were ordered per the design, however most were on backorder and only a limited number were available for assembly during the term. An assembly session was held during finals week and four students assembled all of the putters for which there were shafts and grips.

5. Lessons Learned

There are really two categories of lessons learned from this project. The first category is lessons for the faculty member. The second category is lessons for the students in manufacturing engineering.

Managing a project of this type requires considerable faculty effort. This begins with creating the teams. It is necessary to assess what each team member brings to the team. Once the teams are assembled, it is the professor's role to see that the teams operate smoothly. Even with the best selection algorithm there will be conflicts of personality or indecision on the part of each team. With a very limited amount of time to accomplish the project, the professor must at times step beyond the role of facilitator and information provider, and take on the role of "boss."

There were many evenings when, because of deeper knowledge of the equipment, I spent time either debugging code or implementing shortcuts in code that were not known by the students. The key in doing this was not to change the decisions made by the student teams, rather it was to more efficiently implement those decisions. It also provided a teaching tool after the alterations were made. In addition, it remains the professor's role to ensure that there is no damage to the equipment in the course of the project.

Probably one of the biggest concerns is not on the ability of the students to do the work, but their lack of knowledge on how to go about planning the work. Basic project management and scheduling needs to be a part of both the manufacturing engineering and mechanical engineering curricula. Unfortunately, other important technical coursework crowds out this important subject matter. The professor has to be prepared to handle almost all of the project management tasks in this project.

There were several important lessons for the students in the course. First and foremost this was a direct application of machining theory and practice. One of the aspects which most amazed the students was the propensity of 304 stainless to burr on a light cut. Light cuts were not the solution to surface finish problems, because they caused other problems, e.g., burring. Students saw the difference coolant can make in surface finish and tool life. Also, increasing the material removal rate can improve chipping as well as reduce machining time.

Students very quickly learned the problems associated with transitioning a product from a drawing to a machined part. Dimensioning of the drawings may be incomplete or inappropriate for machining operations. Features of the item may not be machinable with existing tooling or tooling which is easily or

cheaply obtained. Both of these situations require interaction and sometimes negotiation with the product's designers.

The holding fixtures were clearly as important as the cutting parameters. One near disaster came when early in the production cycle a tool broke. [I was at a machining conference at the time.] Rather than changing the tool, the students decided to drill all of the shaft holes. Unfortunately, they did not check to see that the fixture was fully seated and secure. All 70 pieces were incorrectly drilled, though not so badly that they could not be used. Fixtures capable of holding workpieces for higher material removal rates allowed the cutting time to be reduced. Also, though the preferred clamping may be in the feed direction, clamping perpendicular to the feed may actually work better in some instances.

6. The Future

There is certainly work left to do on the Kettering Putter. A viable tool monitoring regime has yet to be worked out for machining. Acoustic and vibration sensing have been added to the Haas Milling Machine. Also, there are still possible improvements in both time and tooling. Not all of the tooling recommendations were implemented, because of the time needed to get tooling. Therefore, the opportunity exists to examine how much the productivity can be improved through adoption of these suggestions.

Bibliography

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