AC 2011-2270: ACCLIMATING MECHANICAL DESIGNERS TO MANUFACTURING TOLERANCES IN THE FRESHMAN YEAR

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Acclimating Mechanical Designers to Manufacturing Tolerances in the Freshman Year

Abstract

It is often a challenge for beginning mechanical designers make judicious decisions on appropriate design tolerances. The Mechanical Engineering Technology Program at Kansas State University Salina applies a hands-on approach which acclimates students to tolerancing issues through a freshmen course sequence involving manufacturing processes, CNC, and mechanical detailing. Students learn to perform machining and forming processes to expected tolerance specifications—and to inspect their work. Toleranced part prints and inspection sheets reinforce expectations and provide examples of standard practice. Spring semester experiences in the CNC lab allow students to focus on sources of variation when operator error is negligible. The entire sequence culminates with design teams designing an assembly prototype which must be manufactured to their specifications by another team.

The early awareness and experiences encountered by these students during their freshmen year provide a foundation for future courses and design projects.

Some Approaches Recorded in the Literature

The literature in engineering technology education provides a rich tradition of integrated experiential approaches applying the design-to-manufacture process early in the curriculum. In the 1990's, integration of the design-to-manufacturing process was popular in both industry and education. Ferguson and Berry[1] integrated their manufacturing lab as a junior-level course in "Concurrent Engineering Design" (1996). Ray and Farris brought their 2000 adaptation of this to the freshman level, calling the course "Engineering Product Realization."[2]

Other examples provide approaches to familiarize students with tolerancing issues. Rainy and Hoadly[3] specifically discuss the need for mechanical engineering students to "meet prescribed dimensions and tolerances" in a freshman-level manufacturing processes course aimed at the design engineer.

The approach we discuss attempts to highlight and model standard design tolerancing, production, inspection, and related documentation practices within the freshman course sequence through specific instructional tools and outcomes requirements.

The Freshman Course Sequence

The freshman course sequence of the Mechanical Engineering Technology Program at Kansas State University Salina is designed to immerse beginning students in basic technical graphics, manufacturing processes, and design tools. The course sequence is outlined in Figure 1.

The First Semester

The first semester includes a fairly standard Technical Graphics course which utilizes 2-D sketching and CAD methods for development of part and assembly geometry and print documentation. However, it is the Manufacturing Methods class which gives students their first exposure to part print standards, as prints are used to communicate dimensional and surface tolerances for the parts students are to make in the lab. For example, Figure 2 is the print for the

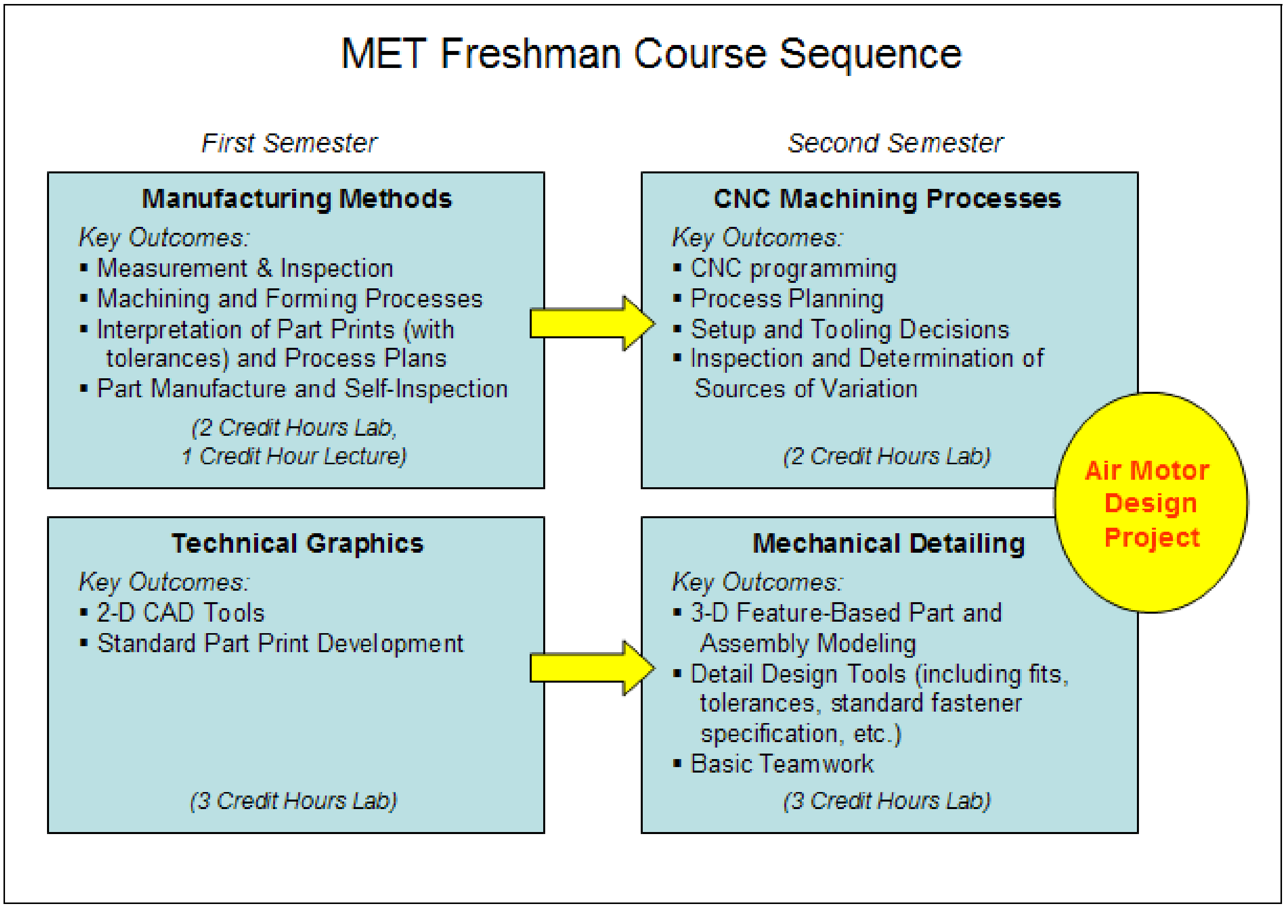


Figure 1. MET Freshman Course Sequence.

first part students' make on the manual engine lathes. Students are taught how to read the print, with particular attention to the specified tolerance ranges.

The prints for Manufacturing Methods lab assignments are accompanied by an inspection sheet, such as the one shown in Figure 3, which requires students to note the part specifications as well as their own success in meeting these. For dimensions which the student does not produce successfully within range, the student must document the cause (or probable cause) of the nonconformance.

The Manufacturing Methods lab also introduces students to process plans. Process plans are provided with some of the labs to communicate expected steps in the processing, as well as to begin to familiarize students with process plan documentation standards which they will be

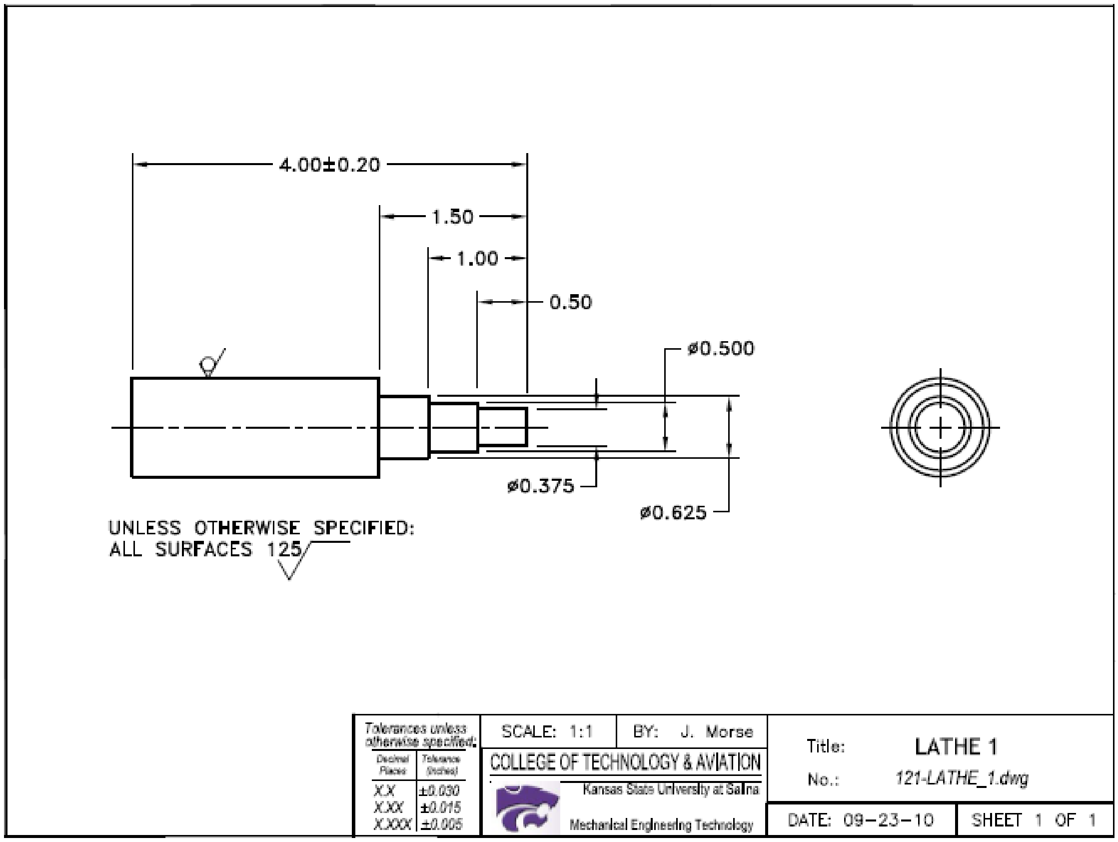


Figure 2. Part Print for Students' First Lathe Work in Manufacturing Methods Lab.

Lab Submission Sheet **MET 121 – Mfg. Methods**
Lathe 1 *J. Morse*

Student Name: ____________________________________

Lab Project Name: ***LATHE 1***

1. **Attach the *Process Plan*** with Speeds and Feeds filled in where appropriate.
2. List below the major specifications and the actual measured dimensions of your part:

Feature Name (e.g. length, height, OD, ID, etc.)	*Specifica-tion*	*Tolerance Range*	*Actual Measure*	*In Spec? (Y/N)*	*Measurement Instrument(s) Used*	*Notes on quality of part, process problems, etc.*
Example: O.D.	*∅0.800*	*± 0.005*	*∅0.804*	*Y*	*inch micrometer*	
Length	4.00					
O.D.	Ø.750					
O.D. Length	1.50					

Figure 3. Inspection Sheet (Partial View) for Student Lathe Work in Manufacturing Methods Lab.

expected to emulate in the following semester when designing their own processing sequences. The process plans are a critical tool in tolerance awareness, since they require students to document the processing steps they specify as appropriate to meet design specifications.

Part No.: *121-HEX_revC.dwg*	Page: 1 of 3	College of Technology & Aviation
Part Name: **HEX PART**	Date: 12/05/06	Kansas State University at Salina Mechanical Engineering Technology **Process Planning Form**
Machine(s): LATHE, DRILL PRESS, ETC.	Prepared By: J. MORSE	Mat'l: STAINLESS STEEL – 2" Hex Stock Specs: 2" Hex Sawn to ______

Process Illustration	Seq.	Operation & Description	Tool No	Tool Description	S(rpm)	F(ipr)	DOC
Process Notes: • Order of steps may be adjusted as expedient. • Deburr and break sharp corners whenever appropriate.							
	(1)	**Hole #1:** **Ø0.501/0.500 Drill and Ream**		Lathe:			
		(1a) Center Drill		Center Drill	____	*Manual*	- -
		(1b) Pilot Drill		Ø ______ Pilot Drill	____	*Manual*	- -
		(1c) Ø31/64 Drill		Ø31/64 Drill	____	*Manual*	- -
		(1d) Break hole edge		Counter Sink	____	*Manual*	- -
		(1e) Ø0.500 Ream		Ø0.500 Reamer	____	*Manual*	- -
	(2)	**Face Top Surface:** Face Top Surface (Lathe, cross feed from center hole toward operator)		Lathe: HSS - Right hand tool	____	____	____
	(3)	**Punch Hole Centers - Holes #2 - #7:** (3a) Layout locations (3b) Punch locations					

Figure 4. Process Plan Example (Excerpt) Provided with Student Lab Assignment.

Figure 4 provides an example of the process plan provided for a lab assignment that requires a variety of processing steps. Note that blanks are often left in the process plan for students to fill in appropriate selections of spindle speeds and other processing selection details.

With the required self-inspection of work, sources of variation due to difficulties with processing and geometric assumptions come to light. For example, a part requiring milling is to be made from aluminum angle stock which is first cut to length on the hydraulic shear. Limitations with the tooling at the shear make it difficult to hold the angle stock square while shearing, causing cut edges to be out-of-square. Measuring the length of the cut stock is then problematic, and students inevitably question, “Where do I measure along that angled edge? To the bottom? To the top? The length is different depending on where I measure.” This experience provides awareness of the imperfect nature of features which a part print might presume to be perfectly square or perpendicular--an excellent basis for the introduction of GD&T tolerancing the following semester in Mechanical Detailing.

The Second Semester (Preparation)

In the second semester, while students are busy learning 3-D CAD design tools in Mechanical Detailing, they are also continuing to practice machining techniques in a CNC

Dimension Check Sheet | **MET 125 – CNC Machine Processes**
Spring 2009, J. Morse

Student Name: ______________________________

Part Name: ______________________________

List below the specifications and the actual measured dimensions of your part:

Feature Name *(e.g. length, height, OD, ID, etc.)*	***Specifica-tion***	***Actual Measure***	***Deviation from Target***	***Measurement Instrument(s) Used***	***Likely causes of deviation from target****
Example: *O.D.*	*∅0.800*	*∅0.801*	*+ ∅0.001*	*inch micrometer*	*This small deviation is consistent over the turned length; likely due to measurement variation at PRZ diameter setup*

Figure 5. Inspection Sheet (Excerpt) Required for Student Lab Work in CNC Course.

environment. The CNC programs eliminate the easy excuse of "human error" which was prevalent when students were attempting to meet tolerances with manually controlled lathes, mills, and drill presses. Students are required to use their skills and judgment to determine whether unexpected deviation from the ideal is due to programming error, setup issues, or part or tooling deflection. Figure 5 provides an excerpt of the standard inspection form students must fill out when inspecting their own CNC work.

As students begin to work on assembly modeling in the Mechanical Detailing course, fits and their associated tolerances becomes part of the study. Ultimately, student teams apply these tools in the design of a functioning "air motor" assembly.

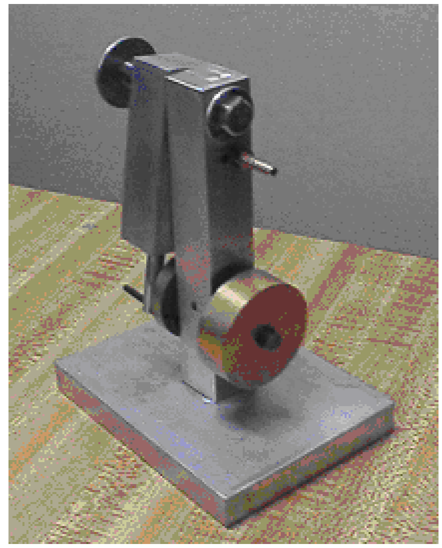
The Freshman Design Project

The Air Motor Project is a joint project between the Mechanical Detailing and CNC courses. In the Mechanical Detailing course, student teams design an air motor assembly (using previous designs as a starting point), as described in Figure 6. They develop an assembly model with motion animation and provide part and assembly prints to be given to a team in the CNC Machining Processes course for manufacture of a working prototype.

Teams in the CNC class are assigned such that no one is responsible for machining his or her own team's design. This measure forces the design team to make sure specifications are all appropriately communicated in the part and assembly prints, not added in as the prototype is being built. CNC students document their work by developing process plans that correspond to the parts they created. They also are responsible for commenting on manufacturing problems encountered and reporting on general design suggestions based on their manufacturing attempt.

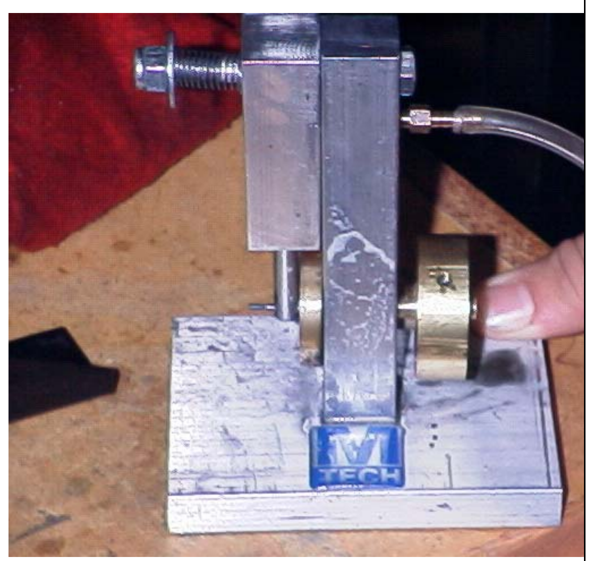
Air Motor Project

This project may involve measurements, review and changing of sizes, materials, and, decision making on process selection. The work also involves preparing detail drawings, assembly drawings, as well as graphing work - all to be done using computer techniques - and simulation using animation with CAD software to observe the proper functioning of the ports.



The following specifications must be kept in mind in the design and manufacturing of the AIR MOTOR:

- Envelope dimensions shall not exceed 3x4x5 in inches.
- Either horizontal or vertical piston movement.
- Single piston - no impeller - no rotary valves.
- Maximum air pressure allowed is 60 psi.
- Inlet port to be threaded to accept tubing compatible with available lab sizes.
- Single acting.
- Drive shaft to be supported by a bushing.
- Bushing must be capable of delivering oil to drive shaft.



Do reverse engineering of Air Motor.
Come up with your own and improved design.
Exchange your product drawings with another group (so the other group can manufacture the product).
Do literature search to identify patent information on air motors.

Figure 6. Air Motor Project Requirements Handout.

Observed Results

This design experience is the students' first for specifying reasonable tolerances. Understandably, they still express some uncertainty regarding the balance between the perfection they desire for the sake of their design and what is reasonably obtained by available manufacturing processes. Students are zealous to obtain the optimum quality possible for their assembly, and so it is still very common to see unreasonably tight tolerances. In the balance, however, the manufacturing teams, building someone else's design, are very quick to point out tight tolerances that seem unreasonable and unobtainable with the resources at hand. Motivated by real processing needs, the manufacturing teams provide a realistic and valuable peer-review. Because each student experiences this project from the viewpoint of the designer and then from the position of a manufacturer, students gain real experience and perspective that balances both sides of the tolerance tradeoff.

There are still some Air Motor teams which seem to recklessly apply a blanket tolerance to all dimensions, regardless of whether it is needed for part quality or whether the dimension is a non-critical, overall part dimension. This may be in part due to students in too big of a rush to attend to proper detail. The good news is that some teams are starting to recognize and specifically loosen up tolerances where there is no need for exacting precision.

On an anonymous survey made at the end of the 2010 spring CNC course, the class of nine students was asked to respond to their level of agreement of the following statements:

(1) The Air Motor Project increased my appreciation for part print specifications and tolerancing.

(2) The Air Motor Project helped me exercise and/or improve my process planning, setup, and/or machining experience.

Of the five students responding, four reported that they “strongly agreed” and the remaining respondent “agreed” to the statement that the project increased their appreciation for print specifications and tolerancing. To the second question on process planning and machining experience, only two of the five “strongly agreed” and the remaining three “agreed.” It seems that these students left the project more impressed by tolerancing issues than the issues involved in process planning. Given the amount of time and attention they had to devote to determining their own machining plans and setup, the higher affirmation on the tolerancing question seems significant.

The effectiveness of this freshman sequence is perhaps best seen and felt when the lessons learned are exercised in their future work. In previous years, sophomore project drawings largely ignored any need for tolerancing. Sophomore teams are now submitting drawings that apply attention to standard tolerancing.

Students are also applying process planning techniques in their sophomore and senior design projects. Design teams are overheard discussing options, when someone points out the associated manufacturing requirements: “Yes, but how are you going to build that?”

Local employers are returning positive feedback about the skills MET students are bringing after their freshman year. Students have a firm enough grasp of practical tolerancing to begin to apply these concepts to design and production judgments in their part-time jobs in local industry.

Conclusions

Overall, following the implementation of the freshman sequence emphasizing hands-on attention to tolerances and processing capabilities in both design and process documentation, a majority of students self-report an increased appreciation for specifications and toleraning. Design work later in their degree program shows more consistent thought put into tolerances and related process planning, design decisions, and documentation.

Bibliography

[1]Jeff Ray and John Farris, “First Year Engineering Product Realization,” 2000 ASEE Annual Conference.

[2]Gregory L. Ferguson and John T. Berry, “Teaching Manufacturing As Concurrent Engineering Design,” 1996 ASEE Annual Conference.

[3]Paul Rainey and Rod Hoadley, “A Manufacturing Processes Course for Mechanical Engineers,” 2007 ASEE Annual Conference.