



## A Hands-on Approach in Teaching Machine Design

### Dr. Luis E Monterrubio, Robert Morris University

Luis E. Monterrubio, Ph.D. Mechanical Engineering

Assistant Professor of Mechanical Engineering

Luis Monterrubio joined the Robert Morris University Engineering Department as an Assistant Professor in the Fall of 2013. He earned B.Eng from the Universidad Nacional Autónoma de México, a M.A.Sc. from the University of Victoria, Canada and his Ph.D. in from the University of Waikato, New Zealand. All degrees are in Mechanical Engineering and both M.A.Sc. and Ph.D. studies are related with vibrations. After his Ph.D. he worked at the University of California, San Diego as postdoctoral fellow in the area of bioacoustics.

He teaches dynamics, machine design, numerical methods and finite element method. His research interests are in vibration, numerical methods, finite element methods, continuum mechanics and acoustics.

He has work for the automotive industry in drafting, manufacturing, testing (internal combustion engines –power, torque and exhaust emissions, vibration fatigue, thermo-shock, tensile tests, etc.), simulations (finite element method) and as a project manager (planning and installation of new testing facilities).

### Dr. Arif Sirinterlikci, Robert Morris University

Arif Sirinterlikci is a University Professor of Industrial and Manufacturing Engineering and the Department Head of Engineering at Robert Morris University. He holds BS and MS degrees, both in Mechanical Engineering from Istanbul Technical University in Turkey and his Ph.D. is in Industrial and Systems Engineering from the Ohio State University. He has been actively involved in ASEE and SME organizations and conducted research in Rapid Prototyping and Reverse Engineering, Biomedical Device Design and Manufacturing, Automation and Robotics, and CAE in Manufacturing Processes fields.

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## Introduction

The purpose of this paper is to present a modified curriculum for a Machine Design course. The modified curriculum aims to provide students with hands-on experience in the development of new products following procedures used in the research and development departments in the industry. The hands-on laboratories included in the course Machine Design are carried out after an introduction to the design philosophy presented by Eggert<sup>1</sup> and most of the first two parts of the textbook by Budynas and Nisbett<sup>2</sup>. The design philosophy included in this course splits the design process in five phases<sup>1</sup> (formulation, concept design, configuration design, parametric design and detail design), whilst the first two parts of the textbook by Budynas and Nisbett<sup>2</sup> cover an introduction to mechanical engineering design and stress analysis including theories of failure and fatigue. Part three of the textbook by Budynas and Nisbett<sup>2</sup> covers the design of mechanical elements that will be given in lectures alternating with laboratories to design and test a plastic injection mold of a very simple part.

## 1. Content of the new Machine Design course

The itinerary of the sessions for the new curriculum for Machine Design is given below. Chapters referred to the book by Budynas and Nisbett<sup>2</sup> unless otherwise noted:

- 1 Syllabus, Design Philosophy<sup>1</sup>  
The design philosophy as defined by Eggert<sup>1</sup> is divided in five phases:
  - a) Formulation
  - b) Concept Design
  - c) Configuration Design
  - d) Parametric Design
  - e) Detail DesignKey Concepts:
  - a) Form is the solution to a design problem
  - b) Design is the set of decision making processes and activities to determine the form of an object, given the customer's desired function.
- 2 Chapter 1 Introduction to Mechanical Engineering Design
- 3 Chapter 2 Materials.
- 4 Chapter 3 Shear force diagram and bending moment diagram
- 5 Chapter 3 Shear force diagram and bending moment diagram
- 6 Chapter 3 Stress, strain, stress-strain diagram, stress-strain relationships
- 7 Chapter 3 stresses due to axial load, bending moment, shear force and torsion
- 8 Chapter 3 Example of combined stresses including the four loading cases above
- 9 Chapter 3 Mohr's circle, principal stresses, stresses in pressurized vessels, stress concentration factor, contact stresses
- 10 Chapter 5 Theories of failure. Rankine, Tresca and Von-Misses Models
- 11 Chapter 4 Deflection and slope of a beam using direct integration method

- 12 Chapter 4 Deflection and slope of a beam using direct integration method
- 13 Chapter 4 Strain energy. Deflection and slope of a beam using Castigliano's method
- 14 Chapter 4 Deflection and slope of a beam using Castigliano's method
- 15 Midterm
- 16 Midterm's solutions review, measurements of a simple plastic part
- 17 Drawing of a simple plastic part using SolidWorks. Students will be given a brief overview of SolidWorks and a tutorial to produce the drawing of a simple part during class. Instructions to finish the engineering drawing will also be given.
- 18 Design for manufacturing and design for assembly. See Chapter 7 of the book by Eggert<sup>1</sup>
- 19 Step by step instructions to produce a simulation of the filling of a simplified plastic injection mold using Moldflow
- 20 Chapter 6 Fatigue. The stress-life method
- 21 Chapter 6 Fatigue. The strain-life method
- 22 Generating a G code using Mastercam. Step by step instructions are given to generate the code of the mold of a simple plastic part created in SolidWorks. CNC machining of the mold will be scheduled at convenient times for the workshop and students.
- 23 Chapter 7 Shaft and shaft components
- 24 Special topic. Implementing a code in Matlab to solve for natural frequencies and critical loads of beams
- 25 Chapter 8 Non-permanent joints, Chapter 9 Permanent joints and Chapter 10 Mechanical springs
- 26 Chapter 11 and chapter 12 Bearings
- 27 Mold is tested with the production of a small batch of pieces using in the plastic injection machine (BOY 22 A) - shown in Figure 5.
- 28 Chapter 13 and chapter 14 Gears
- 29 Chapter 15 Gears and Failure Modes and Effect Analysis (FMEA) from the book by Eggert<sup>1</sup>
- 30 Measurements of plastic part and mold using a coordinate measurement machine

The objectives of the course are

- a) understand the basics of machine design, including the design process, engineering mechanics and materials, failure prevention and characteristics of the principal types of mechanical elements
- b) have experience developing the design of a machine
- c) have real world experience with many major machine design components and their respective engineering principles

The following ABET outcomes are applicable for this course according to the existing course description:

- a) an ability to apply knowledge of mathematics, science, and engineering
- c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- e) an ability to identify, formulate, and solve engineering problems

## 2. Hands-on project

The added hands-on project consists in basic laboratories to design and test an injection plastic mold. The activities will be carried out in groups of three students. Although there are several publications from previous ASEE Conferences related to capstone projects<sup>3</sup> and Machine Design courses<sup>4</sup>, this publication differs in that this work proposes a new curriculum that mixes the design philosophy by Eggert<sup>1</sup>, the typical theory covered by Budynas and Nisbitt<sup>2</sup> and a sequence of activities used in the industry to in new designs. The lectures of the course related with the activities used in the industry to develop new designs correspond to class sessions 17, 18, 19, 22, 27, 29, 30 plus an extra-session outside the schedule of the lectures to use a CNC machine to manufacture the mold. A brief description of the activities is given below:

a) Session 17. Drafting of a single plastic part using computer-aided design (CAD) software such as AutoCAD/Inventor, SolidWorks or CATIA: This part of the project also helps students to refresh their knowledge and skills in delivering an engineering drawing according to standards. Figure 1 presents a sample of the parts to be used for this project. Students are also given a brief overview on basic SolidWorks functionality, but can choose to use one of the packages listed above. Notice the simplicity of the part – it is easy to draw and it does not require a complicated mold.

b) Session 18. A class to introduce/refresh the concepts of design for assembly (DFA), design for manufacture (DFM) will be included at this point. This lecture is based on Chapter 7 of the book by Eggert<sup>1</sup>.

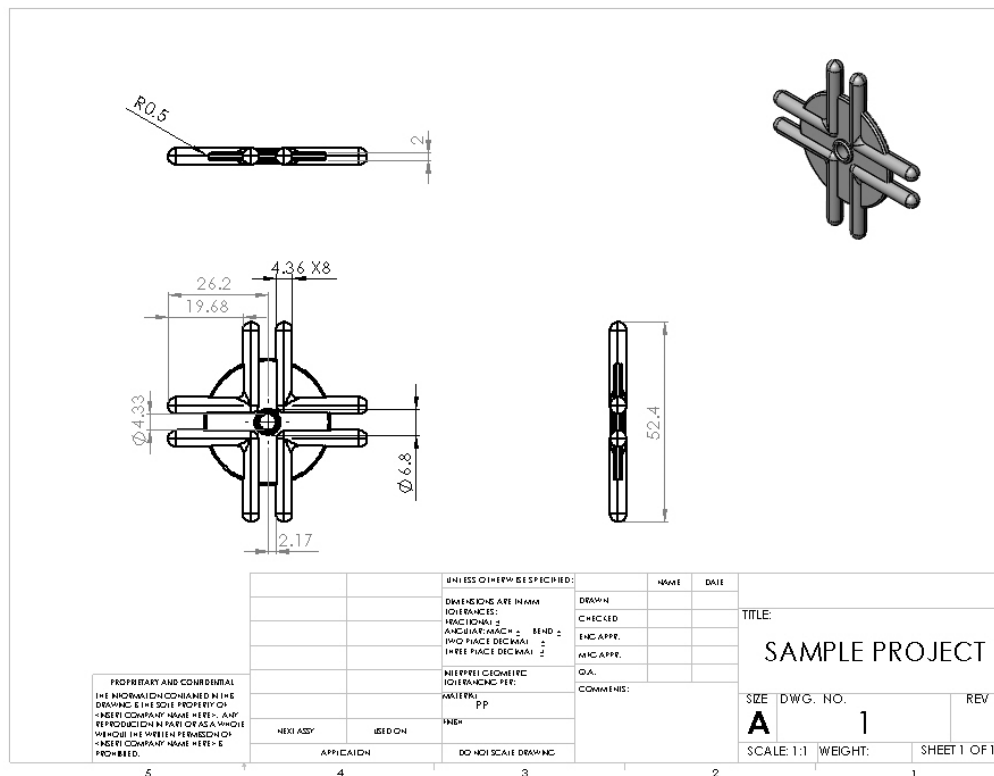


Figure 1. Sample of the plastic injection project

c) Session 19. Mold design through the use of a high-end plastic injection molding computer-aided engineering software. Analysis of the filling for a simplified model of the mold will be carried out to produce results for filling time (Figure 2), confidence of fill, quality prediction, injection pressure, pressure drop, temperature at flow front, average temperature at the end of the fill, time to reach ejection temperature, air traps, weld lines and grow form. Moldflow was used to create results shown in Figure 2.

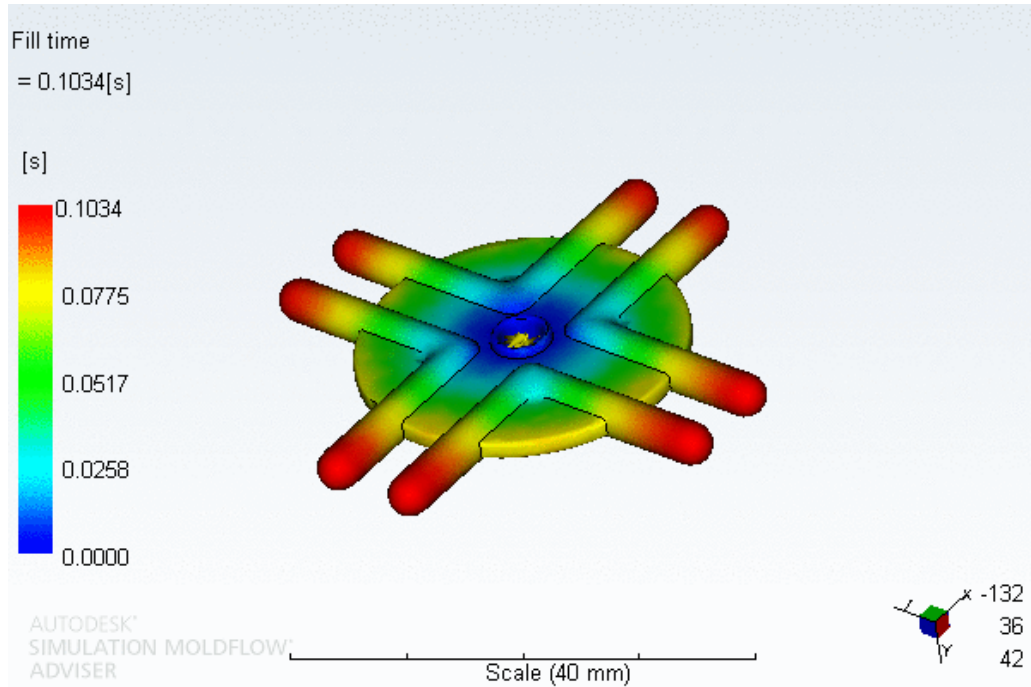


Figure 2. Plastic injection molding simulation using a computer-aided engineering software Moldflow. Results in this figure correspond to filling time in seconds

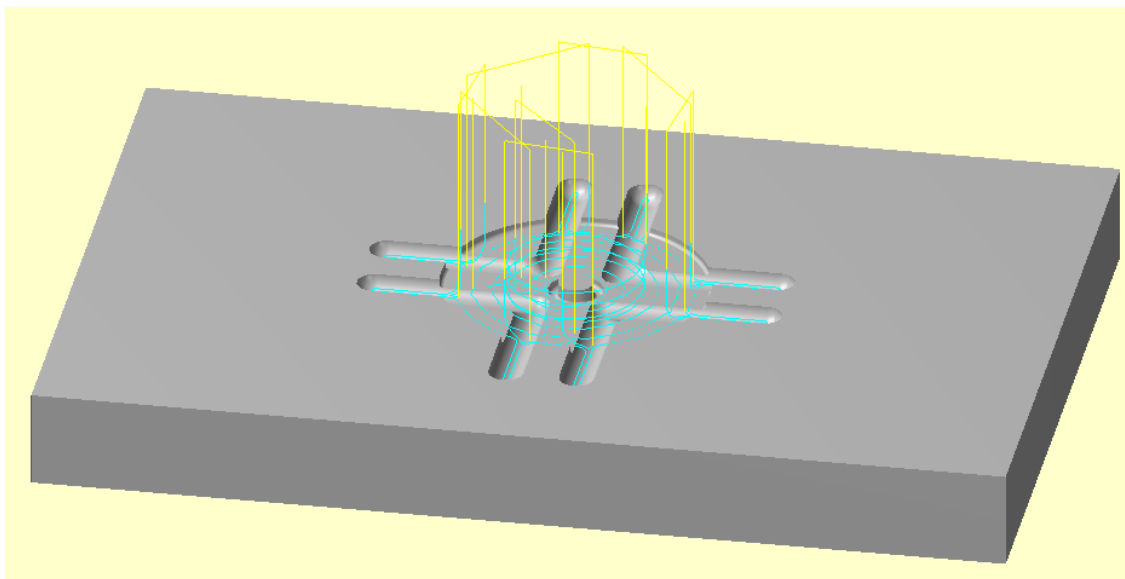


Figure 3. Path generated using MasterCam

d) Session 22. The next step in this project is to generate a G-code of the plastic mold for a computer numerical controlled (CNC) mill using computer-aided manufacturing (CAM) software. The commercial software MasterCam will be used to generate a G-code and to visualize the manufacturing of the mold from a raw aluminum block as shown in Figure 3.

e) Activity outside the lecture schedule. Manufacture of the mold with a CNC machine. There is only one CNC milling machine available in the machine shop of this shop, other than two smaller routers. Thus groups will have to show up at the workshop at different times. The CNC machine shown (HAAS VF1 Vertical Milling Machine) in Figure 4 will be used to manufacture the mold. Students will be given step by step instructions to save their G-codes in the Haas mill controller and manufacturing of their mold. If the students have taken Rapid Prototyping and Reverse Engineering course, they may already have competency in using this machine tool.



Figure 4. Milling CNC machine



Figure 5. Plastic injection machine

- f) Session 27. Plastic injection process: The mold will be used in a plastic injection machine (BOY 22 A) - shown in Figure 5 below to test the mold.
- g) Session 29. A class to introduce the Failure Modes and Effect Analysis (FMEA) will be given at this point.
- h) Session 30. Use of a coordinate measurement machine (Mitutoyo Bright Apex) shown in Figure 6 for quality assurance of both the mold as well as the plastic parts made in the mold will be the last step of the injection molding laboratory.

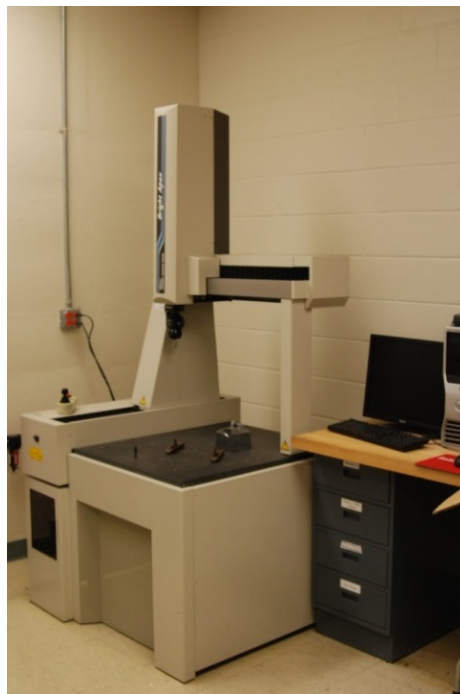


Figure 6. Coordinate measurement machine

### 3. Assessment of the laboratories

Written reports will be used to evaluate students, as well as the quality outcome of their practical work. One report is required for each laboratory of the project to pace the progress of students and help providing feedback to students more frequently. The content of each report is

- Cover Page 5%
- Introduction 15%
- Procedure 20%
- Results 30%
- Conclusions 30%

To ensure teaching success, it is important that students present their results in writing in an organized way together with comments and observations. Conclusions will also be used to analyze if students grasped the main concepts of the laboratories. In addition, project related questions will be included in the exams to gauge student learning.

The rubric used to assess the work of the students is given in Table 1.

Table 1. Rubric of the hands-on components of the course.

<b>Component</b>	<b>Sophisticated</b>	<b>Competent</b>	<b>Not yet Competent</b>
Drafting of single plastic part	Drawing is made according to standards	Drawing mainly follows standards, but misses dimensions, center lines or other information	Drawing has no order and it is clearly out of specification
Mold design through the use of a high-end plastic injection molding computer-aided engineering software.	Simulation of different gate locations of the mold and a decision matrix are presented in a clear way to select the best mold design alternative. Drawing is made according to standards and DFM/DFA	Drawing is made according to standards and DFM/DFA, but missing dimensions, center lines or other information	Drawing has no order and it is clearly out of specification
G-code of the plastic mold	A file in MasterCam that generates a G-code is produced. Standard tools are used in the G-code. Cutting speeds are defined	G-code is written by hand and/or special tools are required and/or Cutting speeds are not defined	G code was not written properly or finished.
Manufacture of the mold with a CNC machine	Mold was manufactured according to specifications	Mold was manufactured, but is out of specifications	Mold was not manufactured
Plastic Injection Lab	Mold produced parts without voids	Mold produced parts with voids	Mold does not work
Coordinate Measurement Machine Lab	A clear and complete data base with expected measurements and actual measurements are presented	A good data base with expected measurements and actual measurements are presented, but some information is missing or not well organized	No analysis of the results is presented

#### 4. Conclusions

With this project, the authors will focus on a rare approach to machine design by including design philosophy, theory of stress analysis and design of machine elements, as well as necessary industrial and manufacturing engineering tools (such as CAM, CAE, DFM, DFA and quality analysis) for improving machine design education. As quoted by Liu and Brown<sup>4</sup> “ABET is making increasing demands to integrate projects into engineering curriculum”. The authors believe that the initiative will also strengthen the impact on the following ABET student outcomes of the courses in focus<sup>5</sup>:



- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints - manufacturability
- (e) an ability to identify, formulate, and solve engineering problems
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Students received an average grade of 91.66% in the hands-on projects, while the average of the rest of the course was 78.12%. This data shows that students put more effort in the projects than in any other part of the course. In specific, some of the written reports about the filling of the mold were outstanding. Students showed results of molds with gates located at different places and evaluated the performance of the mold using Moldflow. The most impressive part of the reports was the way students explained and organized different types of results.

Future work will involve further detail design of the plastic injection molding as well as acquiring statistical and anecdotal qualitative data on student performance. Student feedback and observations of the activities will also be employed in continuous improvements of the efforts.

#### **References**

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