ME 397 – Precision Machine Design

Spring 2015

Lecture:
MW 2:00 pm – 3:30 pm, ETC 7.146

Instructor:
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By appointment

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Course Objectives:

Advanced course on modeling, design, integration and best practices for use of machine elements such as bearings, springs, gears, cams and mechanisms. Modeling and analysis of these elements is based upon extensive application of physics, mathematics and core mechanical engineering principles (solid mechanics, fluid mechanics, manufacturing, estimation, computer simulation, etc...). These principles are reinforced via (1) hands-on in-class experiences wherein students conduct experiments and disassemble machines and (2) a substantial design project wherein students model, design, fabricate and characterize a mechanical system that is relevant to a real world application. Students master the materials via problem sets/quizzes that are directly related to, and coordinated with, the deliverables of their project. Student assessment is based upon mastery of the course materials and the student's ability to synthesize, model and fabricate a mechanical device subject to engineering constraints (e.g. cost and time/schedule).

Grading Policy:

The course grade will be based on:

- In-class exercises and quizzes (50%)
- Project (50%)

Passing quizzes: Some quizzes will be take-home quizzes, some will be in-class quizzes on assigned reading, and some will be focused upon in-class exercises. 5 minute quizzes related to the reading assignment will generally be given at the beginning of class most days. Longer 20 minute quizzes will be given throughout the course of the semester on technical topics. You must understand what you are doing before you start to design/build/make parts, otherwise you are dangerous. ABSOLUTELY no student (or their group) will be given parts/resources to make a part unless they have passed the quizzes (grade > 80%) on technical topics that are related to the part. For example, you must demonstrate understanding of shear & moment diagrams before you

will be given the material to make your shaft. You must demonstrate you understand how to size/select bearings before your bearings are ordered. Make up quizzes may be given, but course schedules will not be changed.

Textbooks:

Required text: Precision Machine Design by Slocum

Useful texts: Mechanical Engineering Design (Shigley/Mischke)

Class Project:

This class will focus on (i) understanding the role of concepts, principles, design process, best practices, mathematics, physics and engineering modeling within mechanical design; and (ii) rigorous application of concepts, principles, design process, best practices, mathematics, physics and engineering modeling to realize a complex and high quality mechanical design. You will learn "by doing" and learn by gaining insight/perspective via interaction with the staff. This year in ME 397, teams of about 4-6 students will model, design, build and characterize the performance of a desktop lathe. Each team will design a 'group' lathe and must build at least one lathe. The construction of a device that meets functional requirements is a critical element of receiving a good grade in this class.

Documentation

Images and video

You must take pictures/video of parts, fabrication processes and experiments as you go. This includes pictures of every part you make, all sub-assemblies (e.g. spindle, carriage, etc…) and then the finished lathe. You must take:

- At least one 10ish second video per part wherein some critical fabrication step is being conducted (e.g. turning)
- At least one 30sih second video per sub-assembly describing how each was assembled, problems in assembly, etc…
- At least one 60ish second video per test describing how each test was conducted and showing a result (e.g. run-out)
- At least one 30ish second video showing both axes working as the lathe cuts aluminum

These images/videos will be due in soft copy on the day their corresponding hardware/results are due.

Design notebook

Each student must keep a design notebook. These must be dedicated notebook in which all of your ideas, calculations, and records are stored. It is expected that you will paste printouts of cad models and simulation results into your notebook. You must bring your notebooks to all class events. They will be collected at the end of the semester and graded, so please make sure they are legible and organized! Loose papers must be stapled or glued in; no loose papers will be included in the grading. We encourage you to paste in pictures of the parts when appropriate.

Final report

A final report of at most 6 pages (not including appendices) is required. The purpose of the report is for you to convince the staff that you learned and used the course material properly. The contents of the report are up to the group; however it would be reasonable to include descriptions of your group's activities, calculations, predictions, results, lessons learned and performance data – how did it do cutting an actual part? All reports are 12 point font, double-spaced and 1 inch margins.

List of parts to be provided and parts to be processed

	Our responsibility	Your responsibility
Spindle	• Housing blank • Shaft blank	• Finished Housing • End cap • Finished Shaft • Bearings • Preload mechanisms
Structure	• Headstock blank • Tail stock blank • Structure tube blank	• Rails • Finished tail stock • Finished tube • Finished head stock
Lead screw drive	• Bearings • Preload tube • Preload end cap • Lead screw bearing seat • Lead screw • Bearing preload nut • Preload washers	• Drive nut • Drive preload nut
Carriage	• Polymer bed blank • End skirt blanks	• Finished polymer bed • Drive flexure coupling • Bushings • Finished end skirts • Bushing flexure coupling • Dial
Cross feed	• Tool holder • Lead screw • Dial	• Rear flexure mount • Front flexure mount • Thrust bearing • Proper dial mount surfaces/flats on screw

Miscellaneous	• Chuck
	• HSS cutting tool
	• Fasteners
	  ○ ¼ - 20 bolts – 0.50 inch long
	  ○ ¼ - 20 bolts – 0.75 inch long
	  ○ ¼ - 20 bolts – 1.00 inch long
		• Motor
		• Belts
		• Pulleys

Design presentation schedules

We will have 10 minute presentations followed by a 10 minute discussion/design review during every meeting. These meeting will occur in the normal class room during class time. A projector will be available. Everyone must present their part of the project (even if there is no progress) and everyone must participate in the questions/discussion. Participation factors into the group

grade that you will receive at the end of the term. Your team should (a) first tell us the purpose of the meeting, (b) then immediately show your Gantt chart and tell us if you are on/behind schedule, followed by other items as you feel appropriate such as (c) details of the work to date, (d) calculations, (e) risks, questions or items for discussion, (f) etc… Remember to have back up slides in the event that the questions/discussions delve deeper into the details. The deliverables listed in conjunction with each design review are due as part of the presentation. Late deliverables will lose 10% per day until they are turned in.

Class Schedule

Date	Week	Topic	Reading
1/21	1	**Introduction:** Overview, assessment, review	
1/26	2	**Fundamentals Review:** • Mechanics • Dynamics • Heat Transfer • Matrices • Errors	Review Shigley: Chapters 2-5
1/28	2	**Fundamentals Review Continued:** • Mechanics • Dynamics • Heat Transfer • Matrices • Errors	Review Shigley: Chapters 2-5
2/2	3	**Fatigue** • Fundamentals • Modeling Methods	Shigley: Chapter 6
2/4	3	**Shafts and Ways** • Deformation • Stresses • Integration	Shigley: Chapter 7
2/9	4	**Structures** • Architectures • HTMs • System Models • Shear and Moment Diagram Quiz	Slocum: Chapter 2 and Chapter 6
2/11	4	**Structures Continued** • Architectures • HTMs • System Models • In Class Exercise	Slocum: Chapter 2 and Chapter 6
2/16	5	**Forces in Machining** • Cutting Equations **Constraints** • Rolling and Sliding Element Bearings	Slocum: Chapter 8 Optional Shigley: Chapter 11

2/18	5	**Constraints** • Hydrostatic/Aerostatic/Magnetic Bearings • Flexure Bearings Elastomechanics and Dynamics • Technical Quiz: HTM	Slocum: Chapter 9
2/23	6	***Design Presentation: Shaft*** • **Deliverable: Finished shaft exercise (Machining Guru Presents)**	
2/25	6	**Constraints** • Constraint, Alignment and Fixturing of Elements/Systems	Handout
3/2	7	**Connections** • Bolted Joints • Technical Quiz: Bearings	Slocum: Chapter 7.1-7.7
3/4	7	**Connections** • Alignment Interfaces • Kinematic Coupling Exercise	Slocum: Chapter 7.7-7.8
3/9	8	***Design Presentation: Error Model*** • **Deliverable: HTM model of lathe (Modeling Guru Presents)** • **Deliverable: FEA Model of structural/thermal modeling (FEA Guru Presents)**	
3/11	8	**Drives** • Screw Drives • Belts and Friction Drives • Technical Quiz: Bolted Joints	Shigley: 8.1-8.2 Shigley: Chapter 17
3/16, 3/18	9	Spring Break	
3/23	10	**Drives** • Gear kinematics, Mechanics and Selection	Shigley: Chapter 13
3/25	10	**Drives** • Gear Exercise	None
3/30	11	***Design Presentation: Spindle*** • **Deliverable: Completed Spindle Assembly (Project Leader Presents)**	
4/1	11	**Instrumentation** • Force and Displacement Sensor Systems • Discussion of Sensors Available for Projects • Sensor Mounting and Calibration • Noise Sources in Sensors	Slocum: Chapters 3, 4, 5 Hale Thesis: Pages 48-59
4/6	12	***Design Presentation: Metrology Plan*** • Informal discussion of groups metrology plans	
4/8	12	**Actuators** • DC Motors • Piezoelectric Actuators • Magnet-coil • Hydraulics	Slocum Chapter 10
4/13	13	**Vibrations** • Machine Dynamics	

		• Damping Techniques	
4/15	13	***Design Presentation: Cross Slide*** • **Deliverable: Completed Cross Slide Assembly (Machining Guru Presents)** • **Deliverable: FEA Simulations of Cross Slide Dynamics (FEA Guru Presents)**	
4/20	14	**Project Work**	
4/22	14	**Project Work**	
4/27	15	**Project Work**	
4/29	15	***Design Presentation: Metrology Results Presentation*** • **Deliverable: Runout/Vibration Measurements Presented to Class (Metrology Guru Presents)**	
5/4	16	**Project work** • Last chance finish any last minute details	
5/6	16	**Assessment** • **Deliverable: Project Presentation (Group Leader Presents and demonstrates Lathe)** • **Deliverable: Project reports** • **Deliverable: Lathe demonstrations**	

Lathe project deliverable schedule

All parts, models, measurements, document drafts/components and presentation drafts/components must be started/finished no later than the following respective dates. You are responsible for (a) arranging all required meetings, (b) scheduling required resources, (c) placing timely orders for parts/ materials, and (d) fabricating/calibrating the experimental setup. DON'T GET FRUSTRATED IF YOU GET STUCK. ASK FOR HELP SO WE CAN KEEP YOU MOVING. We reserve the right to (and we will!) ask you for proof of start/finishing at random intervals. If you are not on schedule, this will be reflected in your grade, no exceptions.

Fabrication task dates

Item	Start	Finish
Spindle shaft	02/03	02/23
Housing	02/24	03/12
Housing end caps	02/24	03/12
Cross-feed flexure	03/03	04/15
Lead screw flexure	03/03	04/22

Error model task dates

Item	Start	Finish
List of spindle error sources	02/08	02/26
Model individual spindle errors	02/08	02/26
Finish full spindle error model	02/08	03/04

Structural thermal model	02/17	03/04
Structural compliance model (v1)	02/17	03/04
- Without connection contributions		
Structural compliance model (v2)	03/17	03/31
- With spindle & bolted joint contributions		
Full structural model	03/31	04/29
- Full error model		
List of flexure error sources	03/03	03/19
Model individual flexure errors	03/03	03/19
Finish full flexure error model	03/03	04/15
List of drive error sources	03/15	04/15
Model individual drive error	03/15	04/29
Finish full drive error model	03/15	04/29
Lathe error model (in report)	02/17	05/06

Measurement task dates

Item	Start	Finish
Group 1: Vibration Measurements	04/01	04/29
Group 2: Spindle error motions	04/01	04/29
Group 3: Cross slide error motions	04/01	04/29
Group 4: Carriage error motions	04/01	04/29

Report results and conclusions

Item	Start	Finish
Outline (text, table & figures)	03/29	04/14
Images	02/08	04/28
Tables	02/08	04/28
1st draft in separate modules	04/05	04/28
Integrated, final draft	04/28	05/06
Design notebooks	02/03	05/06

You need to move fast!!!! If your group does not make these dates/deadlines, this will be reflected in your grades.

Rules & logistics for using the ME manufacturing shop

Shop hours

The shop is open Monday through Friday from 8:00 am to 4:45pm and is closed for lunch from 11:45am-1pm. All machining stops at 4:30pm, and cleanup commences.

Process plans for parts that you will make

Before you fabricate a part, you must first meet with the Shop Assistant to discuss how to make the part. You must schedule a meeting with him to obtain approval. Remember, he is busy with many classes so contact him early. Everyone who will work on the part must attend the meeting.

You must then generate a process plan (See Appendix A) and keep this plan in your design notebook. When you go to fabricate the part, you must give the process plan to the Shop Assistant for final review.

At a minimum, your group must bring the following to this meeting:

a. 2D printed, CAD drawing with dimensions and tolerances (hand sketches are not allowed)

b. 3D printed rendering of the part (e.g. screen capture from CAD)

c. Properly scaled DXF (see DXF handout) on disc or e-mailed to the Shop Manager if your part is to be waterjet

d. Completed process plan table (see Appendix A) wherein the following are laid out in bullet point form

- Major steps that you will take to make the part, including fixturing and alignment steps
- Tooling that you will need for every step
- Measurement tools that you will need for every step
- Questions/uncertainties

Design verification tests/Metrology experiments

What you must measure as part of your tests and experiments

Each group will be responsible for measuring a different error motion in their lathe. Each group will be responsible for generating the design of their experiment, modeling, understanding, estimating the errors in your experiment, and creating the hardware that is required for you make the measurements. The responsibilities are as follows:

Group 1: Measure vibration of tool holder when motor is running

Group 2: Measure spindle error motions (dx, dy, εx, εy, as a function of θz) on the shaft and on a part in the chuck

Group 3: Measure cross slide error motions (dy, dz, εx, εy, εz as a function of x) as it moves long the x axis

Group 4: Measure carriage error motions (dx, dy, εx, εy, εz as a function of z) as it travels along the z axis

These measurements may be done using any of the available tools in the lab (capacitance probes, interferometry probes) or in the machine shop. You will be responsible for fabricating all of the metrology frames and writing any necessary LabVIEW or matlab code to collect the measurements or analyze the data. You must include a video of the measurement procedure in the presentation you give to the class at the end of April.

Group budgets for experimental setup

Each group will be allowed to spend up to $250 to purchase:

Bearings, Preload washers, Rails, Bushings, Epoxy, Motor, Gears, Belts, Pulleys, Ect….

Let me know what you want to order and I will order them for you. You must provide the (i) part number, (ii) name/description, (iii) quantity, (iv) cost, (v) vendor name and (vi) vendor address/phone. By default, materials will be shipped to me via 3 day ground and you will be notified by email upon receipt. Shipping costs for express shipping come out of your budget. You may then pick them up from my office.

The use of measurement tools in laboratory

You may need to use capacitance probes/interferometry probes and a data acquisition system to measure your error motions. Given the delicate nature of the probes, you must set up a meeting with the Dr. Cullinan in order to run this experiment. You may arrange up to 2 hours per meeting per group. The Dr. Cullinan will help you set up the probes and the data acquisition system.

Gantt Chart
Your group must have a Gantt chart that includes all milestones, assignments, team, and design lab meetings.

Group Gurus
Your group must assign people to be RESPONSIBLE for the administration and conduct of specific tasks. Groups must make tentative assignments the 1st week, and will be allowed to make changes once more, no later than March 1st.

Machining Guru
CAD/FEA Guru (To be trained in structural, thermal and vibration in Solidworks)
Project Leader/Financial/Documentation Guru (Budget/ordering + Pictures, video, etc…)
Metrology Guru (Metrology plan and various measurements)
Modeling Guru (Parametric modeling for error budgets/HTMs)

Appendix A: Process plan chart template

Process plan	Group No.:	Part name:
Date approved:	Group members in attendance:	Date accepted by Cullinan:

Step	Task & questions	Machine	Tooling	Measurement
00				
01				
02				
03				
04				
05				
06				
07				
08				
09				
10				
11				