2023.08.29

2.70 (UG)/2.77 (G) 2023 FUNdaMENTALS of Precision Product Design

https://web.mit.edu/2.70 (in process of updating with course materials)

Videos of FUNdaMENTALS lectures: https://www.youtube.com/@FUNdaMENTALs42

Lecture: *TR3.30-5* (3-442) **Lab:** *T12.30-3.30* (3-442)

Overview

Students learn deterministic design, selection, and assembly of machine elements to create and manufacture robust precision machines, instruments, and systems. The overall approach is to apply the design principles of Functional Requirements, Ergonomics & Environment, Design Parameters, Analysis, References, Ricks, Countermeasures (FRDEEPARRC pronounced "fred park") catalyzed with a Peer Review Evaluation Process (PREP) to create robust mechanical devices. Topics include FUNdaMENTAL precision machine design principles, error apportionment & error budgeting, machine elements, mechanical connections & interfaces, power transmission, structures, selection of manufacturing methods and materials, and metrology. Each topic is covered with respect to its principles of operation, mechanics and performance, with real-world examples. Graduate students learn to develop and present a research proposal according to the scientific method.

Brief Summary:

2.70/2.77 teaches mechanical design from systems to fine detail in accordance with what will be expected from an MIT Mechanical Engineering graduate. For the term project, students will develop a "precision product development proposal" guided by the scientific method (identify problem/opportunity, background, hypothesis including first order analysis, experiment/theory development plan, expected contributions). This is equivalent to a research proposal students typically create as part of their thesis research. Similarly, in industry a "big idea" rarely succeeds unless a development plan is created and executed with careful attention to fine detail. Lectures will support creation of the plan and labs enable students to design and test critical proof of concept elements of the proposal. In addition, pertaining to lecture topics, weekly practice problems are based on past qualifying exams that relate to machine design and product development. Students in small teams assess their answers and solutions are discussed in lab the following week. 2.70/2.77 is thus a very good course for preparing for a great job in the real world of engineering, as well as helping graduate students with developing their thesis proposals and preparing for the doctoral exams in product and machine design.

Grading

Each person in this class is a customer of products, and as a future professional leading who may be leading product development, will need to be able to assess product ideas and people who develop them. Accordingly, the first day in Lab, students will use the FREDPARRC and peer review design process taught in lecture 1 to develop the best way to do peer-review based deterministic grading of problems and projects. The functional requirements include how to give and take feedback objectively, which is an ever more important in today's polarized world.

By week 3, students present a "precision product development proposal" and then based on feedback and refinement over the course of the semester, students will be expected to present a revised version at the end of the semester that has been informed by design/build/test appropriate experiments. This can also help the student in their research and job interviews.

There are no specific funds to support such experiments, hence the focus on product development linked to students' research or work in other areas such as their UROP.

Pre-requisites:

A passion for & demonstrated ability to design & build mechanical systems.

1. Undergraduate (2.70) and graduate (2.77) students are expected to have a strong background in mechanical design (e.g., 2.007) and manufacturing (e.g., 2.008). Practical work experience is a plus.
2. Solid modeling software skills (e.g. SolidWorks) (know how to create dimensioned drawing and a bill of materials, as well as use equation and part configurations).
3. Software-based analysis (e.g., spreadsheets, MATLAB, FEA)

Schedule:

Lecture: Tuesday & Thursday 3:30-5 in room 3-442.

Lab: Tuesday 12:30-3:30 in room 3-442. Some labs will be held in the Hobby Shop (street level NE-41).

Course Communications:

A dropbox link will be created for students to deposit their precision product development proposals. No other materials need be turned in. All communications will be done with email based on the course class list from the registrar unless students provide a different email. Email provides a "permanent" easy to access time stamped record of communication. Professionally, email is recognized by courts and is often vital to resolve disputes.

The class website will be used to post reading materials for students to download and enjoy ☺!

Lab time and Term Projects

1. The "term project" is students develop a "precision product development proposal" that includes design, build, and test an appropriate most critical module to verify potential. Learning in context is the best way to learn, and so students are encouraged to come to lab ask Prof. Slocum questions about course material in the context of their research or whatever project they are working on for fun. As stated above, graduate students are expected to present a thesis research proposal during lab time.
2. Lab time is intended for:
    a. At the beginning and end of the semester, students present a precision product development proposal and all students are expected to provide feedback.

b. Hands-on demos including experiment with the basic kit of elements that will be provided to help students understand the concepts of preload and deterministic design (kinematic and elastic averaging)
c. Some labs will be held in the MIT Hobby Shop (N51 265 Mass. Ave.)
d. Application of course materials to address students' questions regarding their own personal projects.
e. Work on previous week's assigned doctoral qualifying design exam (product design and machine design focus). Design qualifying exams are often based on real world experiences, and practice solving and presenting solutions is a great way to learn details needed for success taking the qualifying exams and/or in real life engineering expected of MIT graduates.

Learning Objectives

In view of the above, students completing 2.70/2.77 should be able to achieve these Precision Learning Objectives:

1. The basic material is the same for undergraduate and graduate students, with graduate students expected to be able to solve more advanced problems.
2. Develop design learning discipline: to read and review materials before coming to class, lab, or design meeting.
3. Develop and demonstrate a deep understanding of deterministic design and the impact of your decisions on machines and on people's lives: Can your design actions help create a more Inclusive, Diverse, Equitable, Awesome, Livable (IDEAL) society for all?
    a. Everything happens for a reason, start with first principles and figure it out…
        i. Prayer may be good in one's personal life, but not for precision product design.
    b. More than just designing products, how does the product fit into/help the ecosystem of people who will buy and use the product.
        i. As part of "risk assessment", consider the impact of the design on the environment and society.
    c. Apply the principle of OOSEH (one over sadness equals happiness: 1/☹ = ☺) so instead of "take from the rich to give to the poor", use design as a means to encourage the rich to invest in opportunities for the poor to live a better life.
4. Understand the functional operation and governing physical laws of machine elements:
    a. Understand common mechanisms and machines and be able to explain why they work. i.e. Linkages, Bearings, Flexures, Couplings, Gears, Rails etc.
    b. Learn what exists, how it works, why it works, how to properly use it, to enable a designer to select/buy if possible so you do not reinvent the wheel.
        i. Do not be afraid of inventing new wheels if needed!
    c. Understand underlying physics of how machines work. i.e.
        i. Stress + strain, parasitic forces, beam bending, proper kinematic constraint, kinematics and homogeneous transformation matrices, error budgeting, effective use of free body diagrams, hydrostatics etc.

5. Learn to apply and use deterministic design to create machine modules and *close the design loop* by comparing with analytical models to deterministically guide the design to meet functional requirements:
    a. Learn to use FRDPARRC and PREP design principles.
    b. Do so in the context of whatever projects on which you are working as you take the class.

Textbook and Readings

1. Prof. Slocum wrote the book *FUNdaMENTALS of Design* and it can be freely downloaded from http://web.mit.edu/2.75/fundamentals/FUNdaMENTALS.html
2. PMD: Precision Machine Design written by Prof. Slocum, available from course admin guru person for $75. Graduate students in particular are advised to obtain a copy as there are suggested reading topics for them in 2.77.
3. Various additional readings from papers (required for graduate students) that will be provided on the class website, including:

Index of /2.70/Reading Materia

Name	Last modified	Size
Parent Directory	08-Sep-2022 11:51	-
2.75 spline paper el..>	14-Jun-2004 10:00	707k
Bolted joint pitch s..>	01-Nov-2022 06:12	1.6M
Design_of_Three-groo..>	07-Feb-2013 21:18	1.5M
Elastic averaging pa..>	21-Jul-2022 08:26	2.9M
Electrify Book compr..>	27-Nov-2022 07:46	27.3M
Electrify Book.pdf	03-Aug-2022 09:16	29.4M
FACT flexure design ..>	18-Oct-2018 12:49	2.4M
Fiskers Shears Exerc..>	19-Jul-2013 08:19	7.4M
Fiskers Shears paten..>	08-May-2013 21:35	212k
Hose coupler deepwat..>	14-Feb-2018 09:55	2.3M
JMDEDB PREP.pdf	08-Aug-2007 17:01	599k
Kinematic coupling r..>	24-May-2021 06:36	2.3M
Kinematic mouse head..>	21-Jul-2022 08:33	4.2M
Nasa rolling bearing..>	22-Apr-2022 15:15	2.2M
OMAX US5472367.pdf	24-Mar-2013 12:12	375k
PMD Ten Step Precisi..>	20-Jan-2016 18:05	53k
Porous air bearing t..>	21-Jul-2022 08:26	1.2M
SKF-bearing-maintena..>	28-Jun-2022 20:07	13.3M
SpaceX Starship_use..>	21-Jul-2022 09:38	2.0M
SpaceX Dragon capsul..>	21-Jul-2022 09:37	989k
SpaceX Falcon-users-..>	21-Jul-2022 09:38	5.4M
Steel Wool Spring ar..>	21-Jul-2022 08:27	1.3M
Transmission_ratio_b..>	25-Oct-2022 06:06	406k
Weibull handbook Ch..>	26-Nov-2006 17:30	551k
Wind Energy - 2011 -..>	06-Jul-2022 05:57	708k
pnas.1810141115.pdf	03-Aug-2022 20:34	841k
solar irradiance for..>	09-Jul-2022 07:29	41.4M

2023 Teaching Staff

Instructor: Prof. Alexander Slocum, Room: 3-445, slocum@mit.edu
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Schedule (see next page)

Week	Date	Theme	Text (All: FNdMNTLS, G's: PMD)	Supplemental readings	Examples	Problem set to do for next week	Lab & review past design PhD exams
1	7-Sep	Overall assessment of challenge	What you have learned in the past		Energy to go up a hill, heat pumps		none
2	12-Sep	FREDPARRC and PREP	FNdMNTLS: topics 1, 2. PMD Chp. 1	KC design, elastic avg, steel wool article	Kinematic Couplings, Well casings	Kinematic Coupling (KC) gift	Kits out & explore, PREP KC design
	14-Sep	Apportionment			Waterjet Machining Center (WMC)		
3	19-Sep	FUNdaMENTALs	FNdMNTLS: topics 3, 4. PMD Chp. 2, 6	OMAX WMC patent US5472367	WMC, topology	3 axis machine design (TAMD)	PREP TAMD, students present initial product proposals
	21-Sep	FUNdaMENTALs (cont'd)		2.75 spline paper elastic average teeth	Wind turbines		
4	26-Sep	Bearings (sliding, rolling)	FNdMNTLS: topic 10. PMD Chp. 8, 9	SKF handbook, FACT	WMC, rolling element, fluid bearings	TAMD bearings	PREP TAMD, students present initial product proposals
	28-Sep	Bearings (air, fluid, flexures)			Hay bailer		
5	3-Oct	Structures	FNdMNTLS: topic 8, 9. PMD Chp. 5, 7	Stander wind turbine review	WMC, structure	TAMD structure	PREP TAMD structure
	5-Oct	Interfaces		Deepwater Horizon: Hose Coupler	Deepwater Horizon: Hose Coupler		
6	10-Oct	No Class		Axtrusion articles		TAMD actuators	No Lab this week
	12-Oct	Actuators (mechanical)	FNdMNTLS: topic 6, 7 PMD Chp. 5, 10		WMC, screws		
7	17-Oct	Actuators (electromagnetic)			traction drive	TAMD total system	PREP TAMD actuators
	19-Oct	Review of materials to date					
8	24-Oct	Students present refined product proposals				None	Students present refined product proposals
	26-Oct	Students present refined product proposals					
9	31-Oct	Dynamics	FNdMNTLS: topics 5, 7. PMD Chp. 3, 4		WMC, screws, traction drive	TAMD dynamics	ASPE conference design challenege
	2-Nov	Sensors, mounting					
10	7-Nov	Tribology, robustness	FNdMNTLS: topic 9. PMD Chp. 5, 8	Huntington Beach Pipeline Failure	Hay baler. ORBIT drive	TAMD life	ASPE conference design challenege
	9-Nov	Fatigure, fracture			Pipelne fracture, wind turbine bearings		
11	14-Nov	Review & answer tech ? on projects				none	Review & answer tech ? on projects
	16-Nov	No Lecture, ASPE Conferencne					
12	21-Nov	Review ASPE conference				none	Design case studies
	23-Nov	No class, Thanksgiving					
13	28-Nov	Tolerances, Error budgets	FNdMNTLS: topics 3, 11. PMD Chp. 2, 6	US5472367	Couplings, WMC	TAMD error budget	Grad students present revised thesis proposals
	30-Nov	Robust Design: Weibull	Dan Frey lectures				
14	5-Dec	Robust Design: Weibull	Dan Frey lectures				Students present final revised thesis proposals
	7-Dec	Robust Design: Weibull	Dan Frey lectures				
15	12-Dec	Robust Design: Weibull	Dan Frey lectures				Students present final revised thesis proposals