Lecture 1

Introduction to Precision Engineering

What is Precision Engineering?

• Precision Engineering is defined as painstaking attention to detail and requires knowledge of a wide variety of measurement, fabrication, and control issues.

• Increasing the precision—the accuracy and repeatability—of a mechanism or process is critical to our country's competitive position in the world of high technology.
What is Precision Engineering?

• The Precision Engineering focuses on many areas
  ➢ research,
  ➢ design,
  ➢ development,
  ➢ manufacture and measurement of high accuracy components and systems.
  ➢ precision controls, metrology, interferometry, materials, materials processing, nanotechnology, optical fabrication, precision optics, precision replication, scanning microscopes, semiconductor processing, standards and ultra-precision machining.

What is Precision Engineering?

• The precision engineering toolbox includes
  ➢ design methodology,
  ➢ error budgeting,
  ➢ uncertainty analysis,
  ➢ metrology,
  ➢ calibration/error compensation,
  ➢ precision controls and actuators and sensors.
Why Precision Engineering?

• Improve Product Performance
  ➢ Accuracy
  ➢ Reliability
  ➢ Improved Life
  ➢ Safety

• Increase Manufacturability
  ➢ Automatic Assembly

• Lower Costs
  ➢ Circuit Integration

• Advance Science And Technology

Precision Engineering

• Design and Production Systems
  ➢ Lifecycle engineering, Product & process modeling, Design theory, CAD/CAM/CAE, Rapid prototyping, Automated & intelligent systems, Production management, MES, CIM, etc.

• Precision Machining
  ➢ Cutting, Abrasive machining, Planarization (CMP etc), Micromachining, EDM, Energy beam machining, Injection molding, Deposition (PVD, CVD), Nanomachining, etc.

• Mechatronics
  ➢ Micromachines, Intelligent robots, Information instruments, Precision positioning, Machine tool & tooling, Intelligent control, Mechanism & mechanical elements, etc.
Precision Engineering

- Metrology
  - Image processing, Optronics, 3D shape measurement, Surface & roughness measurement, Intelligent data analysis, SPM, In-process measurement, Surface and Microform Metrology, Nanoscale Metrology, etc.

- Humans and Environment
  - Human engineering, Welfare engineering, Biomedical precision engineering, Biomedical measurement, Environmental machine & eco-machining, Amusement machine, Techno-history, Human skill, etc.

Precision Engineering - Journal of the International Societies for Precision Engineering and Nanotechnology

- Study and practice of high accuracy engineering, metrology, and manufacturing.
- The journal takes an integrated approach to all subjects related to research, design, manufacture, performance validation, and application of high precision machines, instruments, and components, including fundamental and applied research and development in manufacturing processes, fabrication technology, and advanced measurement science.
- The scope includes precision-engineered systems and supporting metrology over the full range of length scales, from atom-based nanotechnology and advanced lithographic technology to large-scale systems, including optical and radio telescopes and macrometrology.
Precision Engineering

- It includes the analysis and design of components as well as machines and instruments.
- The analysis of components includes modeling, simulation, and prototype behavior. Elements of research are:
  - structural loop components
  - bearing behavior
  - driving system
  - guiding elements
  - probing systems

Precision Engineering

- Important research activities are:
  - structural loop design including materials
  - thermal loop design
  - static behavior analysis (FEM)
  - dynamic analysis and simulation of machine-elements and electro-mechanical servosystems
  - design and validation of precision machinery prototypes:
    - single point diamond turning machines
    - high precision measuring machines
    - high precision probing systems
Best Engineering Practice

- Before we can talk about a process for design, we must consider the things the best designers do as they solve problems
  - Best Engineering Practice entails careful forethought and following standards
    - 62.5 grams of prevention is worth a kilogram of cure!
    - “Random Results are the Result of Random Procedures” Geoffe Portes
  - Prevent problems before they occur:
    - Does not meet customer needs
      - Prevention: Identify the Functional Requirements (FR)
      - Prevention: Develop a Design Parameter that accomplishes each FR
    - Failure
      - Prevention: Design to withstand external and internal loads
    - Poor performance
      - Prevention: Design to be robust to tolerances and errors
    - Cost too much
      - Prevention: Create clever, frugal, manufacturable designs

Play, Sketch, Model, Detail, Build & Test

- Engineering is often very much a tactile, visual, verbal, cerebral, and physical activity:
  - Play with the table and the kit parts
  - Sketch ideas
  - Create physical and analytical models to identify opportunities and test possible strategies
  - Detail the machine using all the engineering skills and tools at your disposal
  - Build & test your machine!
- Students who follow best engineering practice create very impressive machines with just the correct amount of effort
Deterministic Design

- Everything has a cost, and everything performs (to at least some degree)
  - If you spend all your time on a single tree, you will have no time for the forest
  - If you do not pay attention to the trees, soon you will have no forest!
  - You have to pay attention to the overall system and to the details
- Successful projects keep a close watch on budgets (time, money, performance)
  - Do not spend a lot of effort (money) to get a small increase in performance
    - "Bleeding edge" designs can drain you!
- Do not be shy about taking all the performance you can get for the same cost!
  - Stay nimble (modular!) and be ready to switch technology streams
- It is at the intersection of the streams that things often get exciting!

Increasing Difficulty Often Leads to the Integration of Engineering Disciples

- Performance

\[
\text{Difficulty} = \frac{\text{Environment} \times \text{Load} \times \text{Range} \times \text{Speed}}{\text{Accuracy}}
\]
Design Process

Follow a design process to develop an idea in steps from

• **First Step:** Evaluate the resources that are available
• **Second Step:** Carefully study the problem and make sure you have a clear understanding of what needs to be done and what are the constraints (rules, limits)
  ➢ *Steps 1 & 2 are often interchangeable*
• **Third Step:** Start by creating possible strategies using words, analysis, and simple diagrams
  ➢ Imagine possible motions, data flows, and energy flows from start to finish or from finish back to start!
  ➢ Simple exploratory analysis and experiments can be most enlightening!
  ➢ Whatever you think of, others will too, so think about how to defeat that about which you think!

• **Fourth Step:** Create concepts to implement the best strategies, using words, analysis, and sketches
  ➢ Use same methods as for strategies, but now start to sketch ideas
  ➢ Often simple experiments or analysis are done to investigate effectiveness or feasibility
  ➢ Select and detail the best concept…
• **Fifth Step:** Develop modules, using words, analysis, sketches, and solid models
• **Sixth step:** Develop components, using words, detailed analysis, sketches, and solid models
• **Seventh Step:** Detailed engineering & manufacturing review
• **Eighth Step:** Detailed drawings
• **Ninth Step:** Build, test, modify…
• **Tenth Step:** Fully document
First Step: Resource Assessment

Before even thinking about potential solutions to a problem, one has to first take stock of the available resources:

- **What time is available?**
  - *When is the project due?*
  - *How many person-hours a week can be spent on the project?*
  - *What are the hours of operation for support facilities (library, shop, computers...)*
  - *Designer engineers are often way too ambitious!*

- **What materials and components are available?**
  - *Lay out all the materials you have (physically or catalogs) in front of you and play with them, let them talk to you, what are their limits, how have others used them...*
  - *Look through hardware magazines*
  - *Look at other machines*
  - *Knowing your hardware is a POWERFUL design catalyst*

- **What manufacturing processes are available?**
  - *You may not have the time to have a casting made!*
  - *You may not have access to a wire EDM, nor the time to send out the parts!*

Second Step: Understanding the Problem (Opportunity!)

- Any problem can be dissected and understood by establishing a starting point, and then analyzing the system and its elements:
  - *It is like creating a design in reverse*

- Study a problem and then define it in terms of its energy storage and dissipative elements, and its geometry and materials:
  - *Simple physical models*
    - Physically play with the contest table, and each element of the kit: Let the hardware talk to you....
    - A sketch model made from simple materials can be very useful to enable you to play with the problem
  - *Simple drawings*
    - A simple hand-drawn isometric figure helps you to pattern the problem into your bio-neural net
    - A simple solid model can also be very useful, particularly when later seeking to test your solid model solution on the problem
  - *Physics: First-Order-Analysis*
    - Words to describe the physics
    - Simple analysis with guestimates of realistic numbers (spreadsheets)
  - *Words (in a table or bulleted list) to describe what problem must be solved*
    - What must be accomplished? (e.g., tip a balance...functions, events)
    - What are the constraints? (e.g., rules, cost, size, time)
Relation between Machining Accuracy Factors

Cause:
- Geometric error of machine tool

Composition element:
- Structure
- Connection part
- Spindle system
- Feed system

Dynamics:
- Static deformation
- Thermal deformation
- Dynamic deformation

Machine performance:
- Limit of chip removal rate (chatter, vibration)

Cutting process
- Driving mechanism
- Environment

Workpiece
- Error in angular motion
- Error in linear motion
- Dynamic response

Tool wear
- Error due to deformation (profile, dimension)
- Error due to motion (profile, dimension)
- Error due to displacement (dimension)
- Error due to tool wear (dimension)