ENGINEERING DESIGN

LEVEL: ME3060, ME3070, ME4010, ME4020, ME4540

The student guide is written to help you to prepare for the PhD qualifying exam in Engineering Design. To successful complete this example you must demonstrate competence in the following topics:

TOPICS

Engineering Design Process

- Engineering problem formulation
- Elicitation and formulation of engineering requirements
- Concept exploration and concept formulation
- Decision making and concept selection
- Perform order-of-magnitude analysis
- Recognize and identify the steps required for complete solutions
- Identify failure criteria and assess the likelihood of failure in a machine component
- Analyze components within your proposed design solution

Mechanical Component Design

- Power transmission including:
    - Shafts and shaft components, bearings, keyways
    - Gear trains, belts, and chain systems
- Mechanical springs
- Clutches and brakes
- Frames, linkages, and structures

REMARKS

You should show analytical insight through design solutions that exhibit the level of maturity and understanding expected of Master's level students. Remember that there is not a single correct solution to the problem. We are interested in seeing your approach to the problem assigned.

The exams are CLOSED BOOK and CLOSED NOTES.
Tables, graphs, and equations that are required to solve the problems will be provided.
A calculator may be used by the student.

The exam questions will address both qualitative and quantitative aspects of design process and component design.

REFERENCES:

1. Cleghorn, W. L., & Dechev, N. (2005). Mechanics of machines (Vol. 82). New York: Oxford University Press.
2. Norton, R. L. (2014). Machine design: An integrated approach.
3. Shigley, J. E. (2011). Shigley's mechanical engineering design. Tata McGraw-Hill Education.
4. Ulrich, K. T., Eppinger, S. D., & Yang, M. C. (2019). Product design and development. New York, NY: McGraw-Hill Education.
5. Wood, K. L., & Otto, K. N. (1999). Product design. Upper Saddle River, NJ: Prentice Hall.

Approved by: Gregory Mocko and Cameron Turner Revised: April 1, 2022 .

Dynamics and Vibrations

Level

Undergraduate (ME 2060, ME 4450) and introductory graduate (ME 8460) level dynamics and vibrations

Topic list

1. 2D kinematics and kinetics of particles and rigid bodies.
2. 2D rigid body frame-of-reference transformations-velocity and acceleration.
3. Forces, moments, linear and angular momentum, energy principles.
4. Euler-Lagrange equations, generalized coordinates, holonomic constraints, ignorable coordinates and conserved quantities.
5. Modeling and free/forced response of multiple-degree-of-freedom (MDOF) oscillatory systems.
6. Modal analysis and eigen solutions of MDOF systems.

Courses

Undergraduate: ME 2060, ME 4450/6450

Graduate: ME 8460

References

"Engineering Mechanics: Dynamics" Hibbeler;

"Theory of Vibrations with Applications" Thompson and Dahleh;

"Classical Mechanics" Goldstein, Poole, and Safko;

"Methods of Analytical Dynamics" Meirovitch;

"Engineering Vibrations" Inman;

Approved by: Suyi Li Revised: April 1, 2022

FLUID MECHANICS

LEVEL: ME 2030, ME 3080, ME 8010 with subject mastery

TOPICS:

1. Basic laws for finite control volumes
   a) Conservation of mass
   b) Linear momentum equation
   c) First law of thermodynamics

2. Differential forms of fluid equations
   a) Continuity equation
   b) Euler's equations
   c) Navier-Stokes Equations
   d) Basic potential flows

3. Dimensional Analysis and Similitude
   a) Buckingham Pi Theorem
   b) Modeling and Similitude

4. Kinematics
   a) Stream function and velocity potential
   b) Volumetric strain rate, circulation, rotation, vorticity
   c) Eulerian and Lagrangian descriptions

5. Differential Analysis, including exact solutions for classical viscous flows (i.e. laminar flow in pipe, plane Poiseuille flow, Couette flow.)

6. Boundary layer concept and approximations, including Law of the Wall

7. External flow over bodies

References:
1. Fundamentals of Fluid Mechanics, Munson, Chapters 1-9, 11
2. Foundations of Fluid Mechanics, Currie

Approved by: Zhen Li Revised: 3/18/2022

HEAT TRANSFER

LEVEL: ME3040

TOPICS:

Students should have proficiency with each heat transfer mode (conduction, convection, and radiation) and also be able to combine them to develop thermal models for applications. Familiarity with fundamental boiling concepts is also required.

The list below provides an overview of topics.

1. Conduction
    - Heat diffusion equation
    - Solutions of the heat diffusion equation for steady-state and one spatial dimension in Cartesian, spherical and cylindrical coordinate systems
    - One-dimensional heat conduction with heat sources
    - Extended surfaces such as fins
    - Thermal resistances
    - Finite difference methods
    - Transient conduction (lumped capacitance and similarity techniques)

2. Convection
    - Boundary layer analysis
    - Conservation of momentum and energy in differential and integral forms
    - Similarity methods and solutions
    - Reynolds analogy
    - Convection heat transfer correlations for internal and external flows (both forced and natural convection)
    - Free (natural) convection

3. Boiling Fundamentals
    - Modes of boiling
    - Pool boiling

4. Radiation
    - Radiation fundamentals
    - Radiative properties of surfaces
    - Modeling methods for black and gray surfaces
    - Radiation exchange between surfaces

5. Heat Exchangers
    - Heat exchanger configurations
    - Log-mean temperature
    - Overall heat transfer coefficient
    - Effectiveness-NTU methods

REFERENCE:

Primary:

1. Fundamentals of Heat and Mass Transfer, 8th Ed., T.L. Bergman, A.S. Lavine, F.P. Incropera, and D.W. Dewitt, John Wiley & Sons, New York (Chapters 1-13), 2017.

Approved by: Xin Zhao Revised: April 1, 2022

MANUFACTURING PROCESS

LEVEL: ME 3120, ME 4400, ME8930

TOPICS:

1. Manufacturing Properties of Engineering Materials
   Emphasis: Impact of material properties on their suitability for various processing operations.
   i) Fluidity, castability, formability, forgeability, weldability, etc.
2. Tribological and Dimensional Characteristics of Surfaces
   Emphasis: Implication of tribological and dimensional characteristics of tool and part surfaces in manufacturing.
   i) Friction, wear, and lubrication
   ii) Metrology, dimensional tolerances, and surface finish
3. Manufacturing Processes for Engineering Materials
   Emphasis: Analysis of manufacturing processes for engineering materials and the impact of such processes on the microstructure of the workpiece.
   i) Processing of metallic materials
   ii) Processing of polymers
   iii) Processing of ceramics, glasses, and composites
   iv) Joining Processes
4. Selection of Manufacturing Processes
   Emphasis: Methodologies for process selection
   i) Process attributes
   ii) Process selection charts

REMARKS:

Questions will typically deal with qualitative aspects of the working principles associated with various manufacturing processes, fundamental relationships between materials properties and process attributes and with methodologies for process selection. The questions may include the use of quantitative relationships discussed in the reference books listed below to carry out a short supporting calculation (such as determination of the solidification shrinkage, calculation of the minimum forging pressure or total specific work of deformation, computation of the economic batch size of a process, etc.). To this end, a single cheat sheet of US letter size will be allowed. Cheat sheet must be turned in with the exam.

REFERENCES:

1. Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, 6th Ed., M. Groover, Wiley, Hoboken, NJ, 2015, ISBN: 978-1119128694.
2. Manufacturing Processes for Engineering Materials, 5th Ed., S. Kalpakjian and S. Schmid, Pearson, London, United Kingdom, 2007, ISBN: 978-0132272711.
3. Materials Selection in Mechanical Design, 5th Ed., M. Ashby, Chapters 4-7, Butterworth-Heinemann, Oxford, United Kingdom, 2017, ISBN: 978-0081005996.

Approved by: Hongseok Choi & Rodrigo Martinez-Duarte Revised: March 31st, 2022 .

Engineering Materials

Topic list

1. Atomic structure and interatomic bonding
2. Taxonomy of engineering materials: Metals, Ceramics, polymers, and composites
3. Structure of crystalline solids
   - Crystalline and noncrystalline materials
   - Crystal structures
   - Crystallographic points, directions, and planes
4. Engineering properties of materials
   - Mechanical properties (strength, hardness, ductility, fracture toughness, creep)
   - Physical properties (electrical, magnetic, optical, thermal)
   - Environmental effects (wear, corrosion, oxidation)
5. Defects in solids
   - Point defects
   - Dislocations
   - Interfaces
   - Dispersions/voids
6. Diffusion
   - Fick's laws
   - Solutions of the diffusion equation
   - Diffusion coefficients
7. Strengthening mechanisms
   - Elastic and plastic deformation
   - Mechanisms of strengthening in metals
   - Strain hardening, recovery, recrystallization, and grain growth
8. Fracture
   - Modes of fracture
   - Fracture toughness
9. Phase diagrams
   - Unary and binary phase diagrams
   - Eutectic diagrams
10. Phase transformations and development of microstructure
    - Nucleation
    - Crystallization and transformation kinetics
11. Materials processing and impact of microstructure on mechanical properties
12. Structure and properties of ceramics
    - Types and applications of ceramics
    - Fabrication and processing of ceramics
13. Polymer structures
    - Polymer types, synthesis, and processing
    - Mechanical behavior of polymers
    - Deformation and strengthening of polymers
    - Crystallization, melting, and glass-transition phenomena
14. Composite materials

- Particle-reinforced composites
- Fiber-reinforced composites
- Structural composites

15. Materials selection in mechanical design
    - Materials selection charts
    - Mechanical applications

Courses

Undergraduate: MSE2100, ME4300, ME4400.

Graduate: ME 8610 (recommended).

References

It is recommended that you work **numerous** problems from the recommended textbooks below.

- *Materials Science and Engineering: An Introduction*, 10th Edition by William D. Callister Jr. and David G. Rethwisch (essential).
- *Introduction to Materials Science for Engineers*, 8th Edition by James Shackelford (recommended).
- *Mechanics of composite materials* by Robert Jones, Chapters 1 through 3 (recommended).
- *Materials selection in mechanical design*, 5th Edition by Michael Ashby (suggested).
- *Mechanical metallurgy* by George Dieter, Chapters 1 through 7 and 12 through 14 (suggested).

Approved by: Engineering Mechanics Group Revised: April 1, 2022

Engineering Mathematics

Topic list

1D Calculus: limits, L'Hospital's rule; derivatives, chain rule, implicit differentiation; integrals, fundamental theorem of calculus, integration techniques, area, volume; infinite sequences and series, convergence tests, Taylor series;

Vector Calculus: vectors, dot product, cross product, arc length, parametric curves/surfaces; partial derivatives, gradient, directional derivative; double and triple integrals, surface area, change of variables and the Jacobian; vector fields; line integrals, fundamental theorem of line integrals; vector derivatives, divergence and curl; fundamental theorems of vector calculus, Green's theorem, divergence theorem, Stokes' theorem;

Differential Equations: classification, existence and uniqueness theorems; ordinary differential equations (ODEs), solution techniques for linear and nonlinear problems, homogeneous and particular solutions, initial value problems (IVP), boundary/eigenvalue value problems (BVP); linear system of ODEs, reduction to first order system, eigenvalues/vectors and the general solution; integral transforms, Laplace transform; partial differential equations (PDEs), identification, separation of variables, Fourier series technique, Fourier transform;

Linear Algebra: vectors, matrices; manipulation of vectors/matrices, addition, subtraction, multiplication; solution of linear systems of equations, Gauss-Jordan elimination; linear transformation, matrix representation, inverse transformation, matrix products; linear spaces, subspaces, span, image (range), kernel (null space); orthogonal projection, orthonormal basis, Gram-Schmidt orthogonalization; determinants; eigenvalues and eigenvectors, diagonalization;

Complex Variables: complex numbers, polar form, Euler's identity, root solving techniques; analytic functions, trigonometric and hyperbolic functions; conformal mapping;

Numerical Methods: Integration, trapezoid rule; differentiation, finite differences; interpolation; root finding, secant method, Newton's method; differential equations, regular and modified Euler's method;

Courses

Undergraduate: MATH 1060, MATH 1080, MATH 2060, MATH 2080, MATH 3650

Graduate: MATH 6340, PHYS 8110,8120 (recommended)

References

"Advanced Engineering Mathematics" Kreyszig (Chapters 1-12); "Calculus" Stewart (Chapters 1-14); "Differential Equations and Boundary Value Problems" Edwards & Penney (Chapters 1-7,9,10); "Linear Algebra with Applications" Bretscher (Chapters 1-7)

It is recommended that you work **numerous** problems from the Chapter exercises in the recommended textbooks.

SOLID MECHANICS

LEVEL:

ME2040, ME4320

The examination will focus on advanced undergraduate and master's level material in solid mechanics. The emphasis will be on problem formulation and solution approaches to demonstrate maturity of understanding and knowledge in this subject area. The exam will be closed book. The equation sheet will be provided during the exam.

TOPICS:

1. Stress and deformation analysis of rods, shafts, beams trusses, frames, and machines due to mechanical and thermal loads. Both statically determinate and indeterminate structures.
2. Combined stresses, stress and strain transformations in 2-D and 3-D.
3. Generalized Hooke's law.
4. Bending of curved beams.
5. Beams on elastic foundations.
6. Plane stress and plane strain.
7. Static failure theories.
8. Elements of theory of elasticity.
9. Pressured cylinders and spinning disks.
10. Unsymmetric bending and shear center.
11. Torsion of noncircular members.

REFERENCES:

Primary:

1. Mechanics of Materials, Hibbeler (Chapters 1-13)
2. Advanced Mechanics of Materials, Cook and Young (First edition: Chapters 1-3, 5, 8-10; second edition: chapters 1-3, 5-10)

Secondary,

1. Mechanics of Materials, Gere, and Timoshenko
2. Engineering Mechanics of Solids, Popov
3. Mechanics of Solids, Lardner and Archer

APPENDIX:

1. Sample problems on selective topics
2. Equation sheet

Approved by: __Engineering Mechanics Group_____March 18, 2022_____

Clemson University
Department of Mechanical Engineering
Ph.D. Qualifying Exam Information
System Modeling and Control

Updated: April 2022

Test Material:

The exam will test the undergraduate system modeling, analysis and classical control material. At Clemson these topics are covered in the two courses: ME3050 and ME4030. Graduate understanding of the material is expected.

Topics: I) Modeling and Analysis of Dynamic Systems:

1. Modeling principles of lumped parameter systems
   - Mechanical, Electrical, Electromechanical, Fluid, Thermal

2. Recognition of applicable physical laws such as
   - Newton Laws, Kirchhoff Laws, Continuity, Energy

3. Transfer function models
   - Laplace transform and properties, notion of pole and zero, canonical form of the transfer functions, Block diagrams

4. Stability of Dynamic Systems:
   - Stability versus location of poles, Routh-Hurwitz stability criterion

5. State-space models

6. Linearization of nonlinear systems

7. Time Domain Response of Dynamic Systems:
   - Solution of linear ODE's using transfer function or state-space approach
   - Transient Response, time domain specifications, influence of pole and zero locations on the response, damped and undamped vibrations
   - Steady-State Response, DC gain, steady-state errors, system type

8. Frequency Domain Response of Dynamic Systems:
   - Steady-state response to sinusoidal inputs, gain and phase concepts
   - Bode plots

II) Classical Control of Dynamic Systems:

9. Feedback Control Design
   - Closed-loop transfer functions
   - PID control
   - Lead and Lag compensation

10. Root Locus Method for Control Analysis and Design

11. Frequency Domain Methods in Control Analysis and Design
    - Control Design Using Bode plots
    - Nyquist Method, Nyquist Stability Criterion
    - Relative Stability, Phase and gain margins

References: Modeling and Analysis of Dynamic Systems (ME3050)

- **Primary text**: W. Palm, System Dynamics, McGraw Hill, Any Edition.
- K. Ogata, *System Dynamics*, Fourth Edition, Prentice Hall, Any Edition.
- C.M. Close, D.H. Frederick and G.C. Newell, Modeling and Analysis of Dynamic Systems, John Wiley, Any Edition.
- R.H. Cannon, Dynamics of Physical Systems, Dover, 2003.
-

Control of Mechanical Systems (ME4030):

- **Primary text**: N.S. Nise, Control Systems Engineering, John Wiley & Sons, Any Edition.
- K. Ogata, Modern Control Engineering, Fourth Edition, Prentice Hall, Any Edition.
- G. F. Franklin, J.D. Powell, and A. Emami-Naeini, *Feedback Control of Dynamic Systems*, Prentice Hall, Any Edition.
- R.C. Dorf and R.H. Bishop, *Modern Control Systems*, Prentice Hall, Any Edition.

THERMODYNAMICS

LEVEL: ME 2030, ME 3030, and ME 8100

TOPICS: Students are responsible for any and all material in Primary references #1 and #2 (see below). A focus on the following eight topics can be expected.

1. First and Second Law Topics
2. Property Models
    - Equations of State
    - "Real" Substance Behavior
    - Theory of Corresponding States
    - Thermodynamic Tables of Properties
3. Thermodynamic Relations
4. Phase and Chemical Equilibrium
5. Mixtures
6. Entropy
7. Chemical Reactions/Combustion

REFERNCES:

Primary:

1. Fundamentals of Classical Thermodynamics, Van Wylen and Sonntag, --Entire text
2. Fundamentals of Engineering Thermodynamics, Moran and Shaprio—Entire text

Secondary:

1. A Course in Thermodynamics, Kestin
2. Advanced Thermodynamics for Engineers, K. Wark
3. Advanced Engineering Thermodynamics, A Bejan

Approved by: John Saylor Revised: 1/31/2022 .