

Mechanical Engineering Ph.D. Qualifying Exam

The QE will be offered twice per year, once in the fall and again in the spring. Students entering the Ph.D. program **with** a mechanical engineering master's degree must take the qualifying exam within **three long semesters**. Students entering the program **without** a mechanical engineering master's degree are required to sit for the qualifying exam within **five long semesters**. A Ph.D. student is required to submit a qualifying exam application form within the first three weeks of the semester when the exam is taken.

The purpose of the qualifying exam is to determine the student's potential for success in the Ph.D. program. A student who fails in the first attempt in qualifying exam has a second chance to take the qualifying exam in the immediately following long semester.

Exam Format

The qualifying exam will test student's knowledge in one concentration area in mechanical engineering and related background in mathematics. One three-hour written exam is given in one continuous sitting. Students are not to bring any outside materials to the exam, other than an approved calculator (no books or notes).

The following is a list of topics and references in Mathematics, and the four concentration areas: (1) Dynamic Systems and Controls (DSC); (2) Mechanics and Materials (MM); (3) Thermal and Fluid Sciences (TFS); and (4) Manufacturing and Design Innovations (MDI).

Mathematics

Linear Algebra: Systems of linear equations, determinants, vectors and vector spaces, linear transformations, eigenvalues and eigenvectors, quadratic forms. **Calculus:** Complex numbers, multivariable calculus and analytic geometry. Study of polar, cylindrical, and spherical coordinates, vector differential calculus, vector integral calculus, and vector integral theorems.

Ordinary Differential Equations: First order differential equations, system of linear differential equations, stability, series solutions, special functions, Fourier and Laplace transforms. **Partial**

Differential Equations: Analytical methods for the solution of boundary value problems governed by partial differential equations.

References:

- Ermin Kreyszig, *Advanced Engineering Mathematics*, Wiley, 10th edition, 2011.
- Howard Anton, *Elementary Linear Algebra*, Wiley, 10th Edition, 2010.
- William E. Boyce and Richard C. DiPrima, *Elementary Differential Equations & Boundary Value Problem*, Wiley, 10th edition, 2013.

Concentration Area: Dynamic Systems and Controls (DSC) (updated Jan. 2023)

Dynamics: Newtonian dynamics, dynamics equations, kinetics of particles and rigid bodies, force and acceleration, work and energy, impulse and momentum.

- Hibbeler, *Engineering Mechanics: Dynamics*, 14th Edition. [Chapters 12-19]

Modeling: dynamic modeling and system response analysis of either electromechanical or thermo-fluid systems.

- Palm, *System Dynamics*, 3rd Edition [Chapters 2-4, 6-8]

Classic Control: transfer functions and block diagrams, time and frequency response of dynamic systems to input commands, disturbances and noises, poles and zeros, steady-state performance and system types, transient performance indices and relations to pole locations, PID and other dynamic compensators, root locus method for controller design and stability analysis, Bode plots for stability analysis and controller design, PID and lead-lag compensator design using root locus method and Bode plots, Nyquist plot and stability.

- Franklin, Powell, Emami-Naeini, *Feedback Control of Dynamic Systems*, 7th Edition. [Chapters 3-7]

Linear Systems: Basic system properties: causality, linearity, time-invariance, state-space representations, linearization, solutions, realizations, controllability, observability, BIBO and Lyapunov stability, Algebraic Lyapunov equation, state feedback controllers and state estimators, observer-based controller design.

- Chen, *Linear Systems Theory and Design*, 3rd Edition. [Chapters 2-6, 8]

Linear Algebra: systems of linear equations, vectors and vector spaces, determinants, orthogonality, linear transformations, fundamental spaces, eigenvalues and eigenvectors, singular value decomposition, quadratic forms.

- Strang, *Introduction to Linear Algebra*, 5th Edition. [Chapters 1-8]

Concentration Area: Mechanics and Materials (MM)

Intermediate Mechanics of Materials: Principal stresses, failure theories (various failure criteria, fracture mechanics concepts, fatigue), symmetric and unsymmetric beam bending, torsion and shear of thin-walled sections, combined loading, energy methods (unit load method, Castigliano's theorems), two-dimensional elasticity (stress and displacement methods, boundary conditions, Airy's stress function), torsion theories (St. Venant torsion theory, Prandtl method), and column buckling. **Continuum Mechanics:** Tensor analysis, analysis of deformation, analysis of stress, constitutive equations, material anisotropy, mechanical properties of fluids and solids, derivation of field equations, boundary conditions, and solutions of initial and boundary value problems for continua.

References:

- R. D. Cook and W. C. Young, *Advanced Mechanics of Materials*, 2nd edition, Prentice-Hall, Upper Saddle River, NJ, 1999.
- W. M. Lai, D. Rubin and E. Krempl, *Introduction to Continuum Mechanics*, 4th edition, Butterworth-Heinemann, 2009.
- A. C. Ugural and S. K. Fenster., *Advanced Strength and Applied Elasticity*, 5th edition, Prentice Hall, 2012.

Concentration Area: Thermal and Fluid Sciences (TFS) (updated Jan. 2024)

Fluid Mechanics: The students should be able to apply (i) fundamental equations and dimensionless analysis to incompressible fluid mechanics problems, (ii) formulate and apply the concept of laminar boundary layer and the linear stability of laminar flows, (iii) analyze the transition from laminar to turbulent flow, (iv) formulate and apply the concept of turbulent boundary layers (iv) derive the Reynolds equations and turbulence models. The test may include problems both in the laminar regime (Poiseuille, Couette, or wind driven flows) as well as in the turbulent regime (jets, wakes, mixing layers). **Heat Transfer:** Successful demonstration of advanced-level knowledge of the macroscopic view and foundation of the three modes of heat transfer (conduction, convection and thermal radiation) is required. In addition, candidates must demonstrate the ability to conceptualize thermal systems and processes involving thermal transport phenomena. All topics in the reference can be covered excluding phase-change heat transfer (condensation, evaporation, and boiling).

References:

- Students are encouraged to take three core courses in TFS, including Incompressible Fluid Mechanics, Conductive & Radiative Heat Transfer, and Convective Heat Transfer. References for QE are in line with the textbooks in those courses.

Concentration Area: Manufacturing and Design Innovations (MDI)

Engineering Optimization: Basics of design optimization theory, numerical algorithms, and applications in engineering, linear programming, necessary and sufficient conditions, nonlinear programming with no constraints, nonlinear programming with constraints, multi-objective optimization, gradient based optimization, non-gradient based optimization.

Materials Design and Manufacturing: Processing, structure, mechanical properties, and performance of common engineering materials (metals, ceramics, polymers, composites), load and stress analysis, failure due to static and variable loading, imperfections and strengthening mechanisms. **Computer Aided Design:** Parametric and non-parametric curves including Hermite and Bezier curves, surface modeling, solid modeling (feature based, boundary representation, constructive solid geometry), assembly modeling, engineering drawings along with dimensioning, spatial visualization, simulation and analysis of engineering problems (e.g., description of: analysis type, material modeling, boundary conditions & loads, mesh characteristics, interpretation of results).

References:

- Rao S., *Engineering Optimization: Theory and Practice*, 4th edition, Wiley, 2009
- Callister W. and Rethwisch D., *Materials Science and Engineering*, 9th edition, Wiley, 2014.
- Ibrahim Zeid, *Mastering CAD/CAM*, McGraw-Hill, 2005
- Budynas, R. and Nisbett, J., *Shigley's Mechanical Engineering Design*, McGraw-Hill Education, 10th edition, 2014