Mechanical Engineering Program
Physical Sciences and Engineering Division
King Abdullah University of Science and Technology

List of Topics for Ph.D. Qualifying Examination
Effective from Fall 2024

MATHEMATICS

There are five areas within mathematics, as defined below. The student should be prepared to answer questions from *two* areas of their choice. Each area contains a list of topics and a list of courses to indicate the depth of these topics. However, the exam is not intended to be a final exam in any of these courses; instead, the exam evaluates the general mathematical understanding of these areas.

1. **Linear algebra:** finite-dimensional vector spaces, linear transformations and matrices, eigenvectors and eigenvalues, positive definiteness, diagonalization, solution of linear systems, singular value decomposition, orthogonal projections, quadratic forms, applications to differential and integral equations.
2. **Complex variables:** analyticity, integration, series, singular points, residues and applications, Cauchy residual theorem, Taylor and Laurent series.
3. **Ordinary differential equations:** linear systems, initial- and boundary-value problems, Fourier and Laplace transforms, phase plane methods, Green's functions, dimensional analysis, Sturm-Liouville problems.
4. **Partial differential equations:** type and normal forms for second-order equations, qualitative properties for elliptic, hyperbolic, and parabolic equations, well-posedness, separation of variables, transform methods, method of characteristics, shocks, fundamental solutions, Green's functions.
5. **Numerical Analysis:** Interpolation, numerical integration and differentiation, error analysis, dispersion vs. dissipation error, ODE integration schemes, PDE integration schemes, familiarity with linear solvers.

FLUID MECHANICS

The student should be familiar with the material covered in ME 200A and prepared to answer questions from other fluid mechanics topics at the undergraduate level.

1. **Dimensional analysis:** Buckingham pi theorem, Non-dimensional NS, Self-similarity
2. **Free surfaces**: surface tension,
3. **Kinematics:** Eulerian and Legrangian description, fluid deformation, rate of strain, shear, dilatation, vorticity, circulation, material path lines, streaklines, streamlines.
4. **Conservation laws:** for mass, momentum, energy (control volume, differential form), Reynolds Transport Theorem.
5. **Constitutive relations**: Newtonian fluids, Navier-Stokes equations.
6. **Potential flow**: velocity potential, stream function, Kelvin's theorem, d'Alembert's paradox, Bernoulli's equation, complex potential, Blasius' theorems.
7. **Laminar flow:** steady incompressible flow exact solution, oscillations, lubrication theory, low Re flow over sphere, Stokes accelerated plate.
8. **Flow over bluff bodies**: drag, separation, wakes, vortex shedding.

SOLID MECHANICS

The student should be familiar with the material covered in ME 211A and prepared to answer questions from other solid mechanics topics at the undergraduate level.

1. **Fundamentals:** fundamentals of kinematics (description of 3-D displacements, transformations, deformation gradient, finite and infinitesimal strain theory, compatibility), fundamentals of statics for rigid bodies, systems of rigid bodies and deformable bodies (equilibrium equation, traction, stress, boundary conditions), fundamental of constitutive equations (thermodynamics requirements), fundamental of related mathematical concepts (tensors, transformations between basis of vectors, matrices and tensors up to the 4^{th} order).
2. **Linear elasticity:** Basic equations, generalized Hooke's law, plane strain and plane stress, axisymmetric problems, 3- dimensional problems and classical analytical solutions (thick tubes and spheres, torsion of non-circular and thin-walled cross sections, theory of beams, rods, cables). Elastic waves. Normal modes of cantilevers.
3. **Energy methods:** Principle of virtual work, theorem of potential energy, basics of the finite element method, discretization, concepts of nodal degrees of freedom and shape function, stiffness matrix and boundary conditions.
4. **Theory of plates and shells:** Kirchhoff theory of plates, membrane theory of shells.
5. **Elastic buckling of columns:** Column buckling, beam-column theory, Euler loads.
6. **Plasticity and viscoelasticity:** quantitative description of ideal plasticity and strain hardening, Maxwell and Voigt solids, creep and relaxation functions.
7. **Fracture mechanics:** Crack tip fields, stress intensity factor, energy release rate, fracture toughness.

Suggested undergraduate level textbooks:
Engineering Solid Mechanics, Abdel-Rahman Ragab and Salah Eldin Bayoumi, CRC Press
Mechanics of Materials, S.P. Timoshenko and J.M. Gere, DVN Company
Continuum Mechanics, G.E. Mase, Schaum's Outlines

Thermodynamics

The student should be familiar with the material covered in ME 241 and prepared to answer questions from other thermodynamics topics at the undergraduate level.

1. **Intensive and extensive variables**; definitions of temperature, pressure and chemical potential.
2. **Equilibrium** (thermal, mechanical, and chemical);
3. **Thermodynamic potentials**, canonical variables, min/max principles.
4. **First and second law** of thermodynamics.
5. **Entropy** generation, **exergy** destruction, exergy analysis.
4. **Work and heat**: quasi-static and reversible processes, irreversibility, heat flow, maximum work theorem. Carnot cycle, heat pumps.
5. **Formal relations**: Euler equations, Gibbs-Duhem equation, Maxwell relations.
6. **Multiphase systems**: latent heat, Clausius-Clapeyron equation, van der Waals phase transition, continuity of the vapor and liquid states, Gibbs phase rule, corresponding states, critical point phenomena.
7. **Chemically reactive systems**: equilibrium, chemical potential, reversible / irreversible reactions, steady-flow combustion, constant-volume combustion.
8. **Thermodynamic cycles** for power generation and transport.

Dynamics and Control
The student should be familiar with the material covered in ME 221A and prepared to answer questions from other dynamics and controls topics at the undergraduate level.

Dynamics

1. **Kinematics**: Reference frames and coordinate systems. Euler's equations.
2. **Elementary Dynamics**: Newton's principle and inertial reference frames.
3. **Dynamics of isolated particles**.
4. **Theorem of angular momentum**, dynamics of several particles.
5. **Energy concepts**
6. **Rigid-body dynamics**, moments of inertia, parallel axis theorem.

Control

1. **Modeling and analysis of feedback systems**: use of ordinary differential equations for modeling mechanical systems. Stability of equilibrium points and linearization. Input/output modeling and performance specifications (frequency and step response).
2. **Classical control theory**: Control of single-input/single-output systems. Loop analysis of feedback systems using Nyquist and Bode plots. Design of feedback compensators using loop shaping techniques, including PID control.
3. **State-space representation of dynamical systems**: Realization theory, change of coordinate system, controllable, observable systems.
4. **State space control and state feedback**, including controllability and observability.
5. **Optimal control** and linear quadratic regulators.
6. **State estimation** / digital twins, optimal filtering.
7. **Observer-based control** system design.