Department of Mechanical Engineering
Preliminary Exam Topics

Mathematics

Linear Algebra
- Vectors, matrices, projections
- Lines, curves, and planes, tangential planes, normal vectors
- Gaussian elimination/reduction to upper triangular form
- Reduction to echelon and row-canonical forms
- Determinants and inverse matrices
- Null spaces
- Change of basis
- Modified Gram-Schmidt orthogonalization
- Eigenvalues and eigenvectors
- Diagonalization and principal axes
- Quadratic forms and symmetric matrices

Ordinary Differential Equations
- First order equations; separation of variables and linear equations
- Homogeneous linear constant coefficient equations
- Linear constant coefficient equations, method of undetermined coefficients
- Linear constant coefficient equations, method of variation of parameters
- Linear constant coefficient equations, method of Laplace transformation
- Eigenvalue and Sturm-Liouville problems
- Reduction to first order systems
- Solution of first order linear constant coefficient systems
- Critical points of nonlinear autonomous systems

NOTE: In addition to the topics listed above, students taking the Ph.D. preliminary exam are expected to have a good command of Calculus.

Dynamics & Controls

Dynamics
EML 3013C – Dynamic Systems I

Two-dimensional and three-dimensional kinematics
- Particle kinematics
- Rigid body kinematics
- Cartesian coordinates
- Normal and tangential coordinates
- Cylindrical coordinates
- Absolute dependent motion analysis (bodies connected by cables)
- Angular velocity and acceleration
- Relative velocities and acceleration in inertial and noninertial reference frames

Two-dimensional and three-dimensional kinetics
- Particle kinetics
- Rigid body kinetics
- Newton’s second law
- Principle of work and energy
- Principle of impulse and momentum
- Moments of inertia and their transformation properties
- Linear and angular momentum
- Newton-Euler equations of motion

**Analytical Mechanics**

- Constraints, both holonomic and nonholonomic
- Generalized coordinates, generalized forces
- D’Alembert’s and Hamilton’s Principles
- Lagrange’s Equations for unconstrained and constrained motion

**Controls**

*EML 4316 / EML 5311 – Design and Analysis of Control Systems*

**Analog & Digital Control System Analysis**

- Laplace & Z transforms
- Block diagrams
- Routh’s stability criterion
- Bode plots
- Nyquist plots
- Nyquist stability criterion
- Sensitivity
- Transient response
- Steady state response
- Root locus techniques
- State space representation
- Discretization of analog plants (zero-order hold equivalents)

**Analog & Digital Control System Design**

- Root locus
- PID compensation
- Lead and lag compensation
- Discrete-time approximations of analog controllers (emulation design)

**Fluid Mechanics & Heat Transfer**

**Thermodynamics**

*EML 3015 – Thermal Fluids / EML 3016 – Mechanical Systems*

- Mass conservation
- Type of systems (open, closed, isolated)
- Concept of thermodynamic property
- Properties of a pure system (h, s, v, T, P, ..)
- Specific heats
- Property diagrams (P-v, T-s, P-T)
- Concept of ideal gas, ideal gas equations of state
- First law of thermodynamics (all type of systems)
- Work and heat
- Second law of thermodynamics
- Computation of entropy generation
- Carnot Cycle, Carnot Efficiency, Carnot Postulates
- Basic power cycles (Rankine, Brayton, Otto, Diesel)
- Modifications of a Rankine and Brayton cycle (reheating, regeneration, intercooling)
- Isentropic efficiencies of turbines, compressors and pumps
• Concept of thermal efficiency, coefficient of performance
• Refrigeration by vapor compression

Heat Transfer
*EML 3015 – Thermal Fluids / EML 3016 – Mechanical Systems*

Heat Conduction

• Steady state heat conduction in one-dimension with and without internal heat generation (linear, radial and spherical geometry)
• Extended surfaces (fins)
• Thermal resistance networks
• Unsteady heat conduction (lumped capacitance concept).
• Heat diffusion in one dimension

Forced Heat Convection

• Physical mechanism
• Thermal boundary layer
• Parallel flow over a plate
• Flow across cylinders and spheres
• Pipe flow (description of boundary layer, entrance length,...)

Natural Convection

• Physical mechanism
• Natural convection over surfaces (illustrate direction of motion)

Heat Exchangers

• Concept of LMTD and overall heat transfer coefficient
• Parallel and counterflow heat exchangers

Other topics

• Important dimensionless numbers: Re, Nu, Pr, Gr, Ra, Bi, etc.
• Comparison of velocity boundary layer and thermal boundary layer thickness
• Variation of heat transfer coefficient for flow over a plate, a cylinder, a sphere

Fluid Mechanics
*EML 3015 – Thermal Fluids / EML 3016 – Mechanical Systems*

• Conservation of mass
• Conservation of energy
• Bernoulli and Energy Equation
• Static and total pressures and their measurements
• Flow in pipes, entrance region, boundary layer
• Laminar, transition and turbulent flow
• Pipe head loss, minor losses, major losses, friction factor
• Drag and lift
• Fluid statics
• Dimensional analysis

Solid Mechanics & Materials Science

Mechanics of Materials
*EGM 3520 – Mechanics of Materials / EML 3018 – Mechanical Systems*
Mechanical properties of materials

- Stress-strain behavior under uniaxial loading
- Isotropic, orthotropic and anisotropic behavior
- Elastic, plastic regimes
- Rate-dependent and independent behavior
- Ductile and brittle behavior

Force vectors and resultants

- Scalar, vector and tensors
- Vector operations: dot and cross products
- Force-couple systems in 3D and their reductions

Stress and Strain

- Concept of stress and strain
- Normal and shear strain in three dimensions
- Stress and strain deformations
- Body and surface forces, traction vector
- Mohr's circle and principal stresses
- Spherical and deviatoric components
- Plane stress, plane strain and generalized plane and 3D states
- Concept of equivalent stress, von Mises yield criteria
- Failure theories of brittle and ductile materials
- Strain rosettes

Axial loading, Torsion, Bending, Shear, Combined Loading

- Elastic, plastic and thermal loadings
- Statically indeterminate problems
- Stress concentration, inelastic bending and torsion
- Prismatic, built-up and composite members
- Thin walled pressure vessels

Beams and Columns

- Moment diagrams in built-up and composite beams
- Elastic curve: slope and deflections
- Method of superposition
- Discontinuity functions
- Statically indeterminate beams
- Critical loads in columns
- Inelastic buckling
- Application of energy methods
- Anisotropy and composite materials

Materials Science and Engineering

EML 3234 – Material Science and Engineering / EML 4930 – Advance Materials

- Bonding
- Crystal structure
- Miller indices
- Point, line and volume defects
- Mechanical properties
- Stress
- Strain
- Plastic deformation

Revised Spring 2010
• Hardness
• Fracture (ductile vs. brittle)
• Toughness
• Fatigue
• Creep
• Phase equilibria (phase diagrams)
• Electronic properties
• Metals
• Steel, and steel heat treatments
• Alloys
• Semiconductors
• Ceramics
• Polymers
• Composites
• Corrosion
• Processing
• Diffusion
• Microscopy
• Xray diffraction

Mechanical Metallurgy
EMA 4225 / EMA 5226 – Mechanical Metallurgy

Stress and strain relationships for elastic behavior

• State of stress in two/three dimensions
• Mohr’s circle of stress and strain - two/three dimensions
• Stress tensor
• Hydrostatic and deviator components of stress
• Calculation of stresses from elastic strains
• Anisotropy of elastic behavior

Elements of the theory of plasticity

• The flow curve
• Engineering stress-strain
• True stress and true strain
• Instability in tension
• Yield criteria
• Combined stress tests
• Effect of strain rate on flow properties
• Effect of temperature on flow properties

Plastic deformation of single crystal

• Concepts of crystal geometry
• Lattice defects deformation by slip
• Slip by dislocation movement
• Critical resolved shear stress for slip
• Deformation by twinning
• Stacking faults

Dislocation theory

• Burgers vector and the dislocation loop
• Dislocations in the FCC and BCC lattice
• Stress fields and energies of dislocations
• Forces between dislocations
- Dislocation climb
- Intersection of dislocations
- Jogs and dislocation sources

**Strengthening mechanisms**

- Grain boundaries and deformation
- Solid-solution strengthening
- Particle strengthening
- Strengthening due to point defects
- Strain hardening
- Preferred orientation (texture)

**Fracture**

- Types of fracture in metals
- Griffith theory of brittle fracture
- Dislocation theories of brittle fracture
- Ductile fracture