Mechanical Engineering PhD Qualifying Examination Topics List

MATH

1) Vector Differential and Integral Calculus
   a) Curves and surfaces
   b) Vector fields and streamlines
   c) Intrinsic coordinates of curves and surfaces
   d) Tangent vectors, normal vectors, tangent planes
   e) Vector operator, gradient, div, and curl, and their geometric interpretation
   f) Green's, Gauss' and Stokes' Theorems
2) Fourier Analyses
   a) Trignometic series and the Fourier transform
   b) Orthogonal polynomials and series in orthogonal polynomia
   c) Fourier Bessel series
3) Ordinary Differential Equations
   a) Linear equation systems with constant coefficients
   b) Method to solve for a n^{th} order linear inhomogeneous ODE
4) Partial Differential Equations
   a) Classifications of PDEs
   b) Domains and boundary and initial conditions required
   c) Method of separation of variables
   d) Method of eigenfunction expansion
   e) Method of superposition

HEAT TRANSFER – textbook allowed

1) Fundamentals of Heat Transfer
   a) Principle of energy conservation
   b) Fourier law and general heat conduction equation
   c) One dimensional steady state heat conduction problems
   d) Transient heat conduction problems and Lumped Capacitance analysis
2) Steady state conduction problems in Cartesian and Cylindrical Coordinate Systems: solution with Separation of Variables Method
3) Transient Heat Conduction Problems in Cartesian and Cylindrical Coordinate Systems: solution with Separation of Variables Method and Similarity Method
4) Heat Conduction Problems Involving Heat Sources or Sinks.
5) Steady-state and Transient heat conduction problems: solution with Numerical Method— Finite Differences/Finite volume.
6) Radiation ---- Basic Relations
   a) Intensity of Radiation
   b) Blackbody Emission
   c) Radiation Properties
   d) Definitions of Properties for Non-black Surfaces
   e) Radiation Properties of Real Materials
7) Radiation Exchange in an Enclosure, Radiation Exchange among Diffuse-gray (Including Blackbody) Surface; Radiation in Enclosures

CONTROLS – equation sheet provided

1) Modeling Mechanical, Electrical, Rotational Systems
   a) Equations of Motion
   b) Laplace Transform
   c) Transfer Functions (TF)
   d) Time Domain
   e) State-Space (SS) Representation
   f) Converting from TF to SS, SS to TF
2) First and Second-Order Systems
   a) Poles, Zeros, and System Response
   b) Responses of First-Order Systems
   c) Responses of Second-Order Systems
   d) Natural Frequency and Damping Ratio
   e) Types of Second-Order Systems
3) Reduction of Multiple Subsystems
   a) Block Diagrams
   b) Analysis and Design of Feedback Systems
   c) Signal-Flow Graphs
   d) Mason's Rule
4) Stability of Systems
   a) BIBO Principle
   b) Routh-Hurwitz Criterion
   c) Stability in State Space
5) Steady-State Errors
   a) Definitions and Sources of State-State Errors
   b) Steady-State Error for Unity Feedback Systems
   c) Static Error Constants and System Type
   d) Steady-State Error Specifications
   e) Steady-State Error for Disturbances
6) Root Locus Techniques
   a) Vector Representation of Complex Numbers
   b) Root Locus Definition
   c) Root Locus Properties
   d) Sketch the Root Locus
   e) Design via the Root Locus
      i) Lag, Lead, PID Design
      ii) Feedback Compensation
7) Frequency Response Techniques
   a) Bode Plots
   b) Sketch Bode Plots
   c) Design via Bode Plots
      i) Transient Response via Gain Adjustment
      ii) Lag, Lead, Lag-Lead Compensation
   d) Stability via Bode Plots

e) Nyquist Criterion
f) Sketch the Nyquist Diagram
g) Stability via the Nyquist Diagram

LINEAR VIBRATIONS – equation sheet provided

1) System modeling
2) Equations of motion
3) First order systems
4) Second order systems
5) Free response
6) Eigenvalues, eigenvectors
7) Laplace transforms
8) Forced response
9) Transfer functions
10) Under-, critical-, and over-damped systems
11) Multi-degree of freedom systems
12) Numerical methods

CONTINUUM MECHANICS

1) States of stress and strain
2) Principal stresses, strains, and directions
3) Maximum shear stress
4) Body forces
5) Equilibrium
6) Compatibility
7) Airy stress function
8) Heat transfer, temperature distribution
9) Deformation mapping
10) Green-Lagrange strain tensor
11) Cauchy stress tensor
12) Stress vector on a plane
13) Stretch
14) Navier-Stokes equations
15) Tresca and VonMises yield criteria

FLUID MECHANICS (closed book)

1) Basics of Fluid Mechanics
    a) Understand the definitions of fluid properties, e.g., pressure, viscosity, compressibility;
    b) Given a flow field, be able to calculate the stress tensor, find reaction forces on a plane of arbitrary orientation, and perform analysis of fluid kinematics, e.g., velocity, acceleration;
    c) Be able to carry out dimensional analysis;

   d) Be able to use the Bernoulli equation to perform dynamic analysis of the incompressible flow;
2) Differential Analysis of Fluid Flow
   a) Be able to manipulate vector and tensor expressions and identities;
   b) Be able to derive and manipulate the governing equations (conservation of mass, linear momentum, and energy) in vector and index forms;
   c) Given a flow field, be able to simplify the governing equations based on physical justifications (assumptions). Solve the resulting PDE or ODE;
   d) Given a PDE, find the similarity variable of the form $\eta = C\, x^m t^n$ that transforms the PDE and its boundary conditions to an ODE with new boundary conditions
3) Control Volume Analysis
   a) Be able to derive Reynolds Transport Theorem and apply it in deriving the governing equations (conservation of mass, linear momentum, energy) from a material volume point of view;
   b) Be able to apply Reynolds Transport Theorem in both i) deriving the governing equations (conservation of mass, linear momentum, energy) and ii) solving practical problems from the fixed control volume view point.
4) External and Internal Flows
   a) Be able to describe different flow types in pipes;
   b) Be able to describe different flow types over cylinders;
   c) Be able to carry out flow analysis of both external and internal flows using differential analysis, control volume analysis, and dimensional analysis.
5) Boundary Layer Theory
   a) Be able to manipulate boundary layer solutions to obtain boundary layer thickness, displacement thickness for a given boundary layer profile;
   b) Be able to estimate and discuss the magnitude of terms in the governing equations and the timescale of physical mechanisms for a given flow situation.
6) Basics of Finite Difference Method (Optional)
   a) Be able to derive the finite difference schemes for the governing equations of fluid flow;
   b) Be able to carry out basic analysis of the finite difference schemes, e.g., order of accuracy, stability.

<u>APPLIED ELASTICITY</u>

1) Basics
   a) Indicial Notation
   b) Vector and Tensor Operations
   c) Eigenvalue Problem
   d) Green-Gauss (Divergence) Theorem
2) Kinematics
   a) General finite deformation of a continuum
   b) Infinitesimal deformation
   c) Decomposition
   d) Compatibility

3) Kinetics and Constitutive relations of elasticity
   a) Conservation of mass, momentum, angular momentum
   b) Transport theorem
   c) Cauchy's tetrahedron argument
   d) Local equilibrium equations (current state, reference state)
   e) Symmetry of stress tensor (small deformations, conservation of angular momentum)
   f) Piola-Kirchhoff & Cauchy stress tensors
   g) Equations of motion in integral and differential forms
   h) Hyper- Hypo elasticity
   i) General anisotropic elasticity- Cauchy relation
   j) Isotropic linear elasticity
4) Work and Energy balance
   a) Strain energy for elastic materials
   b) Basic equations of linear elasticity
   c) Power and Work
   d) Principal of virtual work
   e) Reciprocal (Betti's) theorem
   f) Castigliano's theorem
   g) Minimum potential energy principle
   h) Boundary value problem and uniqueness of solution
5) Solution methods to the boundary value problem of elasticity
   a) Displacement description (Navier equations)
   b) Cylindrical Polar and Spherical symmetry
   c) Thick wall pressure vessels (cylindrical and spherical symmetry)
   d) Thermoelasticity (shrink fit problem)
6) Plane problems of elastostatics
   a) Cartesian & Polar & Spherical Coordinates
   b) Beltrami Mitchel equations of elastostatics
   c) Plane stress, Plane strain
   d) Airy's stress function and other polynomial stress functions
   e) Stress concentrations around a circular hole embedded in an infinite body under remote tension
   f) General solution to the stress function
   g) Stress function under polar symmetry
   h) Stress description solutions for thick wall cylinders
   i) Concentrated line load (non-dimensional analysis approach)
   j) Punch problems
   k) Edge and Screw dislocations
   l) Asymptotic singular near-tip solution
   m) Gravity and body forces (spinning disc)

<u>DYNAMICS</u>

1) Constraints
   a) Holonomic, nonholonomic
   b) Scleronomic

   c) Rehonomic
   d) Catastatic, acatastatic
2) Equations of motion
3) Langrange’s equations
4) Absolute velocity and acceleration, dynamic forces
5) D’Alembert’s principle
6) Virtual work
7) Path description using unit vectors, radius of curvature