2020-21

Northeastern University

Department of Mechanical & Industrial Engineering

[MIE DOCTORAL QUALIFYING

EXAMINATIONS GUIDELINES]

Important information, deadlines, exams selection procedures

DOCTORAL QUALIFYING EXAMINATIONS

Background and Motivation: To demonstrate breadth and depth in each of the subject exams, cross-over and merging exams are necessary in an effort to provide students with an opportunity to master the core disciplines in mechanical or industrial engineering (at both undergraduate and graduate levels) along with a focus area of importance to their specialization. These exams also provide an assessment as to whether students have adequate knowledge to pursue advanced study, and possess attributes of a doctoral candidate by demonstrating understanding of and the ability to apply fundamental principles. Also, an oral exam tied to the written exams is necessary in an effort to evaluate student's potential to perform independent research in the chosen field of specialization for the doctoral program.

Doctoral Qualifying Examinations Framework: The Doctoral Qualifying Examinations consist of the following two parts:

1. Two ***Written Comprehensive*** exams, which are respectively referred to as major Exam A and minor Exam B.
2. An ***Oral Area*** exam equivalently referred to as the **Area Exam**. This exam can be administered at any time after passing the written comprehensive exams, but no later than the end of the semester in which the written exams are taken and passed.

WRITTEN COMPREHENSIVE EXAMINATIONS

All doctoral students who hold a master's degree must take the written comprehensive exams no later than the first time that it is offered after their first academic year of study. Those admitted directly with a bachelor's degree must take the written comprehensive exams no later than the first time that it is offered after their first two years of study. The written comprehensive exams include **two (2)** exams, **Exam A** and **Exam B**; and are given on Thursday and/or Friday of the first week of classes during regular semesters.

Written Comprehensive Exams Rules: Exam A, about 4-6 hours in length, should be selected from the list of major exams based on the student's concentration (i.e., Industrial Engineering (IND), Materials (MSE), Mechanics (MEC), Mechatronics (DSC), or Thermofluids (TFS)), see **Table 1**. No deviation from this rule will be permitted. As listed in **Table 1**, Exam B, about 1-2 hours in length, is a degree program-dependent exam and should be selected from the list provided for each PhD program in MIE Department (i.e., PhD degree program in Industrial Engineering—IE or PhD degree program in Mechanical Engineering—ME). Only one exam from this list should be selected. All students are required to have their Research Advisor's approval on selection of Exams A and B prior to registering to take the written comprehensive exams. **Note that Exam B cannot be similar or close to one of the topics covered in Exam A.**

ORAL AREA EXAMINATION

The objective of the **Oral Exam**, also referred to as *Area Exam*, is to assess the student's potential to perform independent research in the chosen field of specialization. This exam can be administered at any time after passing the written comprehensive exams, but no later than the end of the semester in which the written exams are taken and passed.

Oral Area Examination Procedure: The student's Research Advisor convenes and chairs an Oral Examination Committee comprised of a minimum of three (3) faculty or affiliated faculty members of the MIE Department deemed appropriate to the student's research field. This committee provides a set of technical papers pertinent to the student's research area. The Oral Examination Committee will then conduct the exam, which is comprised of the following two parts (typically a one-hour session):

1. an oral presentation of at least 30-min on a select number of papers out of the assigned technical papers, and
2. an oral exam of ~30-min by committee members' questions and evaluation of the student covering topics specifically related to the student's research area.

GRADING PROCEDURE

Grading Procedure and Results of the Written Comprehensive Examination: The MIE Graduate Affairs Committee (GAC) will review all students' performance in the written comprehensive exams. Depending on the results of both major and minor exams and in consultation with the student's Research Advisor, the GAC will recommend one of following three possible options:

1. *No invitation to oral area exam:* The student will be dismissed from the program. He/she may be granted an MS degree if the requirements are already met; otherwise, the student may continue to fulfill the requirements for an MS degree in industrial engineering (IE), mechanical engineering (ME), or operations research (OR).
2. *No invitation to oral area exam yet:* The student will be asked to re-take the written exam(s) again in the next offering; and/or take additional courses.
3. *Student is invited to oral area exam*.

Grading Procedure and Results of the Oral Area Examination: If the performance of the student in oral area exam is not satisfactory, the student will be dismissed from the program. He/she may be granted an MS degree if the requirements are met; otherwise, the student may continue to fulfill the requirements for an MS degree in industrial engineering (IE), mechanical engineering (ME), or operations research (OR).

Upon successfully passing the oral exam, the student continues in the PhD program and in case of passing all the required coursework, he/she will become a PhD Candidate. The results of the written and oral exams and any recommended coursework become part of the student's record.

DETAILED LIST OF EXAMS A & B

Table 1: List of Exams A* and B based on student's concentration.

<table>
<tr><th>Concentration</th><th>Exam A</th><th>Exam B</th></tr>
<tr><td>Industrial</td><td>Industrial Engineering (IND)</td><td rowspan="5"><u>Exams B for IE PhD Students:</u>
1. Data Mining (DMN)
2. Human-Machine Systems (HMS)
3. Manufacturing Systems (MFS)
4. Networks and Advanced Optimization (NAO)
5. Reliability and Quality Assurance (RQA)
6. Supply Chain Engineering (SCE)
<u>Exams B for ME PhD Students:</u>
1. Control Systems (DSC3)
2. Dynamic Systems (DSC1)
3. Dynamics and Vibration (MEC2)
4. Electric/Magnetic/Optics (EMO)
5. Engineering Mathematics (MTH)[†]
6. Finite Element Method (MEC3)
7. Fluid Mechanics (TFS2) or Rheology (REO)
8. Heat Transfer (TFS3)
9. Mechanics of Deformable Media (MEC1)
10. Soft Materials (SM)
11. Thermodynamics (TFS1)</td></tr>
<tr><td>Materials</td><td>Materials Science Engineering (MSE)</td></tr>
<tr><td>Mechanics</td><td>Mechanics (MEC)</td></tr>
<tr><td>Mechatronics</td><td>Dynamic Systems and Control (DSC)</td></tr>
<tr><td>Thermofluids</td><td>Thermofluids Science (TFS)</td></tr>
</table>

<u>* List of Exams A</u>

- **Industrial Engineering (IND):** Probability and Probabilistic OR (IND1), Statistics (IND2), and Deterministic OR (IND3).
- **Materials Science Engineering (MSE):** Kinetics of Materials (MSE1), Thermodynamics of Materials (MSE2), and Diffusion, Soft Matter, and Mechanical Behavior (MSE3)
- **Mechanics (MEC):** Mechanics of Deformable Media (MEC1), Dynamics and Vibration (MEC2), and Finite Element Method (MEC3)
- **Dynamic Systems and Control (DSC):** Dynamic Systems (DSC1), Mechanical Vibrations (DSC2), and Control Systems (DSC3)
- **Thermofluids Science (TFS):** Thermodynamics (TFS1), Fluid Mechanics (TFS2), and Heat Transfer (TFS3), and Engineering Mathematics (TFS4) – *TFS area students should choose three out of the four from this list for Exam A.*

[†]Engineering Mathematics (MTH) is <u>REQUIRED</u> as EXAM B for all students taking Exam A in Mechanics (MEC) area.

EXAMS A & B:
TOPICAL COVERAGE AND DETAILS

Engineering Mathematics (MTH) – Exam B

MTH:

- Ordinary differential equations using exact methods, series and transforms.
- Partial differential equations using separation of variables (Fourier series, eigenfunction expansions) and transforms.
- Linear algebra matrices and linear equations, determinants, eigenvalue problems.
- Vector field theory including Cartesian, cylindrical and spherical coordinates, gradient, divergence and curl, and integral theorems (Divergence Theorem, Stokes' Theorem).

Suggested References for Preparation:

[1] Greenberg, M.D., Advanced Engineering Mathematics, 2nd Edition, *Prentice Hall*, 1998.

[2] Hildebrand and Francis, B., Advanced Calculus for Applications, 2nd Edition, *Prentice-Hall*, 1976.

[3] Kreyszig, E., Advanced Engineering Mathematics, 9th Edition, *John Wiley and Sons*, 2006.

[4] Churchill, R.V. and Brown, J.W, Fourier Series and Boundary Value Problems, 7th Edition, *McGraw-Hill*, 2008.

*****Previous Exam problems for MTH provided at the end of this document.***

Industrial Engineering (IND) – Exam A

IND1: Probability and Probabilistic OR (2.5 hours):

- Discrete and continuous random variables.
- Cumulative probability distributions and moment generating functions.
- Expectation of random variables.
- Discrete and continuous probability distributions including: binomial, Poisson, geometric, uniform, exponential and normal.
- Multivariable probability distributions, covariance and independence of random variables.
- Sampling distributions and limiting theorems.
- Stochastic Processes
- Poisson Process and Exponential Distribution
- Markov Chains (Discrete/Continuous time Markov Chain)
- Birth and Death process
- Queuing Theory

Suggested References for Preparation:

[1] Sheldon M. Ross, Introduction to Probability Models (10th edition or newer), *Elsevier*, 2010.

[2] Hillier, F. S. and Lieberman, G.J., Introduction to Operational Research, 9th Edition, *McGraw-Hill*, 2010.

[3] Ross, S. M., Stochastic Processes, 2nd Edition, *J. Wiley*, 1996.

[4] Walpole, Myers, and Myers, Probability and Statistics for Engineering and Scientists, 9th Edition, *Prentice Hall*, 2012.

IND2: Statistics (1.5 hours):

- Parameter estimation
- Confidence intervals and hypothesis testing
- Regression and ANOVA.
- Chi-squared and non-parametric tests.

Suggested References for Preparation:

[1] Montgomery, D. and Runger G., Statistics and Probability for Engineering.

[2] Walpole, Myers, and Myers, Probability and Statistics for Engineering and Scientists, 9th Edition, *Prentice Hall*, 2012.

[3] JayDevore, Probability and Statistics for Engineering and the Sciences, 8th Edition, Cengage Learning, 2010.

IND3: Deterministic OR (2 hours):

- Linear Programming (LP)
  - Formulation of LP models
  - Solution of LP models with the graphical method and the simplex algorithm
  - Theory of the simplex method
  - Duality theory and dual simplex algorithm
  - Sensitivity Analysis in LP
  - The Transportation Problem and the Hungarian algorithm
- Network Optimization Models
  - The Shortest Path Problem
  - The Minimum Spanning Tree Problem
  - The Maximum Flow Problem
  - The Minimum Cost Flow Problem
- Dynamic Programming (DP)
  - Discrete State DP problems
  - Continuous State DP problems

Suggested References for Preparation:

[1] Hillier, F. S. and Lieberman, G.J., Introduction to Operational Research, 9th Edition, *McGraw-Hill*, 2010.

[2] Winston, W.L., Operational Research, 4th Edition, *Duxbury Press*, 2004.

Exam B Listings for Industrial Engineering (IND) Area

Data Mining (DMN):

- Core concepts of data mining and predictive modeling
- Data visualization for exploration and decision making
- Dimension reduction and data curation
- Feature extraction and feature selection
- Evaluating predictive performance of machine learning models
- Multiple linear regression
- k-nearest neighbors for classification and regression
- Naïve Bayes classifier
- Classification and regression trees
- Logistic regression
- Neural networks (multilayer feed-forward neural networks)
- Support vector machine models
- Linear discriminant analysis
- Association rules and collaborative filtering
- Cluster analysis
- Time series analysis

Suggested References for Preparation:

[1] Galit Shmueli, Peter C. Bruce, Nitin R. Patel, (2016). Data Mining for Business Analytics: Concepts, Techniques, and Applications with XLMiner, Hoboken, NY: Wiley, 3rd Edition, 2016, ISBN-10: 1118729277, ISBN-13: 978-1118729274.

[2] Mohammed J. Zaki and Wagner Meira Jr. (2012). Data Mining and Analysis: Fundamental Concepts and Algorithms, Cambridge University Press, ISBN-10: 0521766338, ISBN-13: 978-0521766333

Human-Machine Systems (HMS):

- Sociotechnical Systems and Human Systems Engineering, Human Capabilities and Characteristics.
- Engineering Anthropometry and Biomechanics.

- Physiology related to Human Factors and Workstation Design.
- Taxonomy of Biosensors for various cues (psychological, physiological, physical), states and behaviors of humans.
- Basic principles of biosensors, current technologies for building biosensors.
- Cognition and Information Processing, Decision-Making, Attention and Workload.
- Human-Machine Interface Design, Controls and Displays.
- Safety Engineering, Human Error and Accident analysis.
- Human Factors in Transportation, Automation.
- Human-Robot Interaction and human friendly mechatronics.
- Human Factors in Healthcare and Patient Safety, Human Factors and Ergonomics in Manufacturing and Service Industries.
- Human Factors and Ergonomics (HFE) Program Design, Management, Implementation, and Training, Testing, Evaluation.

Suggested References for Preparation:

[1] Karl, K., et. al., Ergonomics: How to Design For Ease and Efficiency, Prentice Hall International Series in Industrial & Systems Engineering, 2nd Edition, *Prentice Hall*, 2001.

[2] Christopher, W., John D., Lee, Y.L. and Sallie G.B., An Introduction to Human Factors Engineering, 2nd Edition, *Pearson Prentice Hall*, 2003.

[3] Guang-Zhong , Y., Body Sensor Networks, *Springer*, 2006

Manufacturing Systems (MFS):

- Manufacturing operations
- Manufacturing metrics and economics
- Elements of manufacturing systems
- Single-station manufacturing cells
- Manual assembly lines
- Automated production lines
- Automated assembly systems
- Group Technology and cellular manufacturing
- Flexible Manufacturing cells and system
- Mechanical properties of materials

- Fundamentals of metal forming
- Bulk deformation processes in metalworking
- Theory of metal machining
- Cutting tool technology

Suggested References for Preparation:

[1] Mikell P. Groover, (2014). Automation, Production, Systems, and Computer- Integrated Manufacturing, 4rd Edition, Prentice Hall, ISBN-10: 0133499618, ISBN-13: 978-0133499612.

[2] Mikell P. Groover,(2012). Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, Wiley, 5th edition, ISBN-10: 1118231465, ISBN-13: 978-1118231463.

Network and Advanced Optimization (NAO):

- Geometry of Linear Programming
- Revised Simplex
- Duality
- Complementary Slackness
- Representation of Polyhedra
- Solving large scale optimization problems: Column Generation and Constraint Generation (Cutting plane methods)
- Network flows including: trees, assignment and transportation problems, max flow min cut, shortest paths, min cost flow, multi-commodity flow

Suggested References for Preparation:

[1] Introduction to Linear Optimization by D. Bertsimas and J.N. Tsitsiklis (Athena Press)

[2] Network Flows by R. Ahuja, J. Orlin, and T. Magnanti (Prentice Hall 1993).

Reliability and Quality Assurance (RQA):

- Quality planning, Control and Improvement.
- Process control, Discrete and Continuous Control Charts.
- Moving Average and Custom Control Charts.
- Tolerance Design and State Dependent Systems.

- Discrete and Variable Sampling Methods, Mil Standards.
- Process Capability Analysis.
- Quality Engineering Method of Robust Design.
- Mathematical Definitions of Reliability, Hazard Rate, Intensity Function, Failure Rate and Availability.
- Stress and Strength Analysis, Reliability Block Design, Fault Tree Method.
- Network Reliability Methods, Markovian Methods, Reliability Testing.
    - Reliability Estimates from Field and Test Data.
    - Confidence Interval on Reliability.
- Maintenance and Replacement Policies.

Suggested References for Preparation:

[1] Grant E. L. and Leavenworth R. S., Statistical Quality Control, 6th Ed, *McGraw-Hill,* 1988.

[2] Ebeling, Charles, Introduction to Reliability and maintainability Engineering, *Waveland Press*, 2010.

[3] E. E. Lewis, Introduction to reliability Engineering, 2nd Edition, *J. Wiley*, 1995.

[4] Chandra, J., Statistical Quality Control, 1st Edition, *CRC Press*, 2001.

[5] Montgomery, D., Introduction to Statistical Quality Control, 6th Edition, *Wiley*, 2011.

Supply Chain Engineering (SCE):

- Forecasting
- Aggregate planning
- Sequencing and Scheduling
- Inventory analysis and control
- Materials requirement planning
- Pricing and revenue management
- Manufacturing resource planning
- Project management
- Contracts decisions
- Transportation decisions
- Location and distribution decisions

- Supplier selection methods
- Global supply chains

Suggested References for Preparation:

[1] Chopra, S and Meindl, P., Supply Chain Management: Strategy, Planning and Operation, 6th Edition, *Prentice Hall*, 2016.

[2] Simchi-Levi, D., Kaminsky, P. and Simchi-Levi, E., Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies, 3rd Edition, *McGraw Hill-Irwin*, 2008.

Materials Science Engineering (MSE) – Exam A

MSE1: Kinetics of Materials:

- Diffusion and Brownian Motion
- Solidification
- Diffusional and diffusionless transformations in solids

MSE2: Thermodynamics of Materials:

- Three laws
- State functions
- Systems
- Phase equilibria and stability
- Behavior of Solutions
- Relations to phase diagrams
- Reactions among condensed phases and gases
- Statistical Thermo (entropy, heat capacity, etc.)

MSE3: Diffusion/Soft Matter/Mechanical Behavior:

- Molecular/colloidal forces
- Crystal structures
- Dislocation theory
- Mechanical Behavior and strengthening mechanisms
- Fatigue and fracture

Suggested References for Preparation:

[1] Wilkes, P., Solid State Theory in Metallurgy, *Cambridge University Press*.

[2] Blakemore, J.S., Solid State Physics, 2nd Edition, *Cambridge University Press*, 1987.

[3] Omar, M., Elementary Solid State Physics: Principles and Applications, 4th Edition, *Addison-Wesley*.

[4] Porter, D. A. and Easterling, K. E., Phase Transformations in Metals and Alloys, 2nd Edition, *Chapman & Hall*, London, 1992.

[5] Abbaschian, R. and Reed-Hill, R. E., Physical Metallurgy Principles, 3rd Edition, *PWS Publishing*, Boston, 1992.

[6] Gaskell, D.R., Introduction to the Thermodynamics of Materials, *Taylor & Francis*.

[7] Hull, D. and Bacon, D.J., Introduction to Dislocations, 4th Edition *Butterworth-Heinemann*, 2001.

[8] Callister, W.D., and Rethwisch, D.G., Fundamental of Materials Science and Engineering: An Integrated Approach, 4th Edition, *John Wiley & Sons, Inc.*, 2012.

[9] Berg, J.C., An Introduction to Interfaces & Colloids: The Bridge to Nanoscience, *World Scientific Publishing Company*, 2014.

[10] Rodriguez, F. et al., Principles of Polymer Systems, 6th Edition, *CRC Press*, 2014.

[11] Young, R.J. et. al., Introduction to Polymers, 3rd Edition, *CRC Press*, 2011.

Exam B Listings for Materials Science Engineering (MSE) Area

Soft Materials (SM):

- Kinetics of Molecules and Colloids (including drift, diffusion, etc.)
- Thermodynamics of Soft Interfaces (includes surface tension, adsorption, Laplace pressure, etc.)
- Polymers (processing, structure, properties, etc.)

Suggested References for Preparation:

[1] Rodriguez, F. et al., Principles of Polymer Systems, 6th Edition, *CRC Press*, 2014.

[2] Young, R.J. et. al., Introduction to Polymers, 3rd Edition, *CRC Press*, 2011.

[3] Flory, P.J., Principles of Polymer Chemistry, 1st Edition, *Cornell University Press.*

[4] Ward, I.M. et. al., Mechanical Properties of Solid Polymers, 3rd Edition, *Wiley*, 2012.

[5] Callister, W.D., and Rethwisch, D.G., Fundamental of Materials Science and Engineering: An Integrated Approach, 4th Edition, *John Wiley & Sons, Inc.*, 2012.

[6] Berg, J.C., An Introduction to Interfaces & Colloids: The Bridge to Nanoscience, *World Scientific Publishing Company*, 2014.

Electric/Magnetic/Optics (EMO):

- Electronic and Magnetic Materials
- Devices
- Functional Materials

Suggested References for Preparation:

[1] Kasap, S., Principles of Electronic Materials and Devices, 3rd Edition, McGraw-Hill Education, 2005.

[2] Hummel, R., Electronic Properties of Materials, 4th Edition, *Springer*, 2013.

Mechanics (MEC)

Engineering Mathematics (MTH) is <u>REQUIRED</u> for Exam B for ALL students taking the Exam A in Mechanics (MEC) area.

<u>MEC1: Mechanics of Deformable Bodies</u>:

- Basic concepts of stress and strain and stress-strain relations.
- Yield strength and elastic-perfectly-plastic material behavior.
- Transformation of stress, principal stresses in three dimensions, Mohr's circles.
- Boundary and continuity conditions for three-dimensional continua.
- Structural mechanics of bars, shafts, and beams under axial, torsional, and transverse loadings.
- Energy methods (including Castigliano's Second Theorem) and calculation of deflections (including shear deformation) of beams, frames, and rings for statically determinate and statically indeterminate loadings.
- Thin-walled pressure vessels.
- Stability of structures; buckling of columns and structures.

<u>MEC2: Dynamics and Vibration</u>:

- Basic concepts of rigid body kinematics and kinetics.
- Newton's Laws of Motion.
- Energy and momentum methods for particles and rigid bodies.
- Free and forced vibrations of single and multiple degree-of-freedom systems.
- Eigenvalue problems and modal expansions in vibration.
- Simple vibration of rods (longitudinal and torsional) and beams (bending).

<u>MEC3: Finite Element Method:</u>

- Weighted residual methods and identification of essential and natural boundary conditions.
- Implementation of variational methods, such as Rayleigh-Ritz, Galerkin to 1D boundary value problems.
- Derivation of interpolation functions and Cn continuity.
- Truss, beam, and 2D solid elements and element defects.

- Global stiffness matrix, assembly of element equations, numerical implementation of boundary conditions.
- Isoparametric elements and numerical integration.
- Solution of transient problems with implicit and explicit methods.
- Application of finite element method in heat transfer problems.

Suggested References for Preparation:

MEC1:

[1] Boresi, A.P. and Schmidt, R.J., Advanced Mechanics of Materials, 6th Edition, *John Wiley & Sons*, Inc., 2003.

[2] Cook, R.D. and Young, W.C., Advanced Mechanics of Materials, *Macmillan Publishing* Co., 1985.

[3] Shames I. H. and Cozzarelli, F. A., Elastic and Inelastic Stress Analysis, *Taylor & Francis*, 1997 (reprinted from Prentice-Hall, Inc., 1992).

MEC2:

[4] Meriam J. L. and Kraige, L. G., Engineering Mechanics: Dynamics, 6th Edition, *John Wiley & Sons*, 2007.

[5] Inman, D. J., Engineering Vibration, 2nd Edition, *Prentice Hall*, 2001.

MEC3:

[6] Cook, R. D., Malkus, D. S., Plesha, M. E. and Witt, R. J., Concepts and Applications of Finite Element Analysis, *John Wiley & Sons Inc.,* 2002.

[7] Reddy, J. N., An Introduction to the Finite Element Method, *McGraw Hill*, NY, 2006.

Dynamic Systems and Control (DSC)

DSC1: Dynamic Systems

- Dynamics of Mechanical Systems (Translational and Rotational)
- Electrical Circuits and Op-Amps
- Electromechanical Devices and DC Motors
- Thermal Systems Modeling
- Fluid and Level Systems Modeling
- Linearization Techniques
- Laplace Transforms and Application to Dynamic Systems Analysis
- 1^{st}-order and 2^{nd}-order Systems Response Characteristics: Time Constants; Natural Frequency, Damping Ratio, Damped Frequency; Impulse, Step and Ramp Responses; and Steady-state Error
- Approximating Higher-order Systems with equivalent 1^{st}- and 2^{nd}-order System with Dominant Modes

DSC2: Mechanical Vibrations

- Free and Forced Vibrations of Single Degree-Of-Freedom (SDOF) and Multiple Degree-Of-Freedom (MDOF) Systems
- Damped Vibrations
- General Eigenvalue Problem and Modal Analysis/Expansion in Vibrations
- Equations of Motion and Boundary Conditions for Transverse Vibrations of Strings; Longitudinal Vibrations of Bars; and Torsional Vibrations of Shafts
- Free and Forced Transverse (Bending) Vibrations of Euler-Bernoulli (Thin) Beams: Mode Shapes and Orthogonality Conditions

DSC3: Control Systems

- System Modeling Diagrams; Block Diagram Algebra and Reduction
- Effects of Poles/Zeros on System Response
- Routh' Stability Criterion
- The 3-term PID (Proportional, Derivative and Integral) Control Design and Analysis
- Root Locus Plot
- System Type and Analysis of Steady-state Error

- Design via Root Locus and Feedback Compensation Techniques
- Bode Plots
- Nyquist Plot and Nyquist Stability Criterion
- Gain and Phase Margins
- Design via Frequency Response (Lead and Lag Compensations).
- Standard Forms (Input/Output) and State Equations
- State-Space, Observability, Controllability, Control Canonical Form, Pole Placement, Ackerman Formula
- Introduction to Real-time Control Implementation

Suggested References for Preparation:

DSC1:

[1] Palm, W.J., System Dynamics, *McGraw Hill*, 2005.

[2] Close, Fredrick and Newell, Modeling and Analysis of Dynamic Systems, 3rd Edition, *John Wiley,* 2002.

[3] Ogata, K., System Dynamics, 3rd Edition, *Prentice Hall*, 1998.

[4] Kelly, S.G., System Dynamics and Response*, Thomson Publishing*, 2007.

DSC2:

[5] Meirovitch, L., Elements of Vibrations Analysis, 2nd Edition, *McGraw-Hill, Inc*., 1986.

[6] Balachandran, B. and Magrab, E.B., Vibrations, 2nd Edition, *Cengage Learning*, 2009.

[7] Tse, F., Morse, I.E., and Hinkle, R.T., Mechanical Vibrations, Theory and Applications, 2nd Edition, *Allyn and Bacon, Inc*., 1978.

[8] Thomson, W.T., and Dahleh, M., Theory of Vibration with Applications, 5th Edition, *Prentice Hall, Inc*., 1998.

[9] Rao, S.S., Mechanical Vibrations, 4th Edition, *Prentice Hall, Inc*., 2004.

[10] Inman, D.J., Engineering Vibration, 3rd Edition, *Prentice Hall, Inc*., 2008.

[12] Meirovitch, L., Principles and Techniques of Vibrations, *Prentice Hall, Inc*., 1997.

[13] Rao, S.S., Vibration of Continuous Systems, *John Wiley* (2007).

DSC3:

[17] Franklin, P. and Emami-Naeini, Feedback Control of Dynamic Systems, 6th Edition, *Pearson Publishing*, 2010.

[18] Dorf, R.C., Bishop, R.H., Modern Control Systems, *Prentice Hall*, 2000.

[19] Nise, N.S., Control System Engineering, 6th Edition, *John Wiley*, 2010.

[20] Ogata, K., Modern Control Engineering, 5th Edition, *Prentice Hall*, 2010.

[21] Palm, W.J., Modeling, Analysis and Control of Dynamic Systems, 2nd Edition, *John Wiley*, 1986.

Thermofluids Science (TFS)

TFS students should choose three (3) out of four (4) areas listed below for Exam A. *Note:* MTH cannot be taken as Exam B if TFS4 is chosen as a part of Exam A.

TFS1: Thermodynamics

- Thermodynamic properties, vapor dome, intensive, and extensive properties
- Conservation of mass (steady and transient)
- Steady and Transient First and Second law of thermodynamics
- Energy, entropy, exergy, and irreversibility
- Ideal gases, compressibility factor
- Work and heat interaction
- Thermodynamic analyses of systems and control volumes
- Heat engines
- Characteristic function
- Simple system
- Equation of state
- Conversion devices
- Power cycles
- Refrigeration and energy pump
- Dalton law and psychrometrics
- Chemical reaction and chemical equilibrium

TFS2: Fluid Mechanics

- Fluid Statics, forces and flat and curved surfaces
- Finite control volume analyses
    - Reynolds transport theorem; continuity
    - Momentum Principle; conservation of energy
    - Bernoulli equation
- Differential control volume analyses
    - Navier-Stokes equations; laminar flow analyses

- Internal and external flows, function, drag, and lift
- Boundary layer analyses; potential flow analyses
- Stream function, velocity potential function, vorticity, and circulation

- Similitude
  - PI theorem; non-dimensional parameters
  - Model flow vs. prototype flow
  - Non-dimensionalization of governing equations and boundary conditions

TFS3: Heat Transfer

- Conduction
  - Steady and transient heat transfer in multi-dimensional systems (development and solution of the heat equation)
  - Problems involving internal heat generation source
  - Extended surface problems, including fin efficiency
  - Extended surface problems with varying cross section area (Bessel function solutions)
  - Transient problems, lumped capacitance and multi-dimensional systems
- Convection
  - Definition of the heat transfer coefficient
  - Use of correlations
  - Hydrodynamic and thermal boundary layer
  - Use of the integral analysis to calculate the heat transfer coefficient
  - Natural convection, Grashof, and Rayleigh numbers
  - Application of the Navier-Stokes equations to the convection problem
- Radiation
  - Use of the Stefan-Boltzmann Law, Planck's distribution Law and black body emissivity functions
  - Emissivity, reflectivity and transmittance definitions and their use in spectral and gray surfaces
  - Kirchoff's Law and multi-band width problems
  - Definition and use of view factors
  - Solution of multi-surface problems
  - Combined modes of heat transfer problems

TFS4: Engineering Mathematics (MTH):

- Ordinary differential equations using exact methods, series and transforms.
- Partial differential equations using separation of variables (Fourier series, eigenfunction expansions) and transforms.
- Linear algebra matrices and linear equations, determinants, eigenvalue problems.
- Vector field theory including Cartesian, cylindrical and spherical coordinates, gradient, divergence and curl, and integral theorems (Divergence Theorem and Stokes' Theorem).

Suggested References for Preparation:

[1] Gaskell, D.R., Introduction to the Thermodynamics of Materials, 5th Edition, *Taylor & Francis*, Washington, DC, 2008.

[2] Lupis, C.H., Chemical Thermodynamics of Materials, *North-Holland*, New York, 1983.

[3] Moran, M.J. and Shapiro, H.N., Fundamentals of Engineering Thermodynamics, 3rd Edition, *Wiley*.

[4] Gyftopoulos, E.P. and Bretta, G.P., Thermodynamics Foundations and Applications, *Dover*.

[5] Shames, H., Mechanics of Fluids, 4th Edition, *McGraw-Hill*.

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Exam B Listings for Thermofluids Science (TFS) Area

Rheology (REO):

- Non-Newtonian vs Newtonian fluid mechanics
- Generalized Newtonian fluids
- Theory of viscoelasticity
- Material functions
- Experimental techniques
- Molecular models
- Polymer physics (e.g., melts/solutions, Rouse, Zimm, and Doi-Edwards)
- Suspensions and emulsions
- Active matter
- Bio-fluids
- Phase transitions: liquid vapor; solubility and phase separation; mean field theories, scaling
- Behavior, and Landau approach
- Rubber and gel elasticity
- Non-equilibrium dynamics: diffusion, Langevin equations, fluctuation dissipation relations