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


**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:


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:


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:


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:**


**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.

Suggested References for Preparation:

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:


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:


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.
  o Reliability Estimates from Field and Test Data.
  o Confidence Interval on Reliability.
• Maintenance and Replacement Policies.

Suggested References for Preparation:

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:


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:


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:**


**Electric/Magnetic/Optics (EMO):**

- Electronic and Magnetic Materials
- Devices
- Functional Materials

**Suggested References for Preparation:**

Mechanics (MEC)

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

MEC1: Mechanics of Deformable Bodies:

- 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.

MEC2: Dynamics and Vibration:

- 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).

MEC3: Finite Element Method:

- 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:

MEC2:

MEC3:
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:**


**DSC2:**


**DSC3:**


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

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

### TFS3: Heat Transfer

• Conduction
  o Steady and transient heat transfer in multi-dimensional systems (development and solution of the heat equation)
  o Problems involving internal heat generation source
  o Extended surface problems, including fin efficiency
  o Extended surface problems with varying cross section area (Bessel function solutions)
  o Transient problems, lumped capacitance and multi-dimensional systems

• Convection
  o Definition of the heat transfer coefficient
  o Use of correlations
  o Hydrodynamic and thermal boundary layer
  o Use of the integral analysis to calculate the heat transfer coefficient
  o Natural convection, Grashof, and Rayleigh numbers
  o Application of the Navier-Stokes equations to the convection problem

• Radiation
  o Use of the Stefan-Boltzmann Law, Planck's distribution Law and black body emissivity functions
  o Emissivity, reflectivity and transmittance definitions and their use in spectral and gray surfaces
  o Kirchoff's Law and multi-band width problems
  o Definition and use of view factors
  o Solution of multi-surface problems
  o 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:

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