



MASTER OF ENGINEERING
COURSE DESCRIPTIONS

CONTENTS

Civil Engineering.....	2
Electrical Engineering.....	6
Engineering Materials.....	12
Environmental Engineering.....	15
Industrial & Manufacturing Engineering.....	18
Mechanical Engineering.....	22

CIVIL ENGINEERING

Courses offered by Civil Engineering at the graduate level are listed below. Students may take courses other than Civil Engineering with permission of the Head of the Department and the advisor.

All courses listed will not necessarily be offered in any given year.

87-500. Theory of Elasticity and Plasticity

Analysis of stress and strain; elastic and plastic stress-strain relations; general equations of elasticity; yield criteria; applications to elastoplastic problems, including rotating disks, thick-walled tubes, reinforced disks, torsion of various shaped bars; stress concentration. (3 lecture hours a week.)

87-501. Finite Element Methods for Solids and Structures

Structural idealization; stress analysis of 2-D and 3-D solids; error estimation and mesh adaptivity; elastic formulations and uses of beam, plate and shell elements; nonlinear formulations; structural stability; introduction to finite element methods in structural design optimization. (3 lecture hours a week.)

87-502. Analysis and Design of Shell Structures

General theory of thin shells. Membrane stresses in shells of revolution and shells of double curvature. Bending stresses in shells of revolution, cylindrical shells and folded plates. Design of cylindrical shell roofs. (Prerequisite: 87-500 or equivalent.) (3 lecture hours a week.)

87-504. Theory of Plates

Small deflection of laterally loaded rectangular and circular, isotropic and orthotropic plates with various edge conditions, Navier and Levy solutions, energy methods, finite difference approximation, plates under combined action of lateral loading and forces in its plane, local buckling of column elements, buckling of plates under pure shear and under bending stresses, post-buckling strength in plates. (3 lecture hours a week.)

87-505. Theory of Stability

This course is designed to give an insight into the basic phenomenon of structural stability. Elastic and plastic flexural-buckling of columns with axial and eccentric loads is studied. Energy and numerical methods are used. Stability functions are introduced and used to study trusses and rectangular frames, with and without sidesway. Some discussion of torsional and torsional-flexural buckling, lateral buckling of beams. (3 lecture hours a week.)

87-506. Advanced Structural Steel Design

This course is designed to develop and expand the design concepts in steel structures; multiple-storey frames, sway and non-sway frame systems; beam-columns; laterally unbraced beams; local buckling of flanges and webs; plate girders; plastic analysis and

design; characteristics of light gauge steel components; design of cold-formed steel structures. (3 lecture hours a week.)

87-510. Reinforced Concrete Structures

Critical examination of design code requirements for: flexure, shear, bond, eccentrically loaded columns; yield line theory, strip method, and design of slabs. Design of hyperbolic paraboloid shells, domes, cylindrical tanks and rigid-frame structures. (3 lecture hours a week.)

87-511. Prestressed Concrete

Materials, principles of prestressing systems; prestressing losses; analytical treatment of the effect of shrinkage, creep of concrete, and cable friction on stresses; analysis and design of statically determinate and indeterminate structures; design codes; research background; introduction to prefabricated concrete structures. (3 lecture hours a week.)

87-512. Design, Deterioration, and Repair of Concrete

Cementing materials-basic constituents and manufacture; hydration of cement; physical properties of fresh and hardened paste; concrete mix design; properties of fresh and hardened concrete; deterioration processes affecting field concrete; inspection, assessment and remedial techniques of concrete and reinforced concrete structures. (3 lecture hours a week.)

87-513. Structural Dynamics

Formulation of equations of motion; single degree-of-freedom systems: free vibration response and response to harmonic, periodic, impulse, and general dynamic loading; analysis of non-linear structural response; multi degree-of-freedom systems: equations of motion, structural property matrices, undamped free vibration, Raleigh's method, forced vibration response, practical vibration analysis; continuous systems: partial differential equations of motion, analysis of undamped free vibration, analysis of dynamic response, wave propagation analysis. (3 lecture hours a week.)

87-514. Advanced Concrete Technology

Advanced composite materials - constituents and products; structural applications, reinforced concrete members, prestressed concrete members, applications with chopped fibres, repair and rehabilitation; innovative applications. (3 lecture hours a week.)

87-515. Earthquake-resistant Design of Buildings

Formulation of the equations of motion, free vibration response, and forced vibration response of SDOF, MDOF and continuous systems; approximate and numerical methods of analysis; wave propagation analysis. (3 lecture hours a week.)

87-516. Loads and Load Effects on Structures

Nature of loads; stress analysis of structures for volumetric deformations; modal analysis of structures; vibration-induced forces in structures; time-domain and frequency-domain analysis of structures; fatigue damage calculation of solids. (3 lecture hours a week.)

87-519. Advances in Soil Mechanics and Geotechnical Engineering

Consolidation and improvement methods; compressibility of soils and application of new modification techniques; frost action in soils; design of gravity, cantilever and mechanically stabilized retaining walls; recent advances in the bearing capacity of foundations on reinforced soils; pile foundations and pile groups; machine foundations on piles. (3 lecture hours a week.)

87-520. Multiphase, Multicomponent Flows

A thorough treatment of the basic techniques for analyzing one-dimensional multi-phase, multicomponent flows in order to predict flow regimes, pressure drop, etc. Practical applications in fluidization, sedimentation and boiling heat transfer. (3 lecture hours a week.)

87-521. Hydrology

Analysis and synthesis of the hydrograph. Streamflow routing. The hydrograph as a function of drainage characteristics; estimation of runoff from meteorological data. Snowmelt. Flow in rivers with an ice cover. Infiltration theory. Sea water intrusion in coastal aquifers. Application of hydrologic techniques including statistical methods. (3 lecture hours a week.)

87-522. River Mechanics

Theory and analysis of uniform, gradually varied, rapidly varied and steady and unsteady flow in open channels; fluvial processes; design of channels; design of hydraulic control structures. (3 lecture hours a week.)

87-523. Ground Water Contamination

Introduction of Darcy's equation and governing equation; construction of flownets, flow quantification, and ground water resource evaluation; contaminant hydrogeology, mass transport equations, reaction, and adsorption; introduction to biodegradation and natural attenuation; simulation of ground water flow and transport. (3 lecture hours a week.)

87-524. Advanced Hydromechanics

Properties of scalar and vector fields; gradient, divergence and curl. Flow visualization. Flow kinematics: continuity equation, potential flow, stream function. Flow dynamics: transport theorems, integral and differential equations of motion. Boundary-layer theory. Turbulent flow and turbulence models. (3 lecture hours a week.)

87-525. Hydraulic Analyses

This course deals with advanced methods of analyzing hydraulics and water resource systems. Exact and approximate methods are reviewed. The formulation and solution of problems by finite difference and finite element methods is a major part of the course. Typical examples from open channel and ground water flows are included. The method of characteristics is applied to transient flow in open channels and closed conduits. (3 lecture hours a week.)

87-526. Sediment Transport

Regime approach; turbulence theories; suspended sediment; tractive force method; bedforms and bedload transport; the Einstein method; modified Einstein method; reservoir siltation; recent developments; design of mobile bed channels; design of sedimentation basins; channel degradation. (3 lecture hours a week.)

87-527. Coastal Engineering

Introduction to linear and nonlinear wave theory. Wave transformation: shoaling, refraction, diffraction, reflection and breaking. Wave interaction with piles, walls and rubble mounds. Computation of forces and moments. Stability analysis. Wave generation and prediction. Computation of design water levels. Statistical nature of wind-generated waves in deep and shallow waters. Littoral zone processes. Computation of longshore transport. Effect of shore structures on littoral processes. Design of shore protections. Design of small harbours. This course involves the use of microcomputers and physical models. (3 lecture hours a week.)

87-590. Special Topics In Civil Engineering

Selected advanced topics in the field of civil engineering. (3 lecture hours a week.)

87-796. Major Paper

87-797. Thesis

87-798. Dissertation

ELECTRICAL ENGINEERING: COURSE DESCRIPTIONS

The graduate course offerings in Electrical Engineering are designed to complement the areas of specialization. Course requirements for the Ph.D., M.A.Sc., and M.Eng. degrees in Electrical Engineering will be selected from the courses listed below and related courses in other programs.

Graduate students will be associated with one of the areas of research. Their program of studies will be formulated in consultation with the graduate advisors and approved by the Chair of the Program Graduate Committee coordinator.

Only a selected number of the courses listed below will be available each year. The current list will be provided by the Coordinator of Graduate Studies in Electrical Engineering.

Graduate standing is required for all graduate courses in the Department of Electrical and Computer Engineering.

88-514. Advanced Power Systems

Synchronous machine models are developed from the voltage and flux linkage differential equations. Applying the developed models, numerical simulations are performed to determine the dynamic performances of synchronous machines. (3 lecture hours per week.)

88-521. Digital Signal Processing

Discrete Signals, z-transforms, Time Domain and Frequency Domain Analysis of Digital Filters, Design and Realization of FIR and IIR filters, DFT and FFT, Stability and Stabilization of IIR Filters, Discrete Hilbert Transform, Sectioned and Fast Convolution. (3 lecture hours a week.)

88-522. Applied Time Signals Analysis and Processing

Continuous and discrete signals; sampling theory and practice; filtering, interpolation, coding, statistical concepts, transform methods; power density estimation, correlation functions, convolution. (3 lecture hours a week.)

88-523. System Theory

Continuous and discrete time systems, state formulation techniques, controllability and observability concepts, and system simulation. (3 lecture hours a week.)

88-524. Stochastic Processes

Development and applications of probability models in the analysis of stochastic systems; review of probability, random variables and stochastic processes; correlation functions applications to filtering, prediction, estimation and system identification. (3 lecture hours a week.)

88-525. 2-Dimensional Digital Signal Processing

Fundamentals of 2-D Signals and Transforms; Z, Fourier, discrete Fourier, etc., 2-D FFT, Design Techniques for 2-D FIR and IIR Digital Filters using Transformation and Optimization Techniques. Stability and Stabilization of 2-D Filters, Homomorphic Filtering, Reconstruction of Signals from their Projections. (3 lecture hours a week.)

88-527. Speech Processing

Production, perception, and acoustic-phonetic characteristics of speech signal; auditory models; linear prediction of speech; cepstral analysis; speech recognition; speech synthesis; spoken language processing; human-computer communications. (3 lecture hours a week.)

88-528. Image Processing

This course presents digital and hybrid representation of images, fundamentals of colour, 2-D systems, 2-D filter design and 2-D filtering of digital images, image enhancement techniques: homomorphic filtering, histogram equalization and modification techniques, median and statistical filtering, 2-D FFT algorithms, properties of digital images. Projects are given as a means of learning practical applications of the field. (3 lecture hours per week.)

88-529. Discrete Transforms and Number Theoretical Methods

Introduction to orthogonal transforms, DFT, DCT, DHT; implementation methods; fast algorithms, FFT, WFT; polynomial transforms; finite rings and fields; number theoretic techniques; residue number systems; conversion and computation; finite polynomial rings; VLSI implementation consideration. (3 lecture hours a week.)

88-531. VLSI Design

Overview of VLSI designs, CAD tools, application, technology; review of properties of silicon, solid state physics and devices; SPICE models; analog simulation; IC technology; target CMOS process; static CMOS logic; principles of standard cell CMOS design; dynamic characteristics of static CMOS logic; dynamic logic; system level considerations; hardware description languages; silicone compilers. (3 lecture hours a week.)

88-533. Computational Intelligence

Models of the human brain and sensory systems. Neural networks and learning algorithms. Fuzzy sets, fuzzy logic, and fuzzy systems. Evolutionary computation. Advanced topics in computational intelligence. (3 lecture hours a week.)

88-535. Nonlinear Systems

Introduction to the analysis and design of nonlinear control systems, mathematical preliminaries, second-order systems (including Lyapunov stability, center manifold theorem, input-output-stability) perturbation theory; control design for non-linear systems. (Prerequisite: For Electrical Students 88-324; For Mechanical Students 92-412.) (3 lecture hours a week.)

88-536. Automotive Control Systems

Introduction to automotive control systems; engine operation and dynamics; engine management and control; robust engine control; hybrid powertrain modelling and control; estimation of vehicle parameters and models; vehicle control system; automotive electronics. (Prerequisite: For Electrical Students 88-324; For Mechanical Students 92-412.) (Crosslisted with 92-545.) (3 lecture hours a week.)

88-541. Low Power CMOS Design

This course is designed to prepare students for advanced VLSI design where low power dissipation is of critical concern. Topics will include: Introduction to low power techniques for CMOS circuit design; design levels of abstraction; sources of power dissipation, capacitance analysis, and power estimation; simulation-based and probability-based power estimation; low-level and high-level power optimization; advanced techniques for modern IC fabrication, and low power design tools from an industrial perspective; recent advances in low power CMOS design (Prerequisites: 88-217 and 88-316.) (3 lecture hours per week plus project.)

88-550. Adaptive Signal Processing

This course presents topics on optimum linear filtering (Wiener filter, linear prediction, and Kalman filtering), constrained linear estimation, Newton's method, steepest-descent method, stochastic-gradient algorithms: least-mean-squares (LMS) algorithms, affine projection algorithms (APA), recursive least-squares (RLS) algorithms. Comparative performance analysis of adaptive filters: steady state error, tracking error, convergence rate; finite precision effects. The students are introduced to applications on adaptive noise cancellation, interference canceling, and system identification. (3 lecture hours a week.) (Prerequisite: 88-524 or equivalent.)

88-551. Advanced Digital Signal Processing

Review of discrete-time systems and digital filters. Multirate systems including decimators, interpolators, polyphase decomposition, Nyquist filters, two-channel, and M-channel filter banks. Adaptive equalization including equalization techniques for digital receivers, linear and non-linear equalizers, adaptive algorithms, and blind equalization. Analysis of finite wordlength effects including coefficient quantization, arithmetic round-off errors, dynamic range scaling, and low-sensitivity digital filter structures. (3 lecture hours a week.) (Prerequisites: 88-524 or equivalent, 88-521 or equivalent, or permission of the instructor.)

88-552. Advanced Topics in Microelectromechanical Systems (MEMS)

Review of advanced topics related to the theory and modeling of MEMS design and fabrication techniques. Topics to be covered include: advanced micromachining techniques, smart microelectromechanical sensing and actuation techniques, microfluidics, photonic MEMS, advanced materials, device modeling, MEMS design case studies, system integration, micropackaging, MEMS design methodology, and reliability issues related to MEMS devices. Emphasis is on theory, lumped element modeling, 3-D multi-domain finite element analysis, static and dynamic device behavior study using industry standard MEMS modeling tools, simulation of fabrication processes using actual fabrication process parameters, and design verification. (3 lecture hours a week.)

88-553. Analysis of Electrical Machines

This course is concerned with understanding and modeling of induction, reluctance and permanent magnet synchronous generators used in wind power application. In addition, numerical analysis and a review of the basic characteristics used in wind power application. In addition, numerical analysis and a review of the basic characteristics of the above-mentioned electrical machines will be performed. (3 lecture hours a week.) (Prerequisite: 88-313 or permission of the instructor.)

88-554. Automotive Sensor Systems

This course describes topics on sensors, optics & lighting, image representation, feature extraction, image analysis, image classification, 3D imaging techniques, GPS, radar, lidar 3D range imaging, intelligent and night vision, sensor integration and fusion. The students will apply their theoretical knowledge to solve a practical problem by completing a course mini-project. (3 lecture hours a week.)

88-555. Computer Arithmetic

This course presents a detailed description of general class of fixed-radix number systems, floating-point representation, algorithms and architectures for sequential and fast computation of multiplication, division and square root extraction, elementary functions, logarithmic and residue number systems, finite field arithmetic operations, error control in arithmetic processors. Course assignments and mini-projects on practical aspects of the course are required. (3 lecture hours a week.)

88-556. Computer Networks

This course will cover concepts and protocols which enable heterogeneous computer networks to work with each other, including transport (TCP, UDP), network (IP, IPng), routing (RIP, OSPF), network management (SNMP, SNMPv2, RMON), and other important protocols like ARP, ICMP, DNS, BOOTP, DHCP and HTTP. Advanced topics like Mobile IP, real-time and reservation protocols (RTP, RSVP), IP multicast (IGMP, MBONE) and network security will also be examined. Emphasis will be on broad coverage, as well as hands-on programming experiences. Local area networks, performance of queueing, multiple access schemes, IEEE802 standards, wireless LANs and wireless personal area networks will also be covered. (3 lecture hours a week.)

88-557. Multiuser Detection

This course presents an introduction to multiple-access communication systems: time-division multiple access (TDMA), frequency-division multiple access (FDMA), and code-division multiple access (CDMA); linear receivers for synchronous and asynchronous CDMA systems, blind multiuser detection (direct methods and subspace methods), linear decorrelating and minimum mean-square-error (MMSE) detectors, group-blind multiuser detection in multipath channels, adaptive multiuser detection, space-time multiuser detection, and turbo multiuser detection. Practical applications are demonstrated through course assignments. (3 lecture hours a week.) (Prerequisites: 88-524 or equivalent.)

88-558. Network Security

The course presents a concise discussion on the discipline of cryptography- covering algorithms and protocols underlying network security applications, encryption, hash functions, digital signatures, and key exchange. Internet security vulnerabilities, firewalls and their limitations, cryptographic technology and services, PPP and data layer security, IPsec and key management for network layer security, TLS, SSH and transport layer security, secure e-mail, secure infrastructure protocols, Kerberos authentication, secure RPC, remote authentication, authorization and tunneling protocols, virtual private networks, secure remote access, multicast security are covered. Practical applications are covered through assignments. (3 lecture hours a week.)

88-559. Physical Design Automation for VLSI and FPGAs

Introduction to backend CAD flow for VLSI and FPGAs; algorithms and CAD tools for technology mapping, floor planning, partitioning, placement and routing; exposure to timing analysis and timing-driven layout; assignments will involve use of academic and/or industrial CAD tools as well as development of simple CAD tools for specific layout tasks. (3 lecture hours a week.) (Prerequisites: consent of the instructor.)

88-560. Reconfigurable Computing

History and evolution of reconfigurable computing (RC) systems; FPGA-based and multi-FPGA systems, CAD mapping tools, run-time reconfiguration, study of recent RC systems from academia and industry targeting a wide range of applications. Literature review and paper presentation on specific topics is also required. The course may require a mix of project and assignments. (3 lecture hours a week.) (Prerequisite: consent of the instructor.)

88-561. Statistical Communication Theory

This course describes the fundamentals of Statistical Communications in detail. The topics covered include: hypothesis testing, Bayes and the Neyman-Pearson criteria, minimum variance unbiased estimation, Cramer-Rao bound, sufficient statistics, maximum likelihood estimation, minimum MSE and maximum a posteriori estimation, linear MMSE estimation, detection of signals in white/colored noise, detection of signals with unknown parameters, composite hypothesis testing, generalized likelihood ratio test, sequential detection, and Wald's test. Applications of digital communications, radar/sonar

signal processing, seismology, and biomedical engineering are discussed. (3 lecture hours a week.) (Prerequisites: 88-419 or equivalent, and 88-524 or equivalent.)

88-562. VLSI Implementation of Digital Signal Processing Systems

The course provides a concise discussion on the various aspects of implementations for DSP algorithms. The course begins with an overview of DSP algorithms. Topics discussed are: implementation platforms, pipelining and parallel processing, systolic architecture, finite wordlength effects in digital filters, pipelined and parallel filters and adaptive filters, and bit-level arithmetic architectures. (3 lecture hours a week.) (Prerequisite: 88-521 or equivalent.)

88-563. Wireless Communication Systems

Overview of mobile communications, the characterization and modeling of time-variant fading and/or dispersive channels, digital communication system performance over fading dispersive channels, diversity reception, optimum receiver, trellis-coded modulation, (fundamentals, performance evaluation and applications to mobile communications), spread spectrum systems, and code division multiple access (CDMA), TDMA, FDMA, multiple access schemes, CSMA, Aloha. Concepts on wireless ad hoc networks will also be introduced, MAC, routing, QoS protocols for these networks will be covered. (3 lecture hours a week.) (Prerequisite: 88-419 or equivalent.)

88-590. Special Topics

Selected advanced topics in a field of research in the Electrical Engineering. (May be repeated more than once for credit if the topics are different.) (3 lecture hours a week.)

88-797. Thesis

88-798. Dissertation

ENGINEERING MATERIALS: COURSE DESCRIPTIONS

Course requirements for the Ph.D. and M.A.Sc. programs in Engineering Materials will be selected from the courses listed below and related courses in other programs. A student's course program will be formulated in consultation with the Graduate Studies Committee for Engineering Materials and requires approval of the research advisor and Chair of the Program Graduate Committee. Students will take no more than 2 of the 4 required courses from their supervisor(s).

All courses listed will not necessarily be offered in any given year.

89-501. Advanced Crystallography

Application of X-ray diffraction principles to the study of materials, application of Fourier series, single crystal techniques, studies of preferred orientation, imperfections. (3 lecture hours a week.)

89-502. Phase Transformations

Phenomenological treatment of transformation processes; diffusion controlled and diffusionless (martensitic) transformations; application of thermodynamic and phenomenological rate laws to transformations: nucleation, recrystallization, precipitation, spinoidal decomposition, ordering, eutectoid decomposition, etc. (3 lecture hours a week.)

89-505. Strengthening Mechanisms in Materials

Dislocation-particle interactions, strengthening by dislocation substructures, particle and fiber reinforcement, strong microstructures from the melt, strong microstructures from the solid. (3 lecture hours a week.)

89-506. Microscopy of Materials

The theoretical and technical aspects of the study of microstructure and composition of materials, optical microscopy, electron microscopy (scanning and transmission) including electron diffraction and image analysis principles, electron microanalysis, x-ray topography, field-ion microscopy, relationship of observed microstructures to the macroscopic properties of materials. (2 lecture, 2 laboratory hours a week.)

89-507. Fracture Mechanics

The fracture mechanics approach to design; physical significance of fracture toughness; measurement of fracture mechanics parameters; non-destructive inspection techniques; principles of fracture-safe design; the relation between the microscopic and macroscopic aspects of plane-strain fracture; fracture of specific metallic and nonmetallic materials. (3 lecture hours a week.)

89-510. Solidification Fundamentals

Fundamental principles of solidification theory including thermodynamics, kinetics, solid-liquid interface morphology and growth mechanics. Solidification mechanisms of

pure metals. Heat flow phenomena in casting and crystal growth. Effect on solidification heat transfer of process variables, casting and mold properties, metal and mold temperatures. Students will apply the fundamentals of thermodynamics and kinetics to materials processes such as casting and welding. (3 lecture hours a week.)

89-511. Casting: Modeling and Simulation

Review of casting fundamentals. Techniques for mathematical model formulation. Development of general numerical method based on control volume finite difference scheme to predict mold filling, heat transfer, and solidification phenomena. Treatment of gates, runners, risers, and overflow. Mesh generation for full casting. Applications using commercial casting-simulation software. Students will apply their knowledge of engineering mathematics and transport phenomena to the processes of manufacturing light weight automotive components. (3 lecture hours a week.)

89-512. Metal Casting Technology

Introduction and historical overview of casting. Casting processes, mould design and materials, metallurgical simulation. Metallurgical considerations, liquid metal treatment, heat treatment, casting defects and their prevention. Discussion of challenges faced by today's foundries. (3 lecture hours a week.)

89-513. Tribology: Materials and Manufacturing Aspects

This course will prepare students to perform experimental and analytical work on the materials and manufacturing aspects of tribology. Fundamental equations of wear, wear testing methods; micromechanisms of wear, modeling of surface contacts, frictional heating during sliding contact; tribology of internal combustion engines, friction and wear during machining operations; wear control via surface coatings, coatings for cutting tools. (3 lecture hours a week.)

89-590. Special Topics in Materials

Selected advanced topics in the fields of engineered materials and materials Engineering. (3 lecture hours a week.)

Current topics include:

- Creep of Metals and Alloys
- Microscopy of Materials II
- Wear of Materials
- Composite Materials
- Fatigue of Metals and Alloys
- Polymers
- Ceramics
- Welding
- Materials Degradation
- Polymer Injection Molding
- Thin Films and Coatings
- Computational Contact Mechanics in Tribology

89-797. Thesis

89-798. Dissertation

ENVIRONMENTAL ENGINEERING

Courses offered by Environmental Engineering at the graduate level are listed below. Students may take courses other than Environmental Engineering with permission of the Head of the Department and the advisor.

All courses listed will not necessarily be offered in any given year.

93-530. Water Pollution Control

Water quality criteria; methods of wastewater disposal and their effects on ecology; theory and design of different unit operations and processes for water purification; theory and design of different design operations and processes of wastewater treatment; reuse and recycling of wastewater. (3 lecture hours a week.)

93-531. Advanced Water Pollution Control

Discussion on recent advances in the design of water and wastewater treatment plants and new developments in water pollution control practices. (Prerequisite: 93-530 or equivalent.) (3 lecture hours a week.)

93-533. Solid Waste Management

A study of municipal and industrial solid wastes, quantities, composition, methods of disposal or reclamation; economic viability of the various methods related to the quantities involved. (3 lecture hours a week.)

93-534. Environmental Separation Processes

Application of the principles of surface chemistry to separation processes involving phase equilibria, ion exchange, membrane separation, adsorption, absorption, flocculation, spherical agglomeration, sedimentation, filtration, and centrifugation. (3 lecture hours a week.)

93-535. Water Quality Management

Water quality criteria; methods of wastewater disposal and their effects on ecology; stoichiometry, reaction kinetics and material balance; movement of contaminants in water bodies; modelling of water quality in natural systems. (3 lecture hours a week.)

93-536. Environmental Engineering Thermodynamics

An advanced study of the application of classical thermodynamic principles to environmental engineering practice; flow systems; composition relationships between equilibrium phases; systems involving surface effects, electric or magnetic fields. (3 lecture hours a week.)

93-537. Kinetics

Basic concepts of chemical reaction kinetics; characterization of chemical and biochemical systems; reactor flow models and consideration of non-ideality. (3 lecture hours a week.)

93-538. Biological Treatment of Wastewater

Wastewater characteristics; biological kinetics; flow and loading variation; wastewater treatment processes; mass balances; aeration; sedimentation; lagoons; fixed-film processes; sludge characteristics. (3 lecture hours a week.)

93-539. Industrial Wastewater Treatment

Sources and characteristics of industrial wastewater; pretreatment and primary treatment; physical and chemical treatment; biological treatment; waste minimization; treatment of wastes from various industries. (3 lecture hours a week.)

93-540. Numerical Modeling of Heat and Mass Transfer and Flow in Porous Media

Introduction to finite difference and finite element approaches for simulation of the diffusion and the advection-dispersion equations; development of finite difference formulation of 1-D and 2-D transient heat transfer, nonlinear conductance and source/sinks; 1-D and 2-D mass transport with reaction; 1-D and 2-D heat transfer with finite element approach. (3 lecture hours a week.)

93-541. Air Pollution from Mobile Sources

Air pollutants; emissions from vehicles; testing vehicles for emissions; combustion thermodynamics; thermodynamics and kinetics of pollutant formation; measures to reduce emissions; modeling. (3 lecture hours a week.)

93-542. Air Pollution Modelling

Air quality standards; emission inventory, source estimation; development of transport models; models with chemical reactions. (3 lecture hours a week.)

93-550. Sustainability: Principles and Practices

This course examines the evaluation, design, and management of products, processes, or projects to achieve sustainability. The main topics include: assessing and scoping environmental effects from engineering and other technical activities; eco-balance approaches; life cycle assessment; design-for-environment principles; and decision making for environmental and sustainability objectives. The course will discuss typical examples (e.g., automobiles, infrastructure, electronics), and also draw upon the industrial and research experience and knowledge of the class attendees. Class-based projects will focus on understanding, interpreting, and implementing the knowledge acquired. (Not open to students who attended 93-532, Engineering and the Environment, since 2002.) (3 lecture hours per week.)

93-590. Special Topics In Environmental Engineering

Selected advanced topics in the field of environmental engineering. (3 hours a week.)

Current topics include:

Air Pollution Control;

Transport Phenomena;

Environmental Law and Policy

Atmospheric Chemistry and Physics of Air Pollution.

93-796. Major Paper

93-797. Thesis

93-798. Dissertation

INDUSTRIAL AND MANUFACTURING SYSTEMS ENGINEERING: COURSE DESCRIPTIONS

Courses offered by Industrial and Manufacturing Systems Engineering at the graduate level are listed below. Students may take courses from outside Industrial and Manufacturing Systems Engineering with permission of the Chair of the Program Graduate Committee and the advisor.

All courses listed will not necessarily be offered in any given year.

91-500. Optimization

Classical theory of optimization. Kuhn-Tucker conditions. Unconstrained optimization; gradient methods, conjugate gradient methods, variable metric methods, search techniques. Constrained optimization. Approximation methods, projection methods, reduced gradient methods; penalty function methods; computational algorithms. Recent advances in optimization. Use of computer software packages. (Prerequisite: 91-312 or equivalent.) (3 lecture hours a week.)

91-501. Industrial Experimentation and Applied Statistics

Distributions of functions of variables, estimations and tests of hypotheses, power of tests, non-parametric tests, sampling techniques, analysis of variance, randomized blocks. Latin squares and factorial experiments. (Prerequisite: 91-227 or equivalent.) (3 lecture hours a week.)

91-502. Manufacturing Systems Simulation

Discrete-event system simulation. Random number generation. Stochastic variate generation. Input parameters; identification and estimation. Output analysis. Static and dynamic output analysis; initial and final conditions; measures of performance and their variance estimation; confidence interval. Design of experiments. Various sampling techniques. Single and multifactor designs. Fractional designs. Response surfaces. Regeneration method for simulation analysis; Monte Carlo optimization. (3 lecture hours a week.)

91-503. Production and Inventory Control Systems

Analysis of production-inventory systems. Inventory systems; deterministic, single-item and multi-item models; quantity discounts; stochastic, single-period models; periodic review and continuous review models. Production planning. Static demand models; product mix and process selection problems; multi-stage planning problems. Dynamic demand models; multi product and multistage models. Operations scheduling; job shop scheduling; line balancing. New directions in production systems research. (Prerequisite: 91-413 or equivalent.) (3 lecture hours a week.)

91-504. Advanced Operations Research I

Theory and computational techniques for solving linear and integer programming problems. Theoretical foundations of the simplex algorithm. Duality and sensitivity analysis. Network flow methods. Integer programming problems. Branch and bound

methods, implicit enumeration methods, cutting plane methods. Interior point methods and other recent developments. (Prerequisite: 91-312 or equivalent.) (3 lecture hours a week.)

91-505. Advanced Operations Research II

Probabilistic O.R. models. Markovian decision process. Queueing theory. Single channel and multichannel queueing systems. Queues with general arrival and service patterns. Bulk queues and priority queues. Applications of queueing models. Probabilistic dynamic programming. (Prerequisite: 91-412 or equivalent.) (3 lecture hours a week.)

91-507. Advances in Industrial Ergonomics

Ergonomics and work design; human workload measurement in industry; visual display terminals at the workplace; signal detection and visual inspection; user-computer interaction; human factors aspects of flexible manufacturing systems; effects of individual and combined environmental stressors on human performance. (Prerequisite: 91-415 or equivalent.) (3 lecture hours a week.)

91-508. Reliability Engineering

Basic reliability distributions. Constant failure rate models-exponential reliability function, Poisson process. Time dependent failure models-the Weibull, normal, log-normal distributions. State-dependent systems-Markov analysis. System reliability-system structure function. Reliability growth testing-non-parametric methods, censored testing and accelerated life-testing. Design for reliability-specification, reliability allocation, failure analysis, system safety. Maintainability and availability. (Prerequisite: 91-327 or equivalent.) (3 lecture hours a week.)

91-509. Computer-Integrated Manufacturing

Development of CIM; the CIM pyramid-key functions. System integration; standards for communications-MAP. Data base as the hub of CIM-types of data base. Role of simulation and support systems-decision support systems and expert systems. Sensor technology, robot vision, and group technology. Impact of CIM. Factory of the future. (Prerequisite: 91-411 or equivalent.) (3 lecture hours a week.)

91-510. Advanced Engineering Economy

Principles and methods for engineering analysis of industrial projects and operations. Criteria for economic decisions, project investment analysis, gain and loss estimating and techniques for economic optimization under constraint are included. Emphasis is placed on the construction and use of analytical models in the solution of engineering economy problems. Elements of risk and uncertainty are included through use of probabilistic techniques. (Prerequisite: 85-313 or equivalent.) (3 lecture hours a week.)

91-511. Stochastic Processes

Stochastic processes. The Poisson process-relationship to exponential, Erlang and uniform probability distributions. Markov chains-basic limit theorem. Continuous time Markov chains - birth-and-death processes, time-dependent probabilities, limiting probabilities, relationship to the exponential distribution, uniformization. Renewal

theory-limit theorems, renewal reward processes, regenerative processes, computing the renewal function. Brownian motion and stationary processes. (Prerequisite: Statistics 91-412 or equivalent.) (3 lecture hours a week.)

91-512. Manufacturing Systems Paradigms

Manufacturing systems paradigms (including DML, Batch, Cells, FMS & RMS), components, characteristics, automation, operation, planning and control. Changeability and mass customization. Integrated products/systems design, process planning, GT & CIM. Special topics: Assembly, Robotics, Inspection, Quality and Cost. (Prerequisite: 91-413, or equivalent / permission of instructor). (3 lecture hours a week.)

91-513. Advanced Manufacturing Technology

Developments in nontraditional methods in EDM and ECM. Trends in automation. Recent developments in manufacturing processes; micromanufacturing-integrated circuits and laser machining. Advances in computer technology, CAD and CAM. Kinematics of manipulation robots, artificial intelligence, monitoring and vision systems. (Prerequisite: 91-321 or equivalent.) (3 lecture hours a week.)

91-514. Engineering Design, Methodology & Applications

Engineering Design is a creative, iterative and often open-ended process subject to constraints. Topics include: design creativity & problem solving, engineering conceptual design & embodiment design, practices for product realization design theories and methodologies, parametric design, probabilistic design, industrial design, design and manufacturing integration, concurrent Engineering, materials selection in design, design for x (e.g. manufacturing, assembly), engineering design communication. Significant time is devoted to the applications of design theories and methodologies and to a product/process design realization. (3 lecture hours a week.)

91-515. Artificial Intelligence Applications in Manufacturing

The objective of this course is to teach graduate students how artificial intelligence techniques can be applied to manufacturing operations. Detailed topics to be discussed in this course include: basic knowledge representation methods and problem solving techniques; different search algorithms; introduction to AI high level languages; introduction to the CLIPS shell; AI application in Design; AI application in Operation Management; AI application in Diagnosis; and, AI application in Control. (Prerequisite: 91-503 or 91-504 or equivalent.) (3 lecture hours a week.)

91-516. Computer-Aided Design (CAD)

This course will focus on computer-aided methods and applications. The lectures present basic and generic principles and tools, supplemented with significant hands-on practice and engineering applications. Various topics are studied and practiced using CAD/CAE software, such as Engineering design and the role of CAD, geometric modelling systems, representation of curves and surfaces, surface modelling, solid modelling and applications, parametric representations, assembly modelling, computer-aided engineering (CAE) and applications, distributed collaborative design, and digital mock-

up. (Prerequisite: 91-411 or equivalent.) (2 lecture hours a week and 2 laboratory hours a week.)

91-590. Special Topics

Selected advanced topics in the field of Industrial Engineering. (3 lecture hours a week.)

Current topics include:

Sustainable Manufacturing
Industrial Control & Robotics
Management of Technology
Product Innovation & Design Management
Recent Advances in Industrial Ergonomics
Computer-Aided Modeling of Complex Surfaces
Lean Manufacturing & Supply Chain Management
Automotive Assembly Work Measurement
Manufacturing Systems: Modelling, Analysis and Performance Measures.

91-595. Graduate Seminar

Presentations by graduate students, staff, and visiting scientists on current research topics. Graduate students are required to register and give a presentation in the semester prior to thesis defence. All graduate students are expected to attend each and every seminar and no less than 75% of all seminars. This course will be graded on a Pass/Fail basis. (1 lecture hour a week.)

91-796. Major Paper

91-797. Thesis

91-798. Dissertation

MECHANICAL ENGINEERING: COURSE DESCRIPTIONS

Course requirements for the Ph.D., M.A.Sc. and M.Eng. programs in Mechanical Engineering will be selected from the courses listed below and related courses in other programs. A student's course program will be formulated in consultation with the advisor and requires approval of the Graduate Studies Committee for Mechanical Engineering and the Chair of the Program Graduate Committee.

With the permission of the advisor and Department Head (and under consultation with the Graduate Coordinator), Mechanical Engineering courses with numbers greater than 449 only and related to the graduate field of study may be taken for graduate credit for students enrolled in the M.A.Sc. and M.Eng. programs. Not more than one undergraduate course (numbered greater than 449 only) shall count as credit towards the course requirements for the M.A.Sc. or M.Eng. degree. These courses are not available for course credit towards the Ph.D. degree.

In the case of M.Eng. students, the Chair of the Graduate Committee assumes the role of the advisor.

92-503. Turbulent Flow

General turbulence theories, wall turbulence and free turbulence. (3 lecture hours a week.)

92-506. Thermal Systems Design

Advanced systems design requiring the application of economics, heat transfer, simulation and optimization. (3 lecture hours a week.)

92-507. Experimental Techniques in Flow Measurements

A course covering the theory of flow and velocity measurement. Emphasis will be placed on hot wire instruments and turbulence measurements. (3 lecture hours a week.)

92-509. Multiphase, Multicomponent Flows

A thorough treatment of the basic techniques for analyzing one-dimensional multi-phase, multicomponent flows in order to predict flow regimes, pressure drop, etc. Practical applications in fluidization, sedimentation and boiling heat transfer. (3 lecture hours a week.)

92-516. Industrial and Motor Vehicle Noise

Hearing damage risk criteria and in-plant noise regulations; determination of permissible exposure levels due to continuous and intermittent noise. Measurement of machine noise and standard procedures. Fundamentals of noise control. Characteristics and levels of motor vehicle and traffic noise; motor vehicle noise control legislation and standard procedures for measurement. (3 lecture hours a week.)

92-517. Automotive Applications for Noise, Vibration and Harshness Evaluation

This course introduces the automotive applications and tools for the evaluation of noise, vibration and harshness. It includes reviews of measurement techniques presently used in the automotive industry to measure various aspects of noise, including the concept of sound quality, vibration and the quantification of the term harshness. The course consists of a review of papers which are to be presented to the class. Participants perform critical reviews on the presentations. Three lecture hours per week. Course evaluation is based on weekly reports, presentations of reviews of papers and critical reviews by participants. (3 lecture hours a week.)

92-530. Combustion Engineering

An introductory graduate course on combustion engineering, covering a broad range of topics of importance to the field including chemical thermodynamics and kinetics, flames and combustion rates, and detonation of gaseous mixtures. The emphasis is on the understanding of the combustion processes involved in practical systems. (Antirequisite: 92-590-01.) (3 lecture hours a week.)

92-531. Numerical Heat Transfer and Fluid Flow

This course is concerned with the ability of using numerical methods to predict heat transfer, fluid flow and related processes. The course consists of an introduction to Computational Fluid Dynamics, descriptions of the general governing differential equations, discretization methods for the differential equations, numerical simulation of conductive heat transfer, numerical treatment of convection and diffusion and calculations of flow fields. (Antirequisite: 92-590-02.) (3 lecture hours a week.)

92-532. Modeling of Thermo-fluid Systems

This course will cover the basic types of mathematical models that are used to describe Thermo-fluid systems. Lumped as well as distributed parameter models will be considered with analytical as well as numerical methods of solution. Modern solution tools such as Simulink, Maple, Fluent and Wave will be utilized whenever appropriate. The topics to be considered may include but are not limited to: two-phase flow, transient flow, turbulence, non-newtonian flow, boiling, evaporation, condensation and fluid-structure interaction. (Antirequisite: 92-590-07.) (3 lecture hours a week.)

92-533. Turbulent Reacting Flows

This course will cover the following topics: experimental investigation of flames, thermodynamics of combustion processes, transport phenomena, chemical kinetics, reactions mechanism, laminar premixed and diffusion flames, the Navier-Stokes equations for the reacting flows, turbulent premixed and non-premixed flames, low temperature oxidation and engine knock, and pollutants formation. (Antirequisite: 92-590-08.) (3 lecture hours a week.)

92-534. Introduction to Computational Fluid Dynamics

This course is intended to provide basic knowledge required to initiate research or applications in computational fluid dynamics. Topics include: numerical methods for model hyperbolic, parabolic and elliptic equations; analysis of difference schemes; numerical stability; explicit and implicit methods; artificial viscosity; linearization

techniques; approximate factorization; preconditioning, iterative solutions, successive over-relaxation (SOR), successive line over-relaxation (SLOR), alternating direction implicit (ADI); two-dimensional structured grid generation; introduction to finite volume method. (Antirequisite: 62-577.) (3 lecture hours a week.)

92-535. Advanced Topics in Computational Fluid Dynamics

This course is a continuation of 92-534. Advanced topics in computational fluid dynamics (CFD) will be discussed, including: structured and unstructured grid generation on surfaces and three-dimensional; Navier-Stokes and Euler solvers; applications of finite volume method; turbulence modeling; current issues in CFD. Students will carry out project work using one or more commercial CFD packages.(Prerequisite: 92-534.) (Antirequisite: 62-587.) (3 lecture hours a week.)

92-536. Fundamentals Of Clean Engine Technology

This course focusses on the understanding of fuel properties, combustion processes, exhaust emissions, and pollution prevention in diesel and other lean-burn IC engines. Introduction to Stirling and other external combustion engines.

92-540. Applied Finite Element Analysis

This course focuses on the modeling aspects of the finite element method using three well known commercial Finite Element Analysis (FEA) software packages known as DYNA, IDEAS and ANSYS. A variety of stress analysis problems in two and three dimensions are studied and the accuracy of the simulations are assessed through comparison with available theoretical and experimental results. Both static and dynamic situations are covered. The students are expected to prepare a final report summarizing their work and an oral presentation. (Antirequisite: 92-590-03.) (3 lecture hours a week.)

92-541. Introduction to Vibration Measurement and Modal Analysis

This course is concerned with basic concepts of modal theory, basic modal parameter analysis, single degree of freedom methods, introduction to frequency response functions, general modal analysis and multiple degree of freedom and global methods. The accuracy of Fast Fourier Transforms (FFT) and windowing, FFT analysis options, zoom, coherence and quality assessment, relationship to finite element modeling will also be considered. In addition, basic measurement techniques, calibration techniques, transient and steady state excitation techniques, general frequency response function interpretation, case study (laboratory experiment) and validation of measured and analyzed data are studied. (Antirequisite: 92-590-04) (3 lecture hours a week.)

92-542. Advanced Topics in Mechanical Design

The topics discussed in the course will be selected from the following: design and analysis of mechanical details such as welded and bonded joints, minimum constraint design, fluid power systems, mobile hydraulic systems, project planning, optimization, decision making methodology, ISO/QS9000 quality methods, concurrent engineering, design reports, design reviews, design for manufacture and assembly, design for quality, configuration design, design for minimum cost, parametric design, developing size ranges for families of products, geometric dimensioning and tolerancing, Taguchi

methods, manufacturability and serviceability considerations and product warranties. (Antirequisite: 92-590-05.) (3 lecture hours a week.)

92-543. Product Design and Development

This course covers the process of new product creation including topics selected from: the product development team; the product development cycle; conceptual development; models including technology push products; platform products; process-intensive products and customized products; needs analysis - identifying the customer and their needs; establishing product specifications; concept generation; concept selection; product architecture; industrial design and ergonomics; prototyping; economics of the development process and project management. (Antirequisite: 92-590-06.) (3 lecture hours a week.)

92-544. Finite Element Methods for Crashworthiness and Impact Analysis

The topics include a brief history on the use of numerical tools in automotive/impact field, Explicit and Implicit time integration techniques, Shell and Solid finite element formulations for impact analyses - advantages and disadvantages, Zero Energy Modes (Hourglassing) and Hourglass control, Material modeling for large displacement problems, Finite element modeling for contact, Mesh Adaptivity, Arbitrary Lagrangian and Eulerian Meshes for large deformation problems, Use of implicit integration techniques for impact problems, Quasistatic simulations as well as the development of finite element models for impact analyses. (Antirequisite: 92-590-12.) (3 lecture hours a week.)

92-545. Automotive Control Systems

This course will address advanced control design techniques for automotive systems. The interdisciplinary goal of this course is to present the application of control system design to engine operation and vehicle mechanics as well as the approaches for parameter/model identification and estimation of automotive systems. For graduate students in electrical engineering, this course will make it possible for them to access automotive models and to understand engine dynamics, both for the purposes of applying control design techniques. For graduate students in mechanical engineering, this course will provide a chance for them to learn how to apply advanced control design strategies to automotive systems. It is expected that, after taking this course, graduate students from both engineering fields will be able to address automotive control problems from interdisciplinary point of views and to complement expertise in their own areas. (Prerequisite: 92-412.) (Antirequisite: 92-590-22) (Cross-listed with 88-536.) (3 lecture hours a week.)

92-590. Directed Special Studies

A special course of studies with content and direction approved by the student's chief advisor. Although there may not be formal lectures, the course will carry the weight of three lecture hours.

92-593. Introduction to Finite Element Analysis

This course covers the fundamentals of the Finite Element Analysis (FEA) with emphasis on solid mechanics and stress analysis. The subject of finite elements is treated using variational principles such as the principle of virtual work and total potential energy. The course deals with a variety of structural components such as springs, axially loaded bars, beams under bending, two-dimensional/axially symmetric/three-dimensional continuum elements and their formulation is static and dynamic analysis. In addition to three hours of lecture, a two-hour computer lab is mandatory where the students use different commercial FEA software. (Antirequisite: 62-593) (3 lecture hours a week and 2 laboratory hours a week.)

92-595. Graduate Seminar

Presentations by graduate students, staff, and visiting scientists on current research topics. Graduate students are required to register and give a presentation in the semester prior to thesis defence. All graduate students are expected to attend each and every seminar and no less than 75% of all seminars. This course will be graded on a PASS/FAIL basis. (1 lecture hour a week.)

92-796. Major Paper

92-797. Thesis

92-798. Dissertation