Mechanisms of Machinery

MECH 3030

3 Credits

Pre/Co-Requisites: MECH2020

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Course Description

This course will mainly cover topics on kinematic analysis of mechanisms (position, velocity, and acceleration analysis of solid bodies and mechanisms) and design/synthesis of mechanisms (how to determine the geometry of a mechanism to achieve kinematic goals). The lectures will emphasize mathematical rigor and be presented with a bent for planar mechanisms. The course will also expose students to relevant hands-on experiences using, for example, software tool such as MATLAB and SolidWorks.

Intended Learning Outcomes (ILOs)

On successful completion of this course, students are expected to be able to:
ILO1: Analyze the basic relative kinematics relations of two moving rigid bodies.
ILO2: Identify individual links and categorize the type of connection of the links (joints).
ILO3: Develop analytical equations describing the relative position, velocity, and acceleration of all moving links.
ILO4: Design simple 4-bar linkages to realize angle mapping, two-positions, or three-positions motion sequence.
ILO5: Apply the fundamentals of mechanisms to specific link and joint combinations such as cams and gear systems.
ILO6: Describe standards in gear and cam machine components.
ILO7: Analyze and design two-dimensional (otherwise complex) cam and gear system.

Assessment and Grading

This course will be assessed using criterion-referencing.

Assessment Task	Contribution to Overall Course Grade (%)	Due Date
Midterm exam	35%	Around week 7-8
Final exam	45%	Final examination period
Written homework	10%	Throughout the term
Lab projects	10%	Final examination period

Mapping of Course ILOs to Assessment Tasks

Assessed Task	Mapped Course ILOs	Explanation
Midterm exam	ILO1, ILO2, ILO3, ILO4	This task evaluates the student's understanding of course materials in graphical and analytical analysis of linkages (ILO2, ILO3, ILO4), taking into account their practical constraints in real-world engineering applications (ILO1).
Final exam	ILO1, ILO5, ILO6, ILO7	This task evaluates the student's understanding of course materials in CAM and gears (ILO5, ILO6, ILO7), taking into account their practical constraints in real-world engineering applications (ILO1).
Written homework	ILO1, ILO2, ILO3, ILO4, ILO5, ILO6, ILO7	Students can apply what they learn in lectures by working on the practical problems provided.
Lab projects	ILO1, ILO3, ILO4	This task evaluates the student's ability to use software such as MATLAB and SolidWorks (ILO3, ILO4) to tackle the design and analysis of linkages (ILO1).

Rubric for Homework Assignments and Lab Projects

Criteria	Excellent	Good	Satisfactory	Marginal	Fail	Map to Course ILOs
Conceptual understanding	Demonstrates complete, precise grasp of core kinematic concepts. Clearly states model assumptions,	Shows solid comprehension of primary mechanism concepts; only minor omissions or slight	Possesses basic familiarity with foundational kinematic ideas but lacks depth; contains minor conceptual gaps	Shows fragmented, limited understanding; explanations of mechanisms are incomplete or	Exhibits negligible or no comprehension of fundamental kinematics or mechanisms basics.	ILO1, ILO2, ILO5, ILO6

	limitations, and physical mechanical reasoning behind all calculations and designs.	imprecision in explaining mechanism principles. No critical conceptual misunderstandings.	when describing mechanisms.	partially factually incorrect.		
Application of mechanism analysis and design	Selects and correctly applies all relevant analytical tools without error: graphical kinematic analysis, instant center method, computational position/velocity/acceleration equations, four-bar synthesis rules, cam profile generation, spur gear & planetary gear train formulas.	Uses appropriate kinematic and design methods with consistent logical reasoning; only trivial procedural mistakes in linkage analysis, cam design, or gear train calculations.	Applies standard kinematic solution workflows to routine textbook-style problems, but requires extra justification for design choices or contains moderate procedural errors in mechanism analysis and design.	Attempts relevant analysis/design methods but makes substantial logical errors.	Fails to deploy suitable kinematic analysis or mechanism design techniques.	ILO3, ILO4, ILO7
Mathematical accuracy and problem solving	All derivations, kinematic equations, gear ratio computations, and design geometry calculations are mathematically rigorous, fully organized, and yield exact, correct results with consistent units, clear notation, and labeled coordinate systems.	Numerical and algebraic results are largely correct; only small arithmetic, unit, or sign errors in linkage acceleration, cam displacement, or planetary gear train calculations.	Work demonstrates reasonable effort and partially correct results but includes notable algebraic, geometric or computational mistakes in mechanism analysis and design.	Solutions are unfinished or contain major mathematical flaws in core kinematic derivations and design calculations.	Submission missing most calculations; nearly all derivations and kinematic computations are wrong or absent.	ILO1, ILO3, ILO4, ILO7

Rubric for Midterm and Final Exams

Criteria	Excellent	Good	Satisfactory	Marginal	Fail	Map to Course ILOs
Mechanism topology and mobility	Correctly identifies all links and classifies every joint type; computes mobility via Gruebler's	Identifies links/joints and computes mobility correctly with only minor errors; applies Grashof's	Identifies basic link/joint types and computes mobility for standard mechanisms but may err on special	Shows limited ability to classify joints or compute mobility; contains significant errors in mobility	Fails to identify links/joints or compute mobility correctly.	ILO 1, ILO 2

	formula without error and applies Grashof's criterion to predict linkage motion with clear physical justification.	criterion with sound reasoning.	cases or lack physical justification.	analysis or Grashof classification.		
Kinematic analysis of planar linkages	Independently and correctly performs position, velocity, and acceleration analysis using graphical methods, the instant-center method, and computational approaches for four-bar and slider-crank linkages.	Performs linkage kinematic analysis mostly correctly with only minor algebraic, sign, or direction errors; chooses appropriate methods.	Performs standard position/velocity analysis for familiar linkages but struggles with acceleration analysis, instant centers, or complex configurations.	Attempts kinematic analysis but with major errors in loop-closure equations, velocity polygon construction, or method selection.	Fails to set up or solve basic kinematic equations for linkages.	ILO 3
Linkage synthesis and design	Correctly designs four-bar linkages for function generation, two-position, and three-position motion generation; derives all geometric parameters rigorously, checks circuit/branch defects, and verifies the design against prescribed motion requirements.	Designs linkages correctly with minor errors in geometric derivation or verification; applies synthesis procedures soundly.	Designs basic two-position or angle-mapping linkages but may omit verification, ignore order/branch constraints, or contain errors in three-position synthesis.	Attempts linkage design but with significant errors in synthesis equations or geometric constraint handling.	Fails to apply linkage synthesis procedures to meet prescribed motion.	ILO 4
Cam system analysis and design	Correctly constructs displacement diagrams with standard motion programs, designs cam profiles for translating/oscillating followers using both graphical inversion and analytical approaches, and evaluates pressure angle, radius of curvature, and undercutting/prime-circle criteria with clear engineering judgment.	Analyzes and designs cam systems mostly correctly; minor errors in profile generation, motion-program derivatives, or follower-type selection.	Performs basic cam displacement analysis and profile design for standard radial translating followers but may lack depth in the analytical approach or performance evaluation.	Shows limited understanding of cam motion programming or profile design; contains significant errors in displacement diagram construction or inversion.	Fails to construct cam displacement diagrams or design cam profiles.	ILO 5, ILO 6, ILO 7

Gear system analysis and design	Correctly applies involute gear geometry, computes tooth forces, contact ratio, and interference/undercutting conditions; analyzes simple, compound, reverted, and planetary gear trains using the relative-motion method; demonstrates clear understanding of gear standards.	Analyzes gear systems mostly correctly with only minor errors in gear-train ratio calculations, contact ratio, or involute geometry.	Performs basic spur-gear and simple/compound gear-train analysis but may struggle with planetary gear trains, contact ratio, or interference conditions.	Shows limited understanding of involute gear geometry or gear-train analysis; significant errors in speed-ratio calculation.	Fails to compute gear ratios or apply involute gear principles.	ILO 5, ILO 6, ILO 7
Mathematical accuracy, organization, and clarity	All derivations and calculations are mathematically rigorous, logically structured, and clearly presented with appropriate equations, units, notation, kinematic diagrams, and labeled coordinate systems; final answers are boxed and physically interpreted.	Work is generally accurate and well organized with only minor arithmetic, unit, sign, or notation errors.	Work shows reasonable organization and partial correctness but includes some significant errors or unclear presentation that obscures the solution path.	Work is poorly organized, incomplete, or contains major mathematical errors that invalidate the result.	Work is largely absent, illegible, incoherent, or incorrect.	ILO 1 – ILO 7

Final Grade Descriptors:

Grades	Short Description	Elaboration on subject grading description
A	Excellent Performance	Students demonstrate mastery of kinematic analysis (position, velocity, acceleration) and mechanism design/synthesis for planar systems, with strong command of rigorous mathematical derivations and problem-solving. They proficiently use MATLAB and SolidWorks for mechanism modeling, simulation, and verification; complete all assignments and lab projects with high accuracy. They show strong ability to formulate kinematic goals, derive geometric parameters, validate designs, and present work clearly and professionally.

B	Good Performance	Students show solid understanding of core kinematic principles and mechanism design methods for planar mechanisms, with correct application of mathematical tools. They can use MATLAB and SolidWorks competently to complete required analysis and design tasks. Assignments and lab projects are finished with good quality. They can effectively define kinematic requirements and implement reasonable mechanism geometry solutions.
C	Satisfactory Performance	Students attain adequate comprehension of fundamental kinematic analysis and basic mechanism synthesis. They can perform standard mathematical calculations and complete routine software operations in MATLAB/SolidWorks with guidance. Major steps of analysis and design are correct, though with some simplifications or small mistakes. They meet basic course requirements for mechanism modeling and validation.
D	Marginal Pass	Students display limited understanding of key kinematic concepts and design procedures. Mathematical derivations contain noticeable errors; software skills are inconsistent and incomplete. Assignments and labs are partially finished or below expected standard; mechanism analysis or design fails to fully meet given kinematic goals. Only minimal core competencies are demonstrated.
F	Fail	Students show lack of understanding of foundational kinematics and mechanism synthesis principles. They cannot correctly apply mathematical methods to fulfill basic tasks. Assignments, labs, or design projects are unfinished, severely flawed, or do not satisfy essential kinematic requirements. They fail to meet the minimum learning objectives of the course.

Communication and Feedback

- Homework assessment marks will be provided via Canvas within two weeks of submission.

- Homework solutions will be provided before midterm and final exams.
- Exam marks will be posted on Canvas within two weeks of the exam dates.
- Office hours will be provided for the review of exam papers.

Late Submission Policy
Late assignments will NOT be accepted. Extensions are available for certain conflicts, including illness (email the instructor).

Required Texts and Materials
The main textbook is **K. Waldron, G. Kinzel, and S. Agrawal, "Kinematics, Dynamics, and Design of Machinery," Wiley** (available in the library for Reserve 1-day; e-version is also available (up to 3 users at the same time)). Also, the second reference textbook is R. Norton, "Kinematics and Dynamics of Machinery," McGraw-Hill.

Course AI Policy
Students are NOT permitted to use Generative AI for their assignments.

Academic Integrity
Students are expected to adhere to the university's academic integrity policy. Students are expected to uphold HKUST's Academic Honor Code and to maintain the highest standards of academic integrity. The University has zero tolerance of academic misconduct. Please refer to Academic Integrity | HKUST - Academic Registry for the University's definition of plagiarism and ways to avoid cheating and plagiarism.

Course Outline

Part 1: A short introduction
(Part-1-A-Short-Introduction.ppt)
Part 2: Joints and linkages
(Part-2-Joints-and-linkages.ppt)
Part 3: Mobility
(Part-3- Mobility.ppt)
Part 4: Four-bar linkages and Grashof's inequality
(Part-4-Four-bar-Linkages.ppt)
Part 5: Math review
Part 6: The graphical method of analysis
(Part-6-Graphical-Methods.ppt)
Part 7: The instant center of velocity
(Part-7-Instant-Centers.ppt)
Part 8: Computational analysis of four-bar linkages
(Part-8-Computational-Analysis-of-Four-bar-Linkages.ppt)
Part 9: Computational analysis of four-bar linkages with prismatic joints
(Part-9-Computational-Analysis-of-Slider-Crank-Linkages.ppt)
Part 10: Computational analysis of other linkages (optional)
(Part-10-Computational-Analysis-of-Other-Linkages.ppt)

Midterm exam (3 hours)

Part 11: 4R Four-bar linkage design of angles
(Part-11-4-bar-linkage-design-of-angles.ppt)
Part 12: 4R Four-bar linkage motion design of a rigid body
(Part-12-4-bar-linkage-design-of-motion-rigid-body.ppt)
Part 13: Design of slider linkages of a rigid body
(Part-13-Crank-slider-design-of-motion-of-rigid-body.ppt)
Part 14: CAM – Introduction
(Part-15-CAM-introduction.ppt)
Part 15: CAM – Motion programming
(Part-16-CAM-motion-programming.ppt)
Part 16: CAM profile design – graphical approach
(Part-17-CAM-profile-design-graphical-approach.ppt)
Part 17: CAM profile design – analytical approach
(Part-18-CAM-profile-design-analytical-approach.ppt)
Part 18: Spur gears – Introduction
(Part-19-Spur-gear-introduction.ppt)
Part 19: Involute spur gears
(Part-20-Involute-spur-gears.ppt)
Part 20: Gear trains
(Part-21-Gear-trains.ppt)
Part 21: Planetary gear trains
(Part-22-Planetary-gear-trains.ppt)

Final exam (3 hours)