Course guide
820429 - CDIM - Kinematics and Dynamics of Machines

Last modified: 22/01/2025

Unit in charge: Barcelona East School of Engineering
Teaching unit: 712 - EM - Department of Mechanical Engineering.

Degree: BACHELOR'S DEGREE IN MECHANICAL ENGINEERING (Syllabus 2009). (Compulsory subject).

Academic year: 2024 **ECTS Credits:** 6.0 **Languages:** Catalan, Spanish

LECTURER

Coordinating lecturer: RAMON JEREZ MESA

Others: Segon quadrimestre:
RAMÓN JEREZ MESA
ERIC VELÁQZUEZ CORRAL
JESÚS PETREÑAS

PRIOR SKILLS

The student should be able to perform the calculation:
1. Scalar product, particularly for calculations of forces, power and labor force and moments about an axis.
2. Vector product for calculations of moments of force about a point.
3. Moments about a point or axis.
4. Equivalent systems (resulting forces and moments).
5. Balance in the plane (support reactions).
6. Center of gravity of solids.
7. Calculation time (seconds) of inertia.

REQUIREMENTS

DINÀMICA - Prerequisit

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
1. Understand the theoretical principles of machines and mechanisms.
CEMEC-20. Calculate the characteristics of, design and test machines.

Transversal:
2. EFFICIENT ORAL AND WRITTEN COMMUNICATION - Level 2. Using strategies for preparing and giving oral presentations. Writing texts and documents whose content is coherent, well structured and free of spelling and grammatical errors.

TEACHING METHODOLOGY

In this course different methodologies are combined:
1. Theoretical lectures in which the main content of each topic is presented with the help of powerpoints, promoting interactivity with the student through questions and the discussion of practical aspects related to the explained theory.
2. Simulation with mechanical design software.
3. Self-assessment tests at ATENEA.
4. Practical sessions in the lab.
In addition to the main methodologies, the teacher can be asked for specific tutorials at the request of the students to resolve doubts related to the content of the course.
Students are expected to independently consult the books in the recommended bibliography.

LEARNING OBJECTIVES OF THE SUBJECT

1. Know the language and terminology for the kinematic and dynamic study of the mechanisms.
2. Interpret relciones between geometry, the movement of parts and the forces that generate it.
3. Know the kinematic operational and design parameters of the mechanisms of bars, levers, gears, pulleys and belts.
4. Apply analytical and graphical methods for the study of kinematic and dynamic behavior of the links on the machines.
5. Identify and assess the results of the position, velocity and acceleration of machine elements using kinematic analysis.
6. Identify and assess the results of the forces and torques acting through the static and dynamic analysis.
7. Using the simulation tools necessary to evaluate behavior in the cycle.
8. Evaluate the results and draw conclusions about the behavior of the mechanism.

STUDY LOAD

Type	Hours	Percentage
Hours small group	15,0	10.00
Hours large group	45,0	30.00
Self study	90,0	60.00

Total learning time: 150 h

CONTENTS

Unit 1. Mobility of mechanisms

Description:
This unitfocuses on the basic concepts of mechanisms, both in relation to how they are formed and the functions they can perform. Emphasis is placed on classical mechanisms as tools for developing specific functions in machines, as well as on the inversion of kinematic chains to generate new ones. Subsequently, the degrees of freedom of mechanisms will be calculated using the Grübler-Kurtzbach method, by direct inspection and by elimination of Assur groups.

Specific objectives:
1. Know the general nomenclature to define the construction of mechanisms and machines.
2. Interpret the mobility of the elements of a mechanism from the input movement.
3. Recognize the classical mechanisms (articulated quadrilateral, connecting rod-piston-crank, Scottish yoke, malt cross ...) and their kinematic functions.
4. Define the functions of the bars of an articulated quadrilateral using Grashof's law.
5. Calculate the degrees of freedom of a mechanism using different methods.
6. Identify redundancies in mechanisms.
7. Properly outline mechanisms following the UNE-EN ISO 3952 standard.

Related activities:
Practical session 1. Mobility analysis of the links composing a sewing machine.
Optional self-evaluation tests in ATENEA.
Exercices solved in the classroom.

Related competencies :
CEI-13. Understand the theoretical principles of machines and mechanisms.

Full-or-part-time: 8h 30m
Theory classes: 4h 30m
Laboratory classes: 2h
Self study : 2h

Unit 2. Position, velocity and acceleration of linkages

Description:
This topic presents the tools needed to be able to calculate the positions of links of a mechanism during its motion, as well as the angular velocities and accelerations of its membres for a given instant. We will begin by presenting how to analytically model a mechanism through geometric linking equations, which will be solved by singular mechanisms (classical solutions of the articulated quadrilateral and connecting rod-crank mechanism) and by numerical resolution by the Newton-Raphson method. Subsequently, the linkage equations will be derived to obtain the Jacobian one that governs the motion of the mechanism, as well as its kinematic equations. A second derivation will allow the acceleration equations to be posed.

Specific objectives:
1. Define an appropriate set of generalized coordinates that unequivocally define the position of the elements of the mechanism.
2. Identify the possible configurations of a mechanism based on its geometry and construction.
3. Deduce the geometric linking equations that represent the position of a mechanism at a given instant.
4. Derive the linking equations to calculate angular velocities of the links of a moving mechanism for a certain instant, obtaining in the process its Jacobian.
5. Find singular points of a mechanism (dead centres and forks) from its kinematic equations.
6. Calculate the instantaneous angular accelerations of the links of a mechanism deriving its kinematic equations.

Related activities:
Autonomous activity: "Kinematic and dynamic simulation of a flat mechanism in motion with Solidworks".
Exercices solved in the classroom.

Related competencies :
CEMEC-20. Calculate the characteristics of, design and test machines.
04 COE N2. EFFICIENT ORAL AND WRITTEN COMMUNICATION - Level 2. Using strategies for preparing and giving oral presentations. Writing texts and documents whose content is coherent, well structured and free of spelling and grammatical errors.

Full-or-part-time: 15h 40m
Theory classes: 9h
Self study : 6h 40m

Unit 3. Kinematics of linkage elements

Description:
Once the angular velocities and accelerations of the solids that form the kinematic chains of a machine have been calculated at the previous unit, the calculation of the linear speeds and accelerations of the points that form them is addressed in this one. The focus of study will be mechanisms that are configured so that the absolute speeds and accelerations can be calculated about fixed coordinate axes. The different movements that the links of a mechanism can have depending on their speed range (pure rotation, pure translation and general motion) will be discussed first. Subsequently, the linear velocity equations of a point belonging to a solid will be obtained in the scenario that is in pure rotation and in general motion. By derivation, the equations of linear accelerations will be obtained. The vector equations obtained will be particularised for plane mechanisms. Following the same vectorial approach, the kinematics of solids will be solved by using convenient mobile reference systems to compute relative velocities and accelerarions as a means of reaching the absolute ones. Last of all, the graphical method of the instantaneous centers of rotation and Kennedy's theorem will also be explained to facilitate calculations of instantaneous velocities of singular points of the links of the mechanism.

Specific objectives:
1. Differentiate between angular velocity and acceleration of a solid and the linear velocities and accelerations they cause at the points they are composed of.
2. Identify the type of motion that solid experience depending on its kinematics (general motion, pure translation or pure rotation).
3. Calculate vectorially the absolute velocity and acceleration of a point about a fixed axis system.
4. Particularise vector equations to the motion of plane mechanisms.
5. Understand the need to use mobile reference systems as a support for the calculation of absolute speeds and accelerations in mechanisms that require it for its construction.
6. Calculate absolute velocities and accelerations of points of a member of a mechanism through the relative and Coriolis ones.
7. Locate instantaneous centers of rotation of the elements of a mechanism to calculate instantaneous velocities of their points.

Related activities:
Practical session 2. Simulation of mechanisms: kinematics
Autonomous activity: "Kinematic and dynamic simulation of a flat mechanism in motion with PTC Creo".
Exercises solved in the classroom.

Related competencies :
CEMEC-20. Calculate the characteristics of, design and test machines.
04 COE N2. EFFICIENT ORAL AND WRITTEN COMMUNICATION - Level 2. Using strategies for preparing and giving oral presentations. Writing texts and documents whose content is coherent, well structured and free of spelling and grammatical errors.

Full-or-part-time: 19h 20m
Theory classes: 9h
Laboratory classes: 2h
Self study : 8h 20m

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Unit 4. Kinematics of transmission systems

Description:
This unit presents the kinematics of the main transmission systems used in machines and mechanisms: cams, gears, universal joints, belts and chains. The calculations of speeds and accelerations exposed at the previous units will be particularized to undertake this task.

Specific objectives:
1. Understand how cam-follower transmission occurs and how its kinematic curve is defined.
2. Calculate the transmission ratios in fixed and epicyclic gear trains, as well as in chain and belt transmissions.
3. Identify the different geometric elements that define the gear wheels and their condition so that the gear can be produced.
4. Understand how the output angular velocity transmitted by a Cardan joint varies according to its geometry.

Related activities:
Practical session 3. Construction of the kinematic profile of cams.
Practical session 4. Kinematic analysis of the speeds transmitted by Cardan joints according to the operating angles.

Related competencies :
CEMEC-20. Calculate the characteristics of, design and test machines.
CEI-13. Understand the theoretical principles of machines and mechanisms.

Full-or-part-time: 10h 10m
Theory classes: 1h 30m
Laboratory classes: 4h
Self study : 4h 40m

Unit 5. Interactions between rogid bodies

Description:
This topic presents a taxonomy of the different forces that solids can transmit and how they are taken into account for the subsequent application of vector and energy methods for dynamic calculation. Subsequently, the focus is focused on the analysis of remote forces (springs and shock absorbers), simple friction models and forces transmitted between elements of mechanisms through their kinematic pairs.

Specific objectives:
1. Know the different forces that can act on a link of a mechanism and how they can be transmitted to their adjacent through their kinematic pairs.
2. Understand the concept of forces and inertial moments that define the system of forces to which the elements of machines are subjected.
3. Find the differential equations that represent mechanisms formed by spring-damper pairs.
4. Approach the dynamic behavior of passive forces through simple models of friction.

Related activities:
Exercises solved in the classroom.

Related competencies :
CEMEC-20. Calculate the characteristics of, design and test machines.
CEI-13. Understand the theoretical principles of machines and mechanisms.

Full-or-part-time: 7h 40m
Theory classes: 3h
Self study : 4h 40m

Unit 6. Calculation of dynamic forces in mechanisms

Description:
In this unit the dynamics of mechanisms is solved by means of the application of the theorems of the amount of movement and the kinetic moment, extending the principle of d'Alembert to links of mechanisms and that are transmitted mutual movement to determine all the forces and moments transmitted between them, as well as the dynamic reactions with the ground. The theorems will be applied to the calculation of dynamic reactions of rotating axes. In the second part of this lesson, the method of virtual power shall be presented to calculate driving torques and/or forces in machines. It shall be applied to the specific case of flywheel design.

Specific objectives:
1. Relate the descriptors of mass geometry that characterize the links of a mechanism (mass centres and inertia tensors) with their dynamic behavior.
2. Apply the d'Alembert's principle to the resolution of mechanisms in motion to obtain the forces transmitted by the kinematic pairs and the reactions with the ground.
3. Particularise the application of the method for the calculation of dynamic reactions of rotating axes.
4. Calculate the shaking forces and moments of a machine and study different methods to damp them.
6. Locate the centre of percussion of a link in a mechanism to optimise its mechanical advantage5
7. Deduce the method of virtual power from d'Alembert's principle to obtain balancing forces and torques of a moving mechanism.
8. Apply this method to the dimensioning and design of flywheels.
9. Compute the mechanical advantage of a mechanism.

Related activities:
Practical session 5. Simulation of mechanisms: dynamics
Autonomous activity: "Kinematic and dynamic simulation of a flat mechanism in motion with PTC Creo".
Exercises solved in the classroom.

Related competencies :
CEMEC-20. Calculate the characteristics of, design and test machines.
CEI-13. Understand the theoretical principles of machines and mechanisms.
04 COE N2. EFFICIENT ORAL AND WRITTEN COMMUNICATION - Level 2. Using strategies for preparing and giving oral presentations. Writing texts and documents whose content is coherent, well structured and free of spelling and grammatical errors.

Full-or-part-time: 26h 50m
Theory classes: 12h
Practical classes: 4h
Self study : 10h 50m

Unit 7. Power chain. Motor selection

Description:
This lesson addresses how electric motors are selected to be able to activate mechanisms and kinematic chains, including in the analysis how power and movement are transmitted through a transmission system.

Specific objectives:
1. Calculate the efficiency of motor-transmission-receptor chains.
2. Select the most adequate motor to operate a kinematic chain.

Related activities:
Exercices solved in the classroom. Consultation of commercial catalogs of electric motors.

Related competencies :
CEMEC-20. Calculate the characteristics of, design and test machines.
CEI-13. Understand the theoretical principles of machines and mechanisms.

Full-or-part-time: 11h 50m
Theory classes: 6h
Self study : 5h 50m

GRADING SYSTEM

The qualification of the subject responds to a system of continuous evaluation that fulfills the requirement of guaranteeing that students have a global vision of the subject and is implicated in all the evaluation items. The evaluation mix is composed of three written tests and work developed in teams, with the following relative weights:
>> Mid-term exam 1 (kinematics): 20%
>> Mid-term exam 2 (dynamics): 20%
>> Final exam (integration of dynamics and kinematics): 40%
>> Group project on kinematic and dynamic simulation: 35%. It evaluates competencies aquired during practical sessions and lectures. It is calculated through a weighted average from two grades: one referring to oral and written expressions (20%) and one referred to the report contents (80%).
>> Exam on laboratory practical sessions. It can increase the grade of the project, turning the 80% mark of the contents into 60% contents and 20% the grade the grade of this exam.

In summary, the final grade is calculated with the folloiwng formula:

Final Grade = 0,2*(MidTerm_1 + MidTerm_2) + 0,4*Final + 0,2*(0,2*Oral_Written_Expr + MAX(0,8*Contents; 0,6*Contents+ 0,2*Laboratory))
All grades over 10.

The assessment of the general competence (2nd level - Effective communication: Oral and Written) will be done through the report delivered of the exercise and a brief presentation that will be made in class by each group. It derives from the partial grade of the group assignment related to this aspect.

There is no reassessment exam.

EXAMINATION RULES.

Exams must be individually solved.
Calculators can be used. It is strongly recommended that they allow the student to solve linear systems.
Tests can be started later than the scheduled time as long as no fellow student has left any of the classrooms set up for the test but the due time will be the same as for everyone.

BIBLIOGRAPHY

Basic:
- Cardona i Foix, Salvador; Clos Costa, Daniel. Teoría de máquinas [on line]. 2a ed. Barcelona: Edicions UPC, 2008 [Consultation: 21/04/2020]. Available on: http://hdl.handle.net/2099.3/36645. ISBN 9788498803808.
- Shigley, Joseph Edward; Uicker, John Joseph. Teoría de máquinas y mecanismos. Auckland: McGraw-Hill, cop. 1980. ISBN 0070568847.
- Beer, Ferdinand Pierre; Mazurek, David F; Johnston, E. Russell; Eisenberg, Elliot R; Murrieta Murrieta, Jesús Elmer; Nagore Cázares, Gabriel. Mecánica vectorial para ingenieros. Dinámica. 10ª ed. México [etc.]: McGraw-Hill, cop. 2013. ISBN 9786071509239.
- Norton, Robert L. Diseño de maquinaria. Síntesis y análisis de máquinas y mecanismos [on line]. 5a ed. México [etc.]: McGraw-Hill, cop. 2013 [Consultation: 29/04/2020]. Available on: http://www.ingebook.com/ib/NPcd/IB_BooksVis?cod_primaria=1000187&codigo_libro=5701. ISBN 9781456239770.

Complementary:
- Beer, Ferdinand Pierre; Mazurek, David F; Johnston, E. Russell; Eisenberg, Elliot R; Murrieta Murrieta, Jesús Elmer; Nagore Cázares, Gabriel. Mecánica vectorial para ingenieros. Estática. 10ª ed. México [etc.]: McGraw-Hill, cop. 2013. ISBN 9786071509253.
- Agulló i Batlle, Joaquim. Mecánica de la partícula y del sólido rígido. 2a ed. rev. y ampl. Barcelona: OK Punt, 2000. ISBN 8492085053.

RESOURCES

Audiovisual material:
- Módulo. Mechanism simulation module at PTC Creo (UPC or student licence)

Other resources:
PowerPoints explained in classroom available at ATENEA.
Audiovisual material on ATHENA.
Books from the bibliography.