1EL9000 – Thermodynamics

Instructors: Marie-Laurence Giorgi
Department: DÉPARTEMENT MÉCANIQUE ENERGÉTIQUE PROCÉDÉS
Language of instruction: ANGLAIS, FRANCAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 60
On-site hours (HPE): 35,00

Description

The objective of this course is to provide the theoretical bases, tools and good practices necessary for engineers to understand and design systems that transform raw energy into useful energy, and /or that modify the physicochemical properties of matter through controlled transformations. The knowledge acquired in this course will allow for the design of these systems by determining their optimal operating points (for example by using phase transitions) in order to optimize their energy efficiency.
In particular, the course will show how thermodynamic concepts can be used to meet the challenges of the 21st century (conventional and renewable energy production, energy efficiency of engineering processes, smart materials, recycling, water and waste treatment, etc.) and how recent scientific advances, in particular nonequilibrium thermodynamics, can help predict multiphysical couplings in complex systems.

Quarter number
SG1 and SG3

Prerequisites (in terms of CS courses)
None

Syllabus
1) Energy efficiency (4 courses of 3hr each)
General description of the fundamental concepts (open systems, state functions)
Open systems of energy transformation (energy, entropy and exergy balance)
Efficiency of energy recovery cycles (design of thermodynamic cycles)
2) Phase transitions (5 courses of 3hr each)
Thermodynamic properties of pure substances and solutions
Phase equilibria, phase diagrams
Phase transitions (equilibrium and departure from equilibrium, chemical

reactions, germination / growth)

Class components (lecture, labs, etc.)

The course will be divided into 3 hour periods (1.5 hours of lecture and 1.5 hours of tutorials).
At the end of each part of the course, students will carry out a project by 2 or 3 students (2 x 3 hours to realize the projects and write the reports).
A final evaluation (2-hour written test) will complete the course.
The second session will be an individual assessment of 2 hours.

The language of instruction is French for occurrences 1-1 and 1-2 and English for occurrence 1-3.

Grading

Two projects with two reports (40%) and an individual final assessment (60%)

Course support, bibliography

D. Kondepudi, I. Prigogine, Modern Thermodynamics – From Heat Engines to Dissipative Structures, John Wiley and sons, England, 1998.
C.H.P. Lupis, Chemical Thermodynamics of Materials, Elsevier Science Publishing, New York, 1983.

Resources

• Teaching staff (instructor(s) names): Marie-Laurence Giorgi, Sean Mc Guire
• Maximum enrollment (default 35 students): 35
• Software, number of licenses required: open source software
• Equipment-specific classrooms (specify the department and room capacity):

Learning outcomes covered on the course

At the end of the course, students will be able to:
1. Write energy, entropy and exergy balances
2. Designing and optimizing energy recovery cycles
3. Propose and evaluate solutions to optimize the energy efficiency of systems
4. Understand and use phase diagrams for material design
5. Construct thermodynamic models describing phase equilibria
6. Work as a team independently and interdependently towards a common team objective

Description of the skills acquired at the end of the course

C1.1, C1.2, C1.3, C2.1

SCIENCE AND ENGINEERING CHALLENGE N°2 COURSES

ST2 –21 – MEDICAL ROBOTICS

Dominante : GSI (Large Interacting Systems)
Langue d'enseignement : French
Campus où le cours est proposé : Paris-Saclay

Engineering problem

The development of robotics was originally motivated by industrial problems (manufacturing, evolution in a hostile environment, etc.). However, current developments are increasingly directed towards new markets: healthcare, services to the person, assistance, urban services, logistics, transportation, agriculture, etc. In healthcare, the assistance systems both to medical staff and to patients are inseparable from the notion of human-robot interaction.

These new use cases often require shorter hardware and software development times, an increased customization, and a strict performance validation under constraints of security, costs, size, weight, etc. Design methods regularly include optimization phases based on models of robotic systems and their environments. These phases appear during mechanical design, control design, development of artificial intelligence modules (as for example in medical imaging) etc.

In the context of robotics, the development of models requires a generalized and well-structured approach. In particular, dynamic modeling often uses the Lagrangian formalism which offers a very general scope. The methods discussed in the present thematic sequence are contextualized in the disciplinary field of robotics but their application scope largely exceeds this context.

The present thematic sequence addresses more precisely the problems of robotics within the medical environment through several components: interventional radiology (more precisely vascular radiology) which constitutes an important help in terms of guidance to the medical staff during the phases of intervention; the mini-invasive surgery, often associated with systems of computer vision, which limits the surgical traumas; and the gesture assistance which can be provided by an upper-limb exoskeleton, with interesting prospects for the functional rehabilitation among others.

Advised prerequisites

Prerequisites for the specific module (rigid body dynamics): elementary knowledge of point mechanics (notions of velocity, acceleration, force, moment).

Context and issue modules: These modules aim to give a vision of the theme from several angles:

- General introduction with an opening lecture on the theme "Robotics in the French healthcare system, current status and perspectives"

- Highlighting of the main clinical issues of interventional robotics

- Highlighting of legal aspects, risks, safety and standards, constraint aspect and cost produced by GE Healthcare

- Presentation of existing technologies and barriers via presentations on the theme of "Computer-assisted or robotic medical and surgical procedures”

Specific course (40 HEE): Rigid body dynamics

Short description: Many mechanical systems are intended to ensure specific movements or to transmit forces in a controlled way; they are then mechanisms generally made up of several solids in connection with each other, where one can consider that the displacements are mainly notable at the level of these connections, and that it is thus reasonable to suppose that the solids are indeformable. The study of these mechanisms then allows to quantify the performances they can offer, as well as to dimension them pertinently. In addition, the modeling tools used can be adapted to describe systems from other fields: thus, the course will give many examples from various fields of application, such as, typically:

- the dynamics of land, aeronautical and space vehicles, which involves in particular the problems of control and piloting;

- robotics, with the dimensioning of motion transformation mechanisms and the design of control laws;

- biomechanics and the study of sports gestures.

Challenge week n°1: Modeling and dimensioning of an upper limb exoskeleton

- **Associated partner:** CEA-LIST
- **Location:** Paris-Saclay campus
- **Short description:** An upper limb exoskeleton is a robotic system that can be worn by a human being to assist him/her in performing gestures, carrying heavy loads, etc. Such a system should ideally offer the same possibilities of movement to the human arm as when it is completely free,

while bringing the desired assistance. In this project, we are particularly interested in the way in which the design and the control of the exoskeleton allow to conform to the human morphology and movements. Indeed, the choices of mechanical design and mechatronic dimensioning directly influence the comfort and the anthropomorphism of the possible movements, or the transmitted efforts. In this project, the aim is to develop models of the exoskeleton allowing the analysis of its movements and the efforts transmitted in order to offer the level of performance required for the assistance to the human being.

Challenge week n°2: Modeling and sizing of a medical robot - Modeling of a polyarticulated vascular radiology robot

- **Associated partner:** GE Healthcare
- **Location:** Paris-Saclay campus
- **Short description:** Interventional radiology has become an essential aid to surgeons during vascular operations (heart, lungs, brain, kidneys). Indeed, this type of system reduces recovery time and patient trauma during operations compared to conventional "open" surgery. A vascular radiology system can be made up of one or two polyarticulated robots, placed on the ground or suspended. The system studied has five motorized axes allowing the movement of the image-taking system consisting of an X-ray tube and a receiver. The level of precision required during the movement is closely linked to the imaging objective and depends in part on the design of the actuation system. Moreover, to guarantee safety, this type of system must be able to remain motionless in case of power failure, which leads to a specific choice and dimensioning of the motorization chain. Moreover, the robot sharing its working space with the medical staff and the patient, the problem of detection of unexpected collisions arises to ensure the safety of people. In this project, the aim is to model this type of robot by considering its multi-axis structure.

Challenge week n°3: Modeling and dimensioning of a medical robot - Modeling of a minimally invasive surgery robot

- **Associated partner:** SAAS Laboratory of the ULB (Free University of Belgium)
- **Location:** Paris-Saclay campus
- **Short description:** Surgical robots allow, among other things, to improve the precision of the surgeon's movements and to reduce the effect of tremors. They also provide more freedom of movement and more visibility thanks to the onboard vision system. Minimally invasive surgery aims to reduce the impact of an operation on the patient in terms of trauma and recovery time. The surgeon operates directly inside the patient's body using a camera and tools inserted through holes called trocars. The assistance of the surgeon by means of a robotic system makes it possible to overcome a certain number of constraints encountered by the surgeon in this type of operation (restricted working

space, partial visibility, constraining posture...). The design of such robotic systems requires to consider new constraints of geometry (fixed point at the trocar level), instrumentation (sensors, end effectors...) and safety (collisions in the patient's body or in the working space of the medical staff). In this project, we are interested in the modeling of a robot with four degrees of freedom in order to evaluate its working space and to estimate the external forces in case of collision.