TO: The Engineering Faculty

FROM: The Faculty of the School of Mechanical Engineering

RE: ME 53500 Design and Modeling of Fluid Power Systems - New graduate course

The Faculty of the School of Mechanical Engineering has approved the following experimental course for a permanent course number. This action is now submitted to the Engineering Faculty with a recommendation for approval.

ME 53500 Design and Modeling of Fluid Power Systems, Sem. 1, Class 3, cr. 3. Prerequisite: ME 30900 or equivalent fluid mechanics class, or consent of instructor.

Fluid power is a technology for transmitting mechanical power that competes with mechanical- and electrical- drive systems, and it is particularly advantageous for its high power to weight ratio. This class provides the student with the fundamental knowledge of fluid power drive technology.

The class first describes basic fluid power components such as pumps, motors, cylinder, hydraulic control valves, and accumulators. The basic equations that allow formulating analytical or numerical models of such components are presented.

The second part of the class covers the basics for the analysis, the modeling and the design of complete hydraulic control systems. The control concepts behind primary controlled systems (or pump-controlled systems), metering controlled systems and secondary controlled systems are illustrated for the case of single actuator as well as for the case of multiple actuators. The concepts of open center systems, load sensing systems and constant pressure systems are described along with the modeling equations for simulate real applications. The class also cover the basics of hydrostatic transmissions and hydrostatic actuations. Extension to electro-hydraulic technology and hydraulic hybrids are provided.

The course includes class lectures but also some labs. During the lab experiences, the students will learn how to recognize the different hydraulic components, and how to perform basic tests on components and systems. Every student will also have to work on two independent project assignments aimed at modeling: (i) a hydraulic pump as well as (ii) an entire hydraulic system in MatLab / Simulink. The class evaluation is based on these two project assignments and a final exam.

Reason: Design and Modeling of Fluid Power Systems, has been offered every year for more than ten years under a temporary course number (currently by Dr. Andrea Vacca, and by Dr. Monika Ivantysynova), and it has been a pillar class supporting the ongoing research at the Maha Fluid Power Research Center. The class is also taken by several engineering students outside the Maha Fluid Power Research Center, from departments outside ME, such as Aerospace, Agricultural and Biological Engineering. Attendance for last Spring 2019 was of 13 students. Attendance for the previous years, when the class was taught by Dr. Ivantysynova is estimated to be always between 6 and 15 students every year. This course provides knowledge of fluid power drive technology, which is a fundamental technology for applications in industrial, mobile, aerospace and marine fields. United State industry is particularly strong in these fields and constantly demanding for R&D experts.

Purdue has been leading the fluid power academic research in US for more than a decade and this class will consolidate this tradition for cutting edge education and research in fluid power. The class also provides modeling techniques that a graduate student can use in other research fields.

Details of the course are provided in the two-page course profile attached.

Nicole Key, Associate Head/Professor
School of Mechanical Engineering

ME 597 / ABE 591
Design and Modeling of Fluid Power Systems

Course Outcomes [Related ME Program Outcomes in brackets]

1. Describe the principle of operation of hydraulic components such as pumps, motors, hydraulic control valves, pipes, linear actuators (cylinders) and recognize the technologies available for each component. [1]
2. Model the operation of hydraulic systems through lumped or distributed numerical approaches. [1,2,7]
3. Discuss the features of the hydraulic control technologies commonly available for mobile machinery and industrial applications, particularly in terms of cost, functionality and energy consumption. [2,4,7]
4. Design tests and prepare technical reports related to the modeling and the experimentation of fluid power systems. [2,3,6]
5. Formulate, design, simulate and present the most energy efficient solution for the hydraulic control system of a given fluid power application, given its functional requirements. [1,2,4]

Fluid Power Fundamental Principles (3 wks)

1. Fluid Statics – Pascal's laws
2. Conservation of Mass – Hydraulic Capacitance
3. Momentum Equation – Hydraulic Inertance
4. Momentum Equation – Flow Forces
5. Frictional effects – Hydraulic Resistance
6. Energy Equation
7. Hydraulic Fluids – Viscosity
8. Hydraulic Fluids – Cavitation and Aeration
9. Hydraulic Fluids - Contamination

Fluid Power Components (6 wks)

1. Pumps and Motors – Principles
2. Pumps and Motors – Energy parameters
3. Pumps and Motors - Architectures
4. Control Valves - Principles
5. Control Valves – Stationary Features
6. Control Valves – Dynamic Features
7. Actuators – Linear and Rotary Actuators
8. Accumulators
9. Filters

Fluid Power Systems (6 wks)

1. Control strategies: Primary, Secondary and Metering Control
2. Meter in and Meter out control features
3. Bleed-Off and Open Center Systems
4. Load Sensing Systems
5. Multiple Actuators: Series, Parallel and Priority
6. Hydrostatic Transmissions
7. Hydrostatic Actuators
8. Hydraulic Hybrids

Laboratory Activities - Reports

- Lumped parameter modeling of a Hydraulic Pump
- Lumped parameter modeling of a mobile off-road machine
- Pump stationary characterization
- Meter in and meter out testing

COURSE NUMBER: ME 597 / ABE 591

COURSE TITLE: Design and Modeling of Fluid Power Systems

REQUIRED COURSE OR ELECTIVE COURSE: Elective

TERMS OFFERED: Spring

TEXTBOOK/REQUIRED MATERIAL: Vacca A., Franzoni G., Fluid Power Fundamentals, Wiley (accepted for publication in 2020)

Suggested:

J. Watton, 2009, *Fundamentals of Fluid Power Control*, Cambrige Press

H. E. Merritt, 1967, *Hydraulic Control Systems*, Wiley

PRE-REQUISITIES: ME 309 Fluid Mechanics or equivalent

COURSE DESCRIPTION: Introduction to fluid power technology. Design of hydraulic systems for mobile and industrial application for functionality, cost and energy efficiency. Modeling strategies for fluid power systems. Labs and class projects are given to reinforce the design and modeling learning projects.

ASSESSMENTS TOOLS:

1. Project 1: modeling of a hydraulic pump (Simulink).
2. Project 2: modeling of a off-road hydraulic machine (Simulink).
3. Two experimental labs and reports.
4. Final Exam.

NATURE OF DESIGN CONTENT: Project 1 is aimed at sizing and modeling a hydraulic pump for high pressure application. Energy efficiency parameters and dynamic features have to be found. Project 2 is aimed at sizing and modeling the hydraulic system of the hydraulic functions an off-road vehicle, such as the hydraulic arm of an excavator (or a similar vehicle).

COMPUTER USAGE: The Projects require the students to formulate and implement computer programs in MatLab-Simulink for the detailed steady state and dynamic analsysis of a hydraulic component (Project 1) and a hydraulic system (Project 2).

COURSE STRUCTURE/SCHEDULE:

1. Lecture – 3 hours per week at 50 minutes
2. Laboratory – three two-hours labs (labs replace class lectures).

COURSE OUTCOMES [Related ME Program Outcomes in brackets]:

1. Describe the principle of operation of hydraulic components such as pumps, motors, hydraulic control valves, pipes, linear actuators (cylinders) and recognize the technologies available for each component. [1]
2. Model the operation of hydraulic systems through lumped or distributed numerical approaches. [1,2,7]
3. Discuss the features of the hydraulic control technologies commonly available for mobile machinery and industrial applications, particularly in terms of cost, functionality and energy consumption. [2,4,7]
4. Design tests and prepare technical reports related to the modeling and the experimentation of fluid power systems. [2,3,6]
5. Formulate, design, simulate and present the most energy efficient solution for the hydraulic control system of a given fluid power application, given its functional requirements. [1,2,4]

RELATED ME PROGRAM OUTCOMES:

1. Engineering fundamentals
2. Engineering design
3. Communication skills
4. Ethical/Prof. responsibilities
5. Experimental skills
6. Knowledge acquisition

PREPARED BY: Andrea Vacca **DATE:** March 9, 2019