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SUMMER SCHOOL
Advanced Methods for Vehicle and Powertrain Control and Optimization

CTU, FACULTY OF MECHANICAL ENGINEERING
17.8. – 28.8.2015 VTP ROZTOKY

„Support of inter-sectoral mobility and quality enhancement of research teams at Czech Technical University in Prague“, CZ.1.07/2.3.00/30.0034.

17.8.2015 – Hassan Metered (WG 3)

1) Technology of semi-active devices
2) Application of semi-active devices in mechanical systems
3) Investigation of semi-active vehicle suspension system using Matlab and Simulation

1) Technology of semi-active devices

This lecture presents the main types of semi-active devices focusing on the basic construction, the theory of operation and a brief history, passive and active devices will not be mentioned here. There are a lot of semi-active devices; variable viscous devices, variable stiffness devices, magnetorheological devices, friction devices, tuned liquid dampers, electro-inductive device, air-jet actuators and Shape memory alloy actuators. The first three types will be explained in details because they are the most common devices applied in mechanical systems until now.

2) Application of semi-active devices in mechanical systems

This lecture introduces the main applications of semi-active devices focusing on the control strategies and algorithms for generating semi-active damping force. Several approaches were proposed during last decades, some originating from an adaptation of active control laws, others originating directly from physical considerations of semi-active devices. With a semi-active control device, the energy can be dissipated from the system very effectively. These kinds of devices could be seen as passive dampers with changing characteristics to be adjusted on-line. There are a lot of control laws will be explained in this lecture such as Open-loop Control, On–Off Skyhook Control, Continuous Sky-hook Control, On–Off Ground-hook Control, Hybrid-hook Control, Clipping Control, Linear Quadratic Regulator (LQR) and Fuzzy Logic Control.

3) Investigation of semi-active vehicle suspension system using Matlab and Simulation

This lecture proposes a theoretical application of a semi-active device in vehicle suspension system controlled by the Linear Quadratic Regulator (LQR) and Fuzzy Logic Control (FLC) to enhance the ride comfort and vehicle stability, as case studies. A mathematical model and the equations of motion of the quarter active vehicle suspension system will derive and simulate using Matlab/Simulink software. Also, The LQR and FLC techniques will design and apply in a closed loop control way in details using Matlab/Simulink. The controlled semi-active suspension systems will compare with the passive suspension. Suspension performance will evaluate in both time and frequency domains, in order to verify the success of the proposed control techniques.

18.8.2015 – Mohamed El Morsy (WG 2)

1) **Vehicle Gearbox Fault Diagnosis Based on Vibration Measurements**

Vibration measurement is one of the technologies for health monitoring and diagnosis of rotating machines such as gearboxes. Although, significant research has been undertaken in understanding the potential of vibration measurement in monitoring gearboxes, this has been solely applied on any types of gears (spur, helical, etc.). The condition monitoring of a real vehicle's gearbox, using non-destructive inspection methodology and the processing of the acquired waveform with advanced signal processing techniques is the aim of the present summer school.
During the summer school the acquisition of the vibrational signal will be demonstrated with help of the open loop test stand. The test stand is equipped with three dynamometers; the input dynamometer serves as the internal combustion engine, the output dynamometers introduce the load on the flanges of the output joint shafts. The pitting defect is manufactured on the tooth side of the fifth speed gear on the intermediate shaft. During the lecture will be demonstrated different techniques of the signal processing. The presented concept has an important application in the field of mechanical fault diagnosis and improvement in gears design.

Topics
- Literature survey for fault diagnosis methods
- Value of vibration measurements in vehicle gearbox fault diagnosis.
- Vibration measurement and experimental procedures.
- Modern techniques used in vehicle gearbox fault diagnosis.
- Signals processing.
- Severity index (RMS, Kurtosis…etc.)
- Practical examples.
- Conclusion

19.8.2015 – Michal Vojtíšek (WG 1)

1) Fuels, combustion and emissions workshop

One of the challenges faced by internal combustion engines is finding long-term fuels to reduce dependency on imported petroleum and to reduce greenhouse gas emissions, and to ensure reliable and efficient combustion of such fuels with acceptable consequences on air quality and human health. This workshop will provide an overview of various alternative fuels used or considered for use in internal combustion engines. Adaptation of engines and their fueling systems to biogas, natural gas, alcohols, biodiesel, and other fuels, dual-fuel operation, and various advanced combustion concepts will be discussed. Selected fuels will be tested on one of the laboratory engines. An overview of engine test cell design, procedures, and risk management will be given. Basic experimental procedures, measurement of air and fuel consumption, in-cylinder pressure, and emissions will be presented and demonstrated. (Request from participants to test a specific fuel will be considered.)

20.8.2015 – Eduardo Barrientos (WG 1)

Alternative Powertrains and Advanced Vehicle Technologies and their Impact on Regulated Emissions

1) Compression Ignition Engines Performance and Emissions Optimization workshop
2) Dual Fuel Combustion on Compression Ignition Engines workshop
3) Advanced Electric Vehicle Technologies workshop

1) Compression Ignition Engines Performance and Emissions Optimization workshop

On this session you will learn about some techniques and strategies with great potential to optimize diesel combustion performance and emissions. The first technology covered is engine induced swirl. Swirl is defined as the organized rotation of the engine charge about the cylinder axis. Swirl improves mixing of fuel and air and at optimal value accelerates burn, improves the combustion stability and can decrease particulate matter (PM). However, swirl increases convective heat loss and cylinder charge loss and could increase nitrogen oxides (NOx) emission. High intensity of swirl could impede flame development and increases emissions of unburned hydrocarbons (HC) and carbon monoxide (CO). Therefore, careful and smart selection of swirl optimal values is paramount in order to obtain beneficial impact on combustion and emissions performance.

The second technology discussed is Exhaust Gas Recirculation (EGR). EGR is one of the best technologies known for NOx mitigation. NOx reduction occurs via dilution and thermal mechanisms. Cooling the exhaust gas prior to mixing with fresh intake air reduces NOx emissions further. However, increase of EGR rates has the trade-off of increasing PM formation. Current state of the art on EGR will be covered in this session as well as new development for obtaining optimal EGR rates aimed to attain lower emissions and higher efficiency.

2) Dual Fuel Combustion on Compression Ignition Engines workshop

The past decade has seen a myriad of developments in vehicle technologies and fuel formulation. These have been driven by recent worldwide legislation and concerted efforts to reduce reliance on oil imports and greenhouse gas emissions, while at the same time reducing pollutant emissions. There is a broad effort to develop advanced, efficient, and cleaner powertrain engines. To meet the demands for next generation engines, there has been extensive recent research to develop alternate combustion strategies. Advanced combustion or low temperature combustion (LTC) is a relatively new area of research. The goal of LTC is to have the combustion process to occur at temperatures below those at which Nitrogen Oxide (NOx) forms and at equivalence ratios below those at which there is higher propensity to form soot. Low ignition quality fuels are being studied in advanced combustion modes to control combustion phasing and allow for higher brake thermal efficiency (BTE). One such technology of interest is the dual fuel (or mixed mode) combustion.

In the dual fuel engine much of the energy release comes from the combustion of the gaseous fuel while a small amount of diesel liquid fuel provides ignition through timed cylinder injection. Such operation, with optimum conversion methods, has the potential to provide operational characteristics that are comparable or superior (i.e., enhanced emission characteristics, quieter and smoother operation, improved low ambient temperature operation, and reduced thermal loading) to those of the conventional diesel or spark ignition engines.

In this workshop you will learn about the current state of the art on dual-fuel combustion and also about new research developed by the Josef Božek Research Center for Vehicles for Sustainable Mobility (JBRC) at Czech Technical University (CVUT) on this area.

3) Advanced Electric Vehicle Technologies workshop

As fossil fuel energy sources become more scarce, technologies that show possible potential for decreasing energy use are being increasingly evaluated. Since the transportation sector accounts for about two thirds of the fuel consumption, new transportation technologies are being looked at with increasing vigor. One such new technology are electric vehicles (EV).

Electric vehicles use one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery or generator to convert fuel to electricity. There are many types and configurations of electric vehicles, but generally they fall into three main categories, battery electric vehicle (BEV), extended range electric vehicle (EREV), and Plug-in Hybrid Electric Vehicle (HEVs). HEVs have significant potential to reduce oil consumption, greenhouse gas (GHG) emissions and some regulated emissions.

This workshop will provide an overview of various electric vehicle configurations currently available in the market. Assessment of their impact on emissions and fuel economy will be presented. The well-to-wheel (WTW) cycle impact of each potential powertrain configuration will be evaluated by using the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model developed by Argonne National Laboratory.

<u>21.8.2015 – Ahmed El Sawaf (WG 2)</u>

1) Vibration control using smart structures
2) Multi-actuator optimization for deformation control of smart structure under thermal load

1) Vibration control using smart structures

A smart structure can sense its dynamic loading environment via sensors and modify its behavior in real time, so that it can withstand external dynamic forces. Also, Proportional-Integral-Derivative (PID) control technique and particle swarm optimization (PSO) technique are widely being utilized in many engineering applications. This lecture presents a study on the use of a PSO algorithm to tune the PID controller gains for active vibration control of piezoelectric bonded smart structure. The smart structure is a cantilevered lead-zirconate-titanate (PZT) layered composite plate consists of two PZT layers and graphite-epoxy composite layers. In order to control the vibrations produced by several disturbances, the state space model of the cantilever beam is studied and simulated with the PID controller using Matlab/Simulink software. The PSO technique is used to solve the nonlinear optimization problem to find the PID controller gains for suppressing the vibration induced on the smart structure. The proposed PID tuned by PSO is compared to both the classic PID controller and uncontrolled systems. The simulated results prove that the proposed PID controller tuned by PSO offers a significant improvement in vibration control of the smart structure

2) Multi-actuator optimization for deformation control of smart structure under thermal load

The improvement of smart structures offers great prospective for use in advanced aerospace and vehicle applications which, may exposed to unavoidable thermal environment. This lecture deals with the optimization of the multi-actuator in a smart structure in order to control the deformation caused by a thermal load. It is assumed that prescribed temperature distributions applied to the smart structure while different actuators are placed on the upper surface of the structure when some boundary conditions are imposed. The forces for all actuators are optimized using the particle swarm optimization technique (PSO) in order to control the maximum deformation caused by the thermal load. Illustration of the proposed particle swarm technique will be given. An example model with the theoretical will be showen in Matlab/Simulink program.

24.8.2015 – Vít Doleček (WG 1)

Advanced combustion engine simulation

1) Connection of advantages of 1-D and 3-D simulation methods
2) Use of DASY for optimal downsized engine

1) Connection of advantages of 1-D and 3-D simulation methods

With increasing demands to reduce emissions of greenhouse gases and pollutants combustion engines the need of optimization of the engine during vehicle development is more and more important. The thermodynamic optimization and optimization of individual function groups are one area. The second area is optimization of engine behavior focused on engine control system. If reduction of emission production is the goal, numeric simulation of engine thermodynamics will be our topic.

Numerical simulation can be classified in terms of the level of details from the 3-D simulations to simple algebraic models which its limited accuracy is substituted by computation simplicity. Simplified computational models are more demanding in terms of model calibration, which is compensated by massive reduction of computational time. 3-D simulation models are often used only for limited study area because of computational expensiveness. It can include engine cylinder internal volume or complicated parts of intake or exhaust manifold. Computational time of 3-D simulation of whole engine prevent its use for complete optimization. Simplified 1-D simulation is usually used for engine optimization. Such a model is able to simulate behavior of complete engine and it is also used for control system optimization. It does not affect the formation of the emissions which is main disadvantage of 1-D simulation model.

One possibility is adding detailed model of engine cylinder to 1-D simulation model. It can be either a full 3-D model or the simplified zone model. Both approaches will combine the advantages of 1-D and 3-D simulation models and they enable simulation of the complete engine with emission production.

The first option of simulation models connection is their direct interconnection, where individual equations of both models are calculated in each time-step and they exchange all properties at the volume border, representing their interface. The second option is to use 3-D simulation model only during combustion, when the formation of pollutants happens. The advantage of this solution is further reduction in computational expensiveness. The third option is not direct models connection but create a database of the 3-D simulations results during iterative process. The 3-D simulation results in database could be extrapolated into areas where 3-D simulations are not available. It is possible to further reduce number of 3-D simulations in this way. This method allows subsequent rapid optimization only in 1-D simulation model.

All these methods will be presented with the available results at this seminar.

2) Use of DASY for optimal downsized engine

DASY is an assistance system for design and optimization of engines. This system is being developed at Josef Božek Research Center. This system may include CAD models of individual assemblies, whose dimensions could be optimized in various computational models (FEM, CFD ...). The boundary conditions for computational models can be also supplied by 1-D simulation model.

Engine size reduction (downsizing) is used to increase specific engine power output and thus also to increase its effectiveness. Reduction of mechanical losses, which increases with engine speed, could be arranged by minimizing operation engine speed - downspeeding. Both approaches are applied to modern turbocharged diesel engines. Improving materials and production quality allows a gradual increase in specific engine power output and maximum in-cylinder pressure. Increase of engine specific power also causes increase of mechanical losses caused by higher crank mechanism load and increase of fraction of heat transferred to cooled cylinder walls. During search for total optima were almost all restrictions given by usual engine design removed.

Engine CAD model integrated in DASY, thermodynamic engine model with several other models for mechanical losses determination were used for an optimal downsized diesel engine design. The results of optimization found with help of genetic algorithm will be presented at this seminar.

Several engine variants were derived from optimized simulated working points. They were compared with each other in driving cycle simulations. Downsize intensity could be chosen from the results of driving cycles fuel consumptions for future engine development.

25.8.2015 – Erik Prada (WG 3)

1) Mechatronic systems and their application
2) Geometric mechanics and its application on the Mechatronics field
3) (Practical session) Design and simulation of Electromagnetic actuator

1) Mechatronic systems and their application

The structure of mechatronic systems. What is physical, topological, mathematical and numerical model in process of modeling mechatronic systems. Introduction into modeling and simulation of mechatronic systems.

Decomposition of mechatronic systems - description of logical connections inside mechatronic system. Physical basics of principles actuators and sensors. Control theory and its impact in mechatronics.

Use of mechatronic approach in the automotive industry.

2) Geometric mechanics and its application on the Mechatronics field

Introduction to configuration space. Basics of the term of manifolds, Lie groups, Euclidean Group, functions and curves on the manifold, Fibered manifold, Fiber bundle, Tangent budle, Connection(principal bundle), velocities of mechanical systems and other important terms from differential geometry. Description of the locomotor mechanical systems with formalism of geometric mechanic. Classification of locomotor mechanical systems. Nonholonomic mechanical systems.

3) (Practical session) Design and simulation of Electromagnetic actuator

Physical principles of electromagnetic actuators. The important design and material properties of individual parts of electromagnetic actuator. Creating a numerical model and calculating the magnetic field with using FEM software. Determination of the static characteristics of a particular type of design of electromagnetic actuator with specific materials. Important calculations of magnetic force with application of Maxwell stress tensor. Derive a static characteristic of inductance, and the energy of the magnetic field from numerical solution.

26.8.2015 – Zdeněk Neusser (WG 2)

1) Kinematics of robotic systems
2) Dynamics of robotic systems

1)Kinematics of robotic systems
Seminary deals with the kinematic description of robotic systems and solution of their kinematics by numerical and analytical methods. The course contains modeling of robotic systems, structural analysis, matrix description of kinematics, closed loop solution, sectioning method, body removal method and compartment method. Numerical and analytical solution of the kinematics will be shown.

2)Dynamics of robotic systems
Seminary deals with dynamic description of robotic systems and solution of their dynamics. The course contains assembly of dynamic model using Newton-Euler equations and Lagrange equations of mixed type, integration methods of obtained algebra-differential equations and their stabilization, relation between Newton-Euler and Lagrange equations, explained physical meaning of Lagrange multipliers, recursive methods dynamic equations assembly and dynamic equations of flexible multibody systems.

27.8.2015 – Michal Vojtíšek (WG 1)

1) Particle emissions measurement workshop
Particulate matter emitted by internal combustion engines is probably the most detrimental air pollutant in cities, claiming over 400 thousands premature deaths annually in the EU. This workshop will provide an introduction to the legislated particle mass and number measurement procedures. Vehicle test selection, vehicle preconditioning, exhaust dilution and sampling, filter handling and weighing procedures for gravimetric particle mass measurement, measurement of particle number as per Particle Measurement Program, and new and emerging legislation will be presented and demonstrated. Selected measurements of unregulated properties such as particle size distribution, particle sampling for off-line analysis will be presented and demonstrated. Students can bring their own instruments for comparison and validation. (Requests for specific engines, fuels and tests will be considered.)

28.8.2015 – Michal Vojtíšek (WG 1)

1) **Real driving emissions measurement workshop**

Emissions under real-world operating conditions are often different, typically higher, than during laboratory testing. This workshop will provide an overview of the real driving testing procedures. Vehicle and route selection, measurement of exhaust flow, measurement of regulated and selected unregulated pollutants, using batteries and power electronics and management to provide power to on-board instruments, instrument installation and attachment, and operation and road safety procedures will be demonstrated on a selected vehicle. (Request from participants to test a specific vehicle, or to bring their own vehicle for testing, will be considered.)