DIN

DEPARTMENT OF INDUSTRIAL ENGINEERING

PhD Course in Mechanics and Advanced Engineering Sciences (DIMSAI)

YEARLY PHD STUDENT REPORT - AY *2016/2017*

Curriculum number *2*

Cycle *30°*

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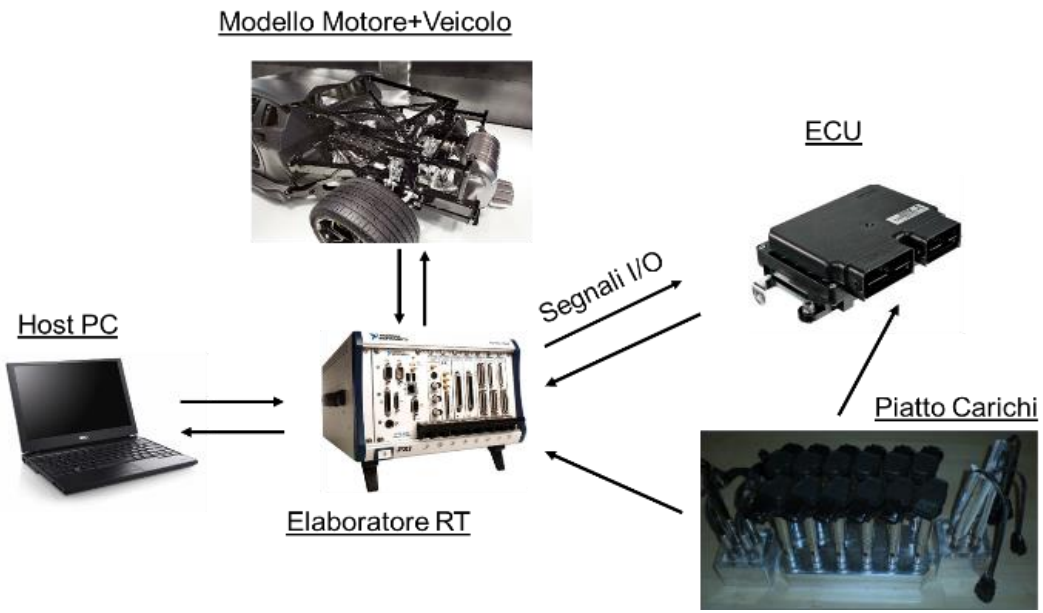
Sviluppi sistemi Hardware-in-the-Loop HIL

IL PRESENTE MATERIALE È RISERVATO AL PERSONALE DELL'UNIVERSITÀ DI BOLOGNA E NON PUÒ ESSERE UTILIZZATO AI TERMINI DI LEGGE DA ALTRE PERSONE O PER FINI NON ISTITUZIONALI

HIL System Definition

Hardware-in-the-Loop scheme:



Main features:

- Low cost
- ECU development system
- ECU pre-calibration system
- Control strategies validation
- Electronic systems testing

HIL system's results depends on accuracy of the simulation's models implemented.

TARGET:

Development of specialized models, related to automotive world, in order to create a library dedicated to HIL systems.

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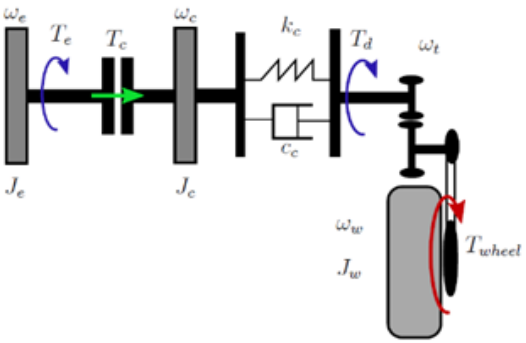
Motorcycle Dynamic Model

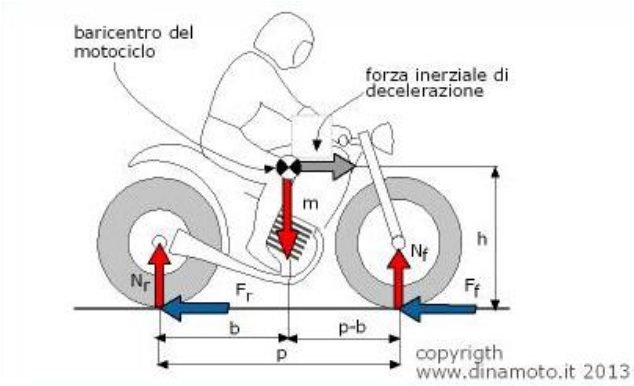
Driveline Motorcycle scheme:



Target:

Motorcycle longitudinal dynamic model for HIL systems, starting from a 4WD vehicle

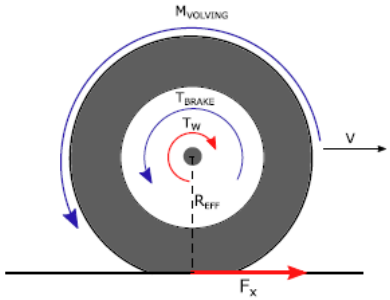
Vehicle Motorcycle scheme:



$$\begin{cases} T_{eng} - T_{clutch} = J_{eng}\omega_{eng} \\ T_{clutch} - T_d = J_{clutch}\omega_{clutch} \end{cases}$$

$$T_{wheel} = \frac{T_d}{\tau_{gear} * \tau_{chain}}$$

Wheel Balance & Paceijka Model:



$$\begin{cases} F_{front} + F_{rear} = F_{drag} + F_{slope} + m^*\ddot{x} \\ mg - N_{rear} - N_{front} = 0 \\ (F_{front} + F_{rear})h - N_{rear}b + N_{front}(p-b) = 0 \end{cases}$$

$$\begin{cases} J_{wheel}\dot{\omega}_{wheel} = T_{wheel} - T_{brake} - M_{volving} - F_{res} * R_{eff} & Rear \\ J_{wheel}\dot{\omega}_{wheel} = -T_{brake} - M_{volving} - F_{res} * R_{eff} & Front \end{cases}$$

$$F_X = D * \sin\{ C\tan^{-1}[B\sigma_{wheel} - E(B\sigma_{wheel} - \tan^{-1}(B\sigma_{wheel}))\ ]\}$$

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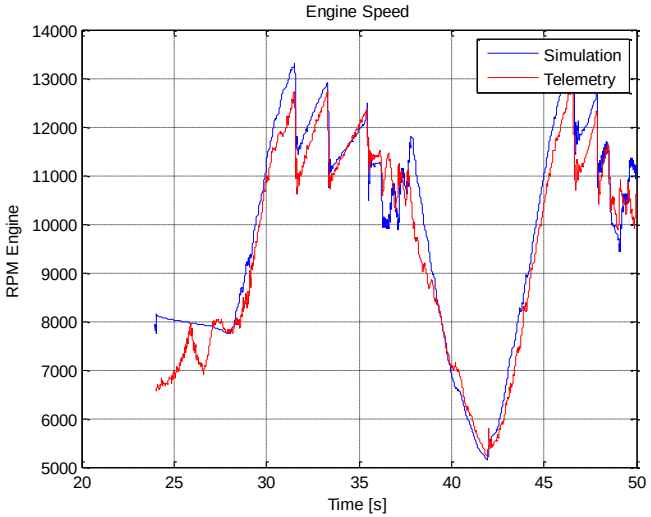
Motorcycle Dynamic Model

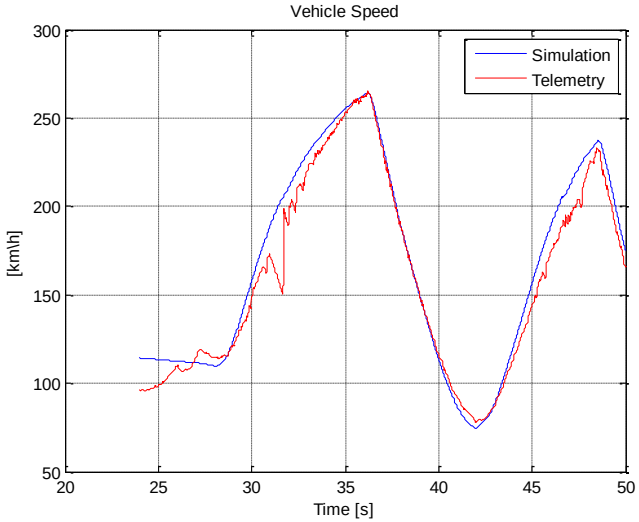
Main features:

- Zero-dimensional model implemented in Matlab-Simulink
- Real time resolution capability
- Racing application possibility
- Identification on telemetry data of a track lap
- Generic model, with a dedicated identification of all the parameters, could simulate another motorcycle's one

Conclusions:

The model, stimulated with appropriate input, is able to simulate real motorcycle's behaviour. Simulations' output, compared to telemetry data, show how model's accuracy agree with HIL system requirements.





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Elastomeric Model

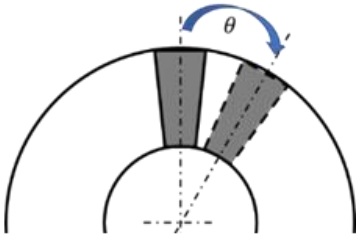
In automotive world, elastomeric components are widespread for:

- Suspension elements
- Damping elements in torque transmission systems

HIL simulations' systems, realized for driveline control strategies, could be enhanced with the insertion of a specific elastomeric model.

Target:

Development of an elastomeric model that could be resolute in real-time condition and that could be identified for different rubber elements with the support of an automatic procedure



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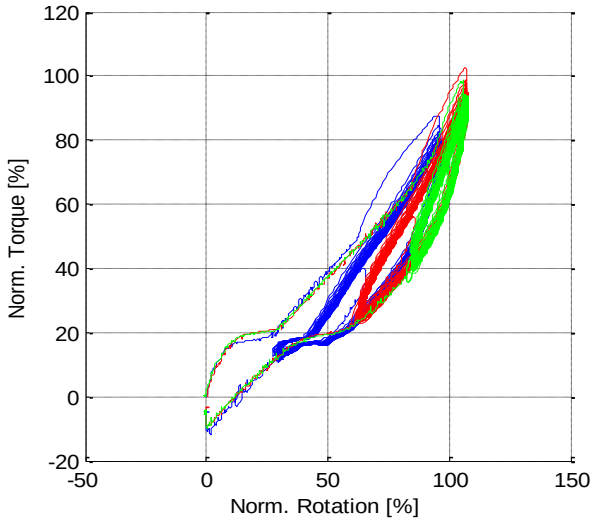
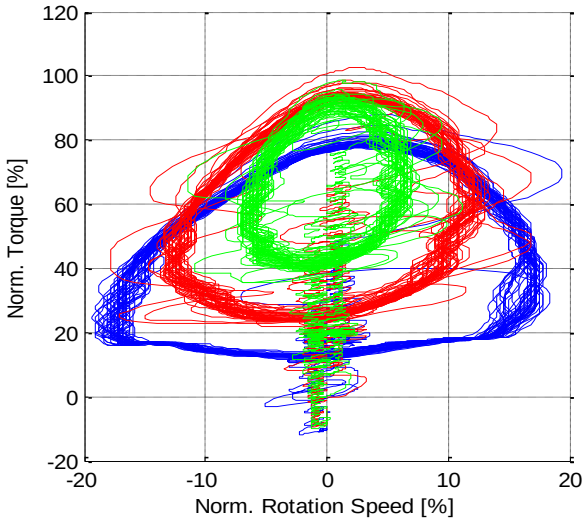
Elastomeric Model (1)

Two elastomeric elements are available to model's study. First component's experimental data and bibliographic papers describe this materials with:

- Presence of a load-deformation hysteresis loop;
- Quasi-linear response during loading phase;
- Non-linear response during unloading phase with decreasing of Young's modulus;
- Variable response with respect to time: firsts cycles are affected by higher stiffness than steady cycles (Mullins Effect);
- Translation of hysteresis loop depending on preload.

All these features have to be taken in account during model's development.





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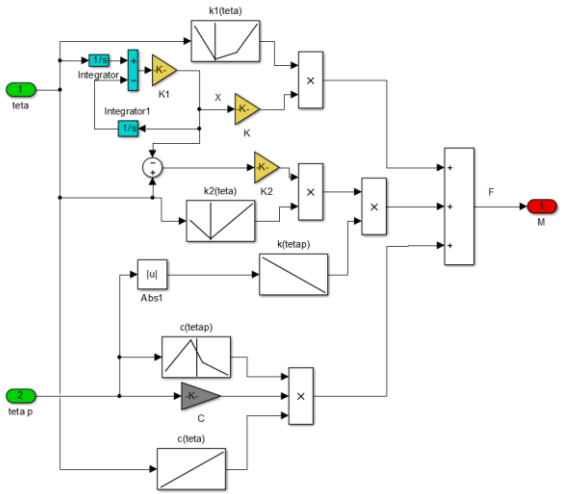
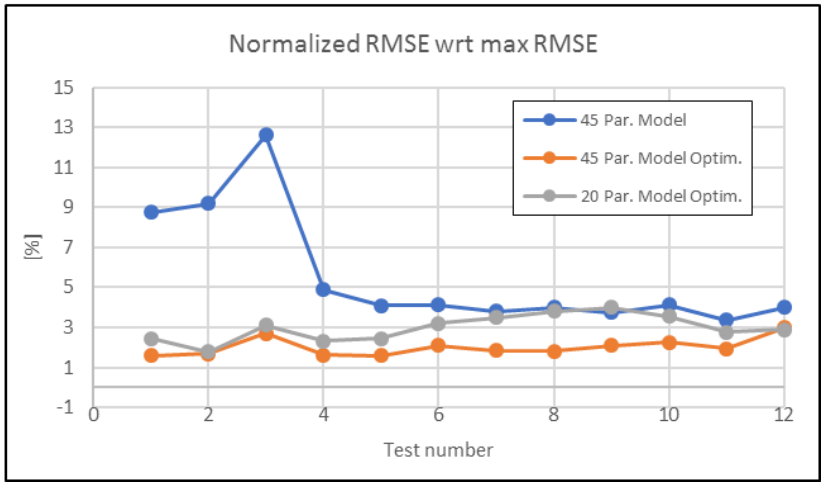
Elastomeric Model (1)

Model features:

- Zero-dimensional model
- Matlab-Simulink implementation
- Mullins effect simulated with first order transfer function
- Automatic procedure for parameters' identification





Conclusions:

- Good results with first attempt parameters in most of available tests
- Better results with automatic procedure of parameters' identification
- Automatic identification allows model simplification keeping good results

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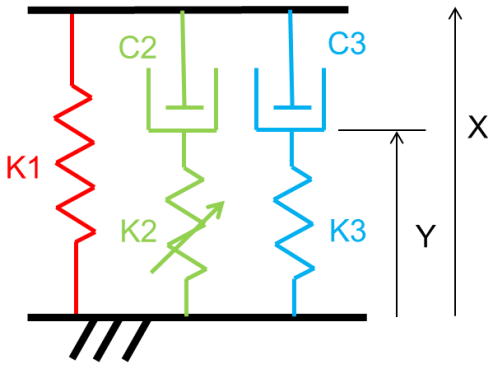
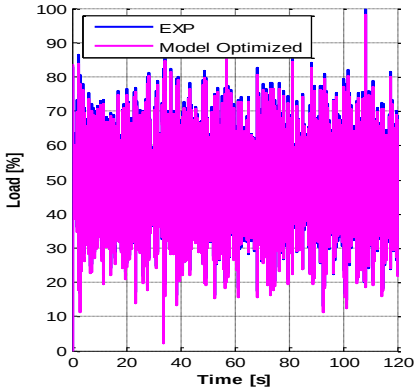
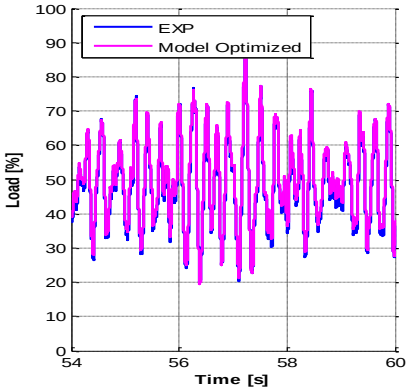
Elastomeric Model (2)

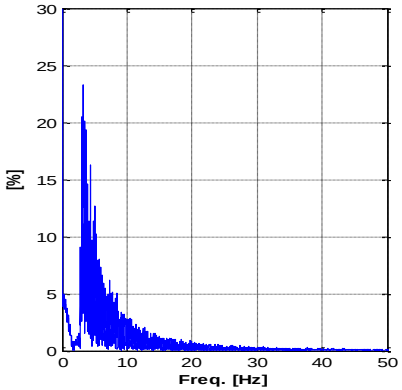
New elastomeric component development:

- Automatic model's identification on new experimental data
- Model simplification due to absence of Mullins effect and non linear behaviors
- New dedicated automating identification
- RMSE in a random test less than 2% (wrt to medium value)









Conclusions:

The model is able to reproduce experimental stress measures in face of imposed displacement for two different components, with a dedicated parameters' identification.

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Knock Model

Closed-loop control strategies of the combustion process are used for performance improvement in automotive racing applications. The focus is on a knock phenomena that could be controlled in closed-loop with the support of Combustion Analysis Systems (CAS) or accelerometers or ION currents.

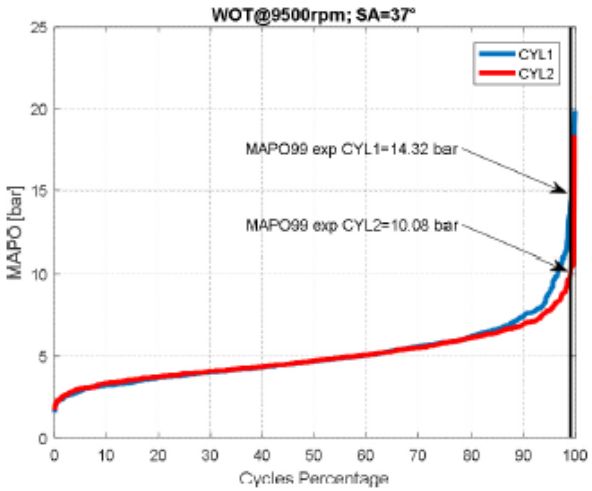
Target:

Development of a knock model in order to study and to validate closed-loop combustion control strategies.

Model has to be studied and validated on a 2 cylinders SI engine.

Main requirements:

- Real-time resolution
- Model has to be correlate with the main engine parameters such as revolution speed, spark advance, geometry, lambda ecc
- Knock value dispersion has to be taken into account due to combustion CoV and knock dispersion itself



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Knock Model

Knock model is basically based on two steps:

- Estimation of the autoignition time of the mixture, with Arrenhius approach:

$$\frac{1}{\tau} = \frac{1}{(\tau_1 + \tau_2)} + \frac{1}{\tau_3} \qquad with \qquad \tau_i = A_i p_{cyl}^{-n} \exp\left(\frac{B_i}{T_{unburned}}\right)\left(\frac{1}{\lambda_i}\right)^{x_i}$$

- Determination of knock intensity index correlated with measured MAPO:

$$kn_{index} = K_1 \frac{rpm}{1000}\left(\int_{IVC}^{EVO} \frac{dt}{\tau}\right) + K_2\left(\frac{k-1}{V}((1 - x_{burn})CHR_{net})\right)$$

Pressure and temperature evolution inside the combustion chamber could be calculated from engine general parameters.

Many combustion simulation first attempt values came from CFD simulation and then recalibrated on a specific engine.

Dispersion combustion behaviour is simulated with a gaussian distribution of the temperature value at the intake valve closing, one of the main model's input.

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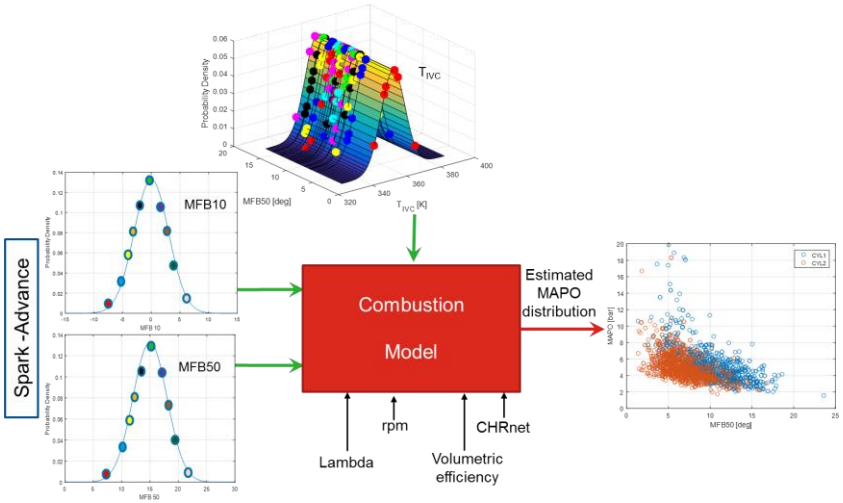
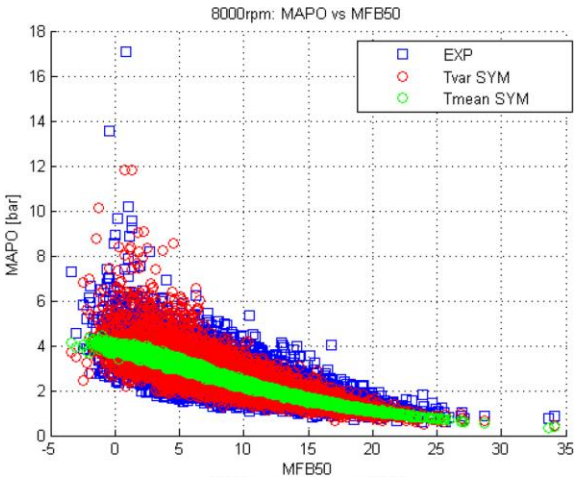
Knock Model

Simulation model scheme:



Simulation results:



Conclusions:

A real time model implementation has been developed in order to capture experimental data. Also combustion dispersion has been taken into account. All model's inputs are engine general parameters, so the model could be appropriate for HIL systems.

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Conclusions

Main results obtained in the development of HIL systems during PhD course:

- Many specific models for HIL systems are presented in order to create general library linked to automotive world
- All the models developed are applicable to different components/systems with a dedicated identification of their parameters
- Development of an automatic parameters' identification procedure
- Models are validated on experimental data
- Real-time requirements are satisfied with zero-dimensional approach

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