POLITECNICO DI MILANO

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Longitudinal dynamics: appendixes

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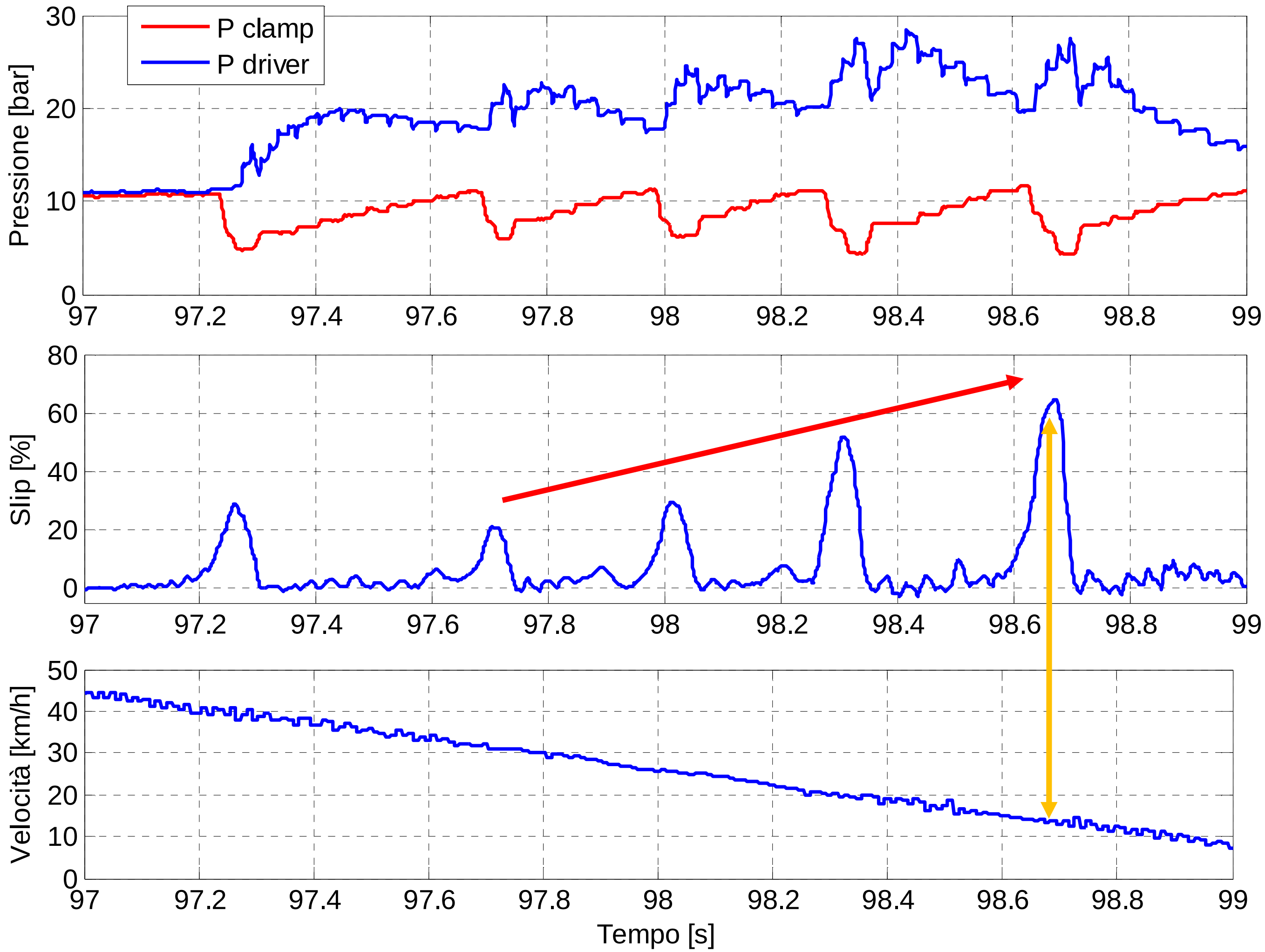
Appendix 1: experimental results (ABS)

The following slides are adapted from those used in the course ''Automazione nei mezzi di trasporto''

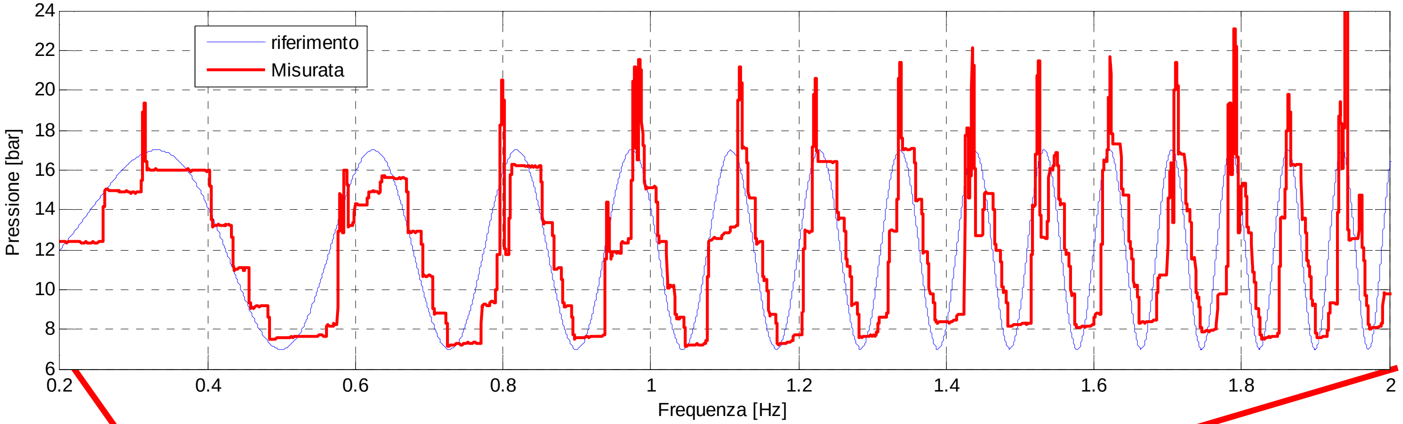
(M.Sc. course at the Politecnico di Milano, Prof. Sergio M. Savaresi)

Application example (ABS standard)
ABS active



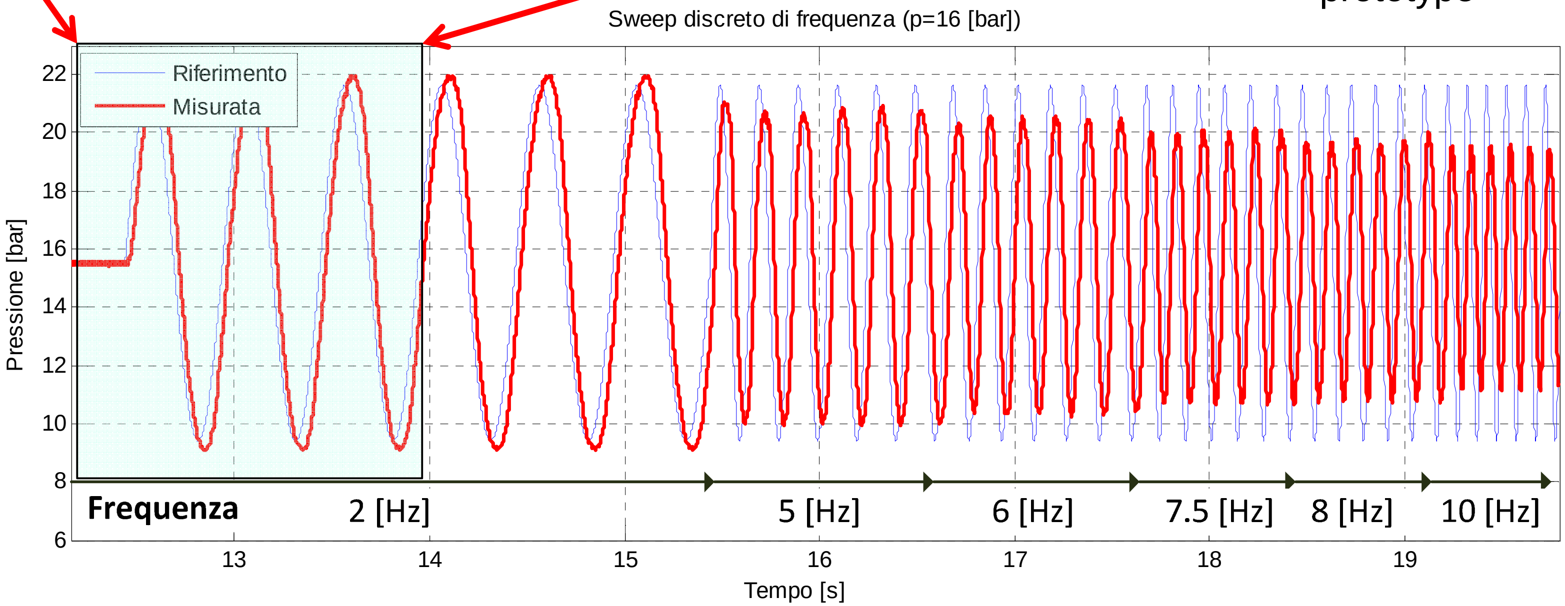
Deceleration average: 0:49 g

Comparison of actuators
Pressure-tracking results (comparison)



Traditional electro-hydrualic system (ABS - in production)

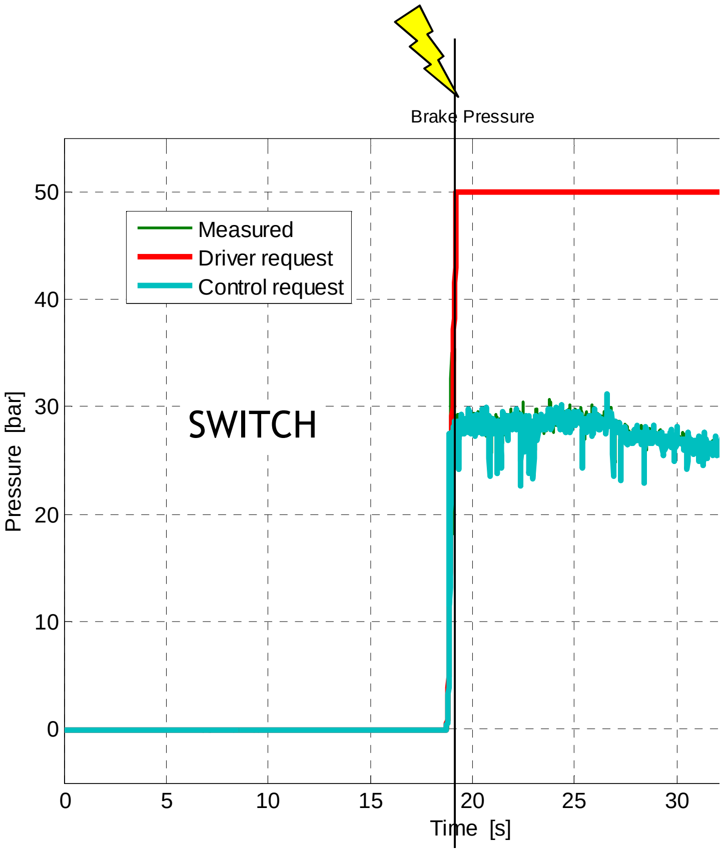
BBW prototype

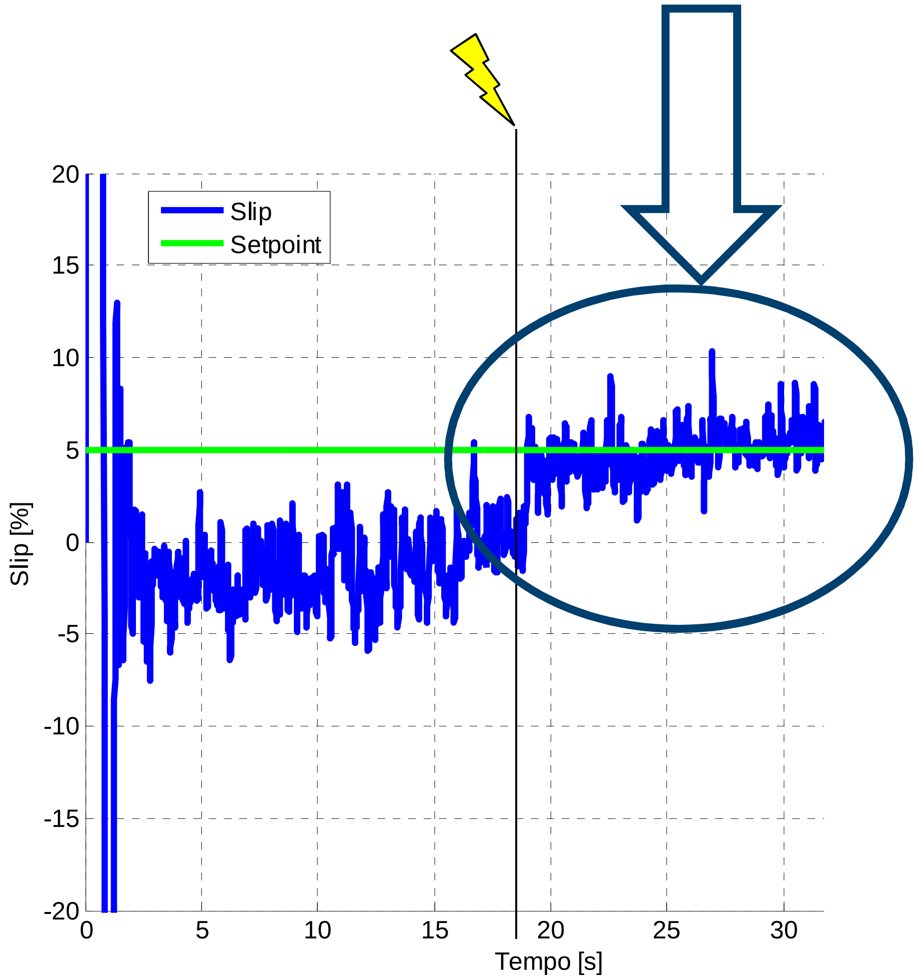


Slip-control results (example – advanced BBW actuator)

Very accurate slip-tracking

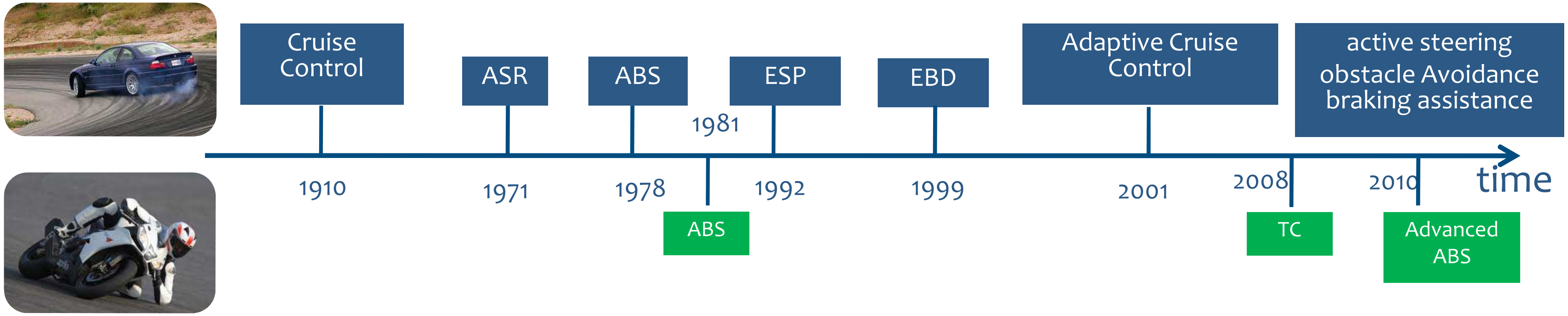
Panic-brake experiment with target slip at 5%





Appendix 2: two-wheeled vehicles

Cars vs. Motorcycles



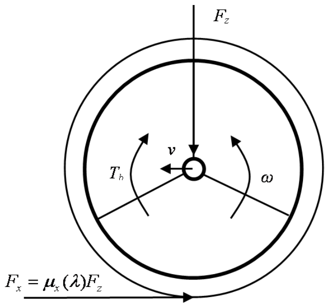
References:

Corno, Savarsi, Balas, Linear, Parameter-Varying Wheel Slip Control for Two-Wheeled Vehicles, IJRNC, 2009.

M. Tanelli, M. Corno, I. Boniolo, S. M. Savaresi. Active Braking Control of Two-Wheeled Vehicles on Curves. IJVAS 2009.

Braking Dynamics

Longitudinal dynamics is mainly influenced by the tyre characteristic and the load acting on the tyre.

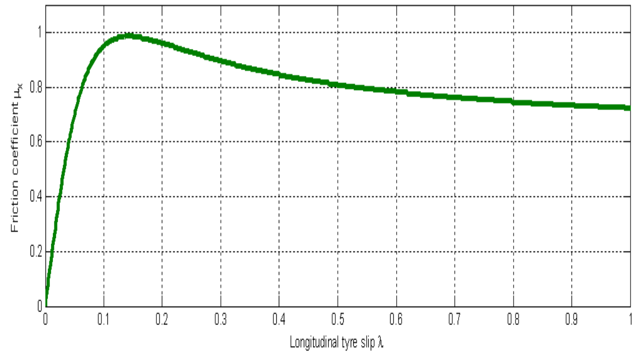


$$\lambda = \frac{v - \omega r}{v}$$

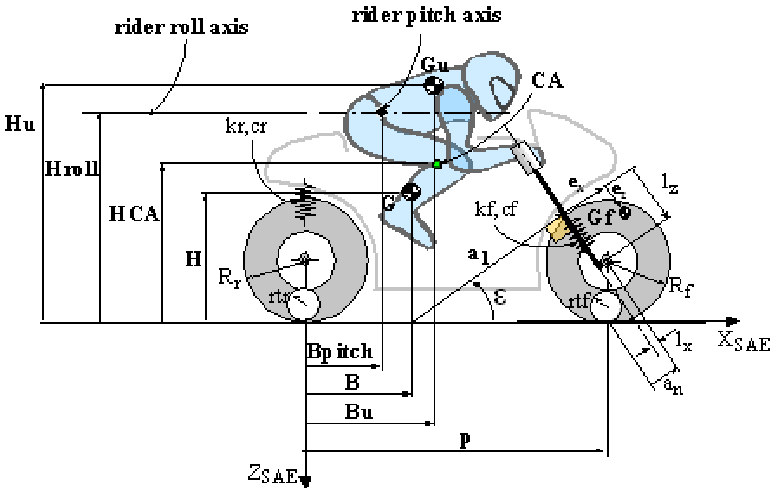
$$F_x = \mu_x(\lambda, \alpha, \gamma)F_z$$

α sideslip

γ camber angle



The **single corner model** fails to account for the varying vertical load. The two-wheeled longitudinal dynamics can be obtained by linearization of a multi-body simulator

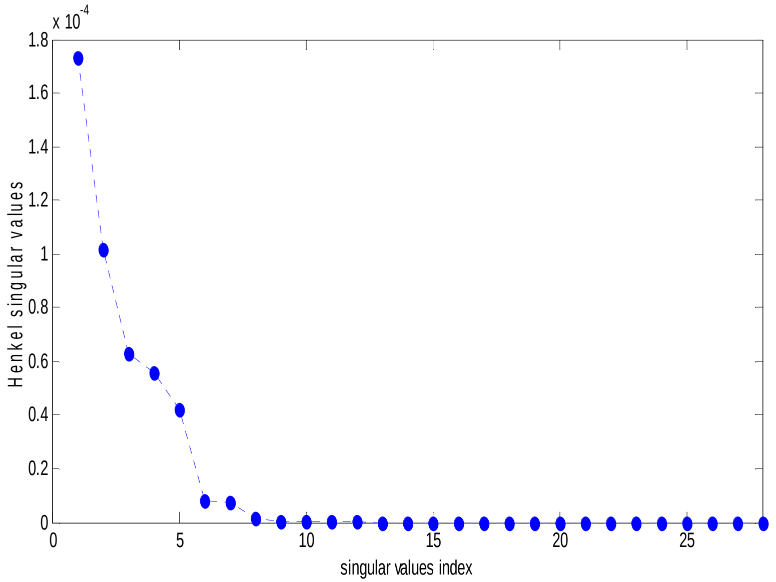


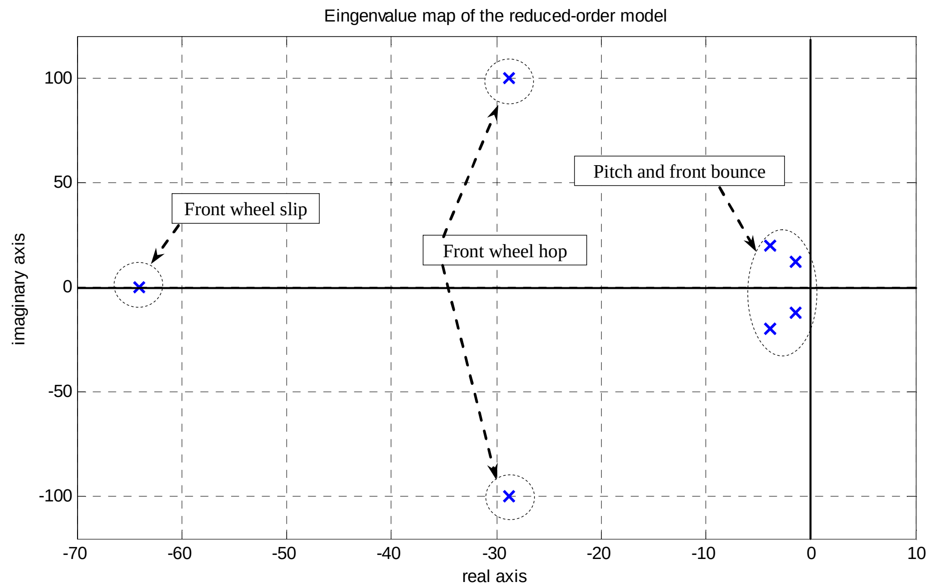
14 degrees of freedom and takes into account phenomena like tire relaxation length, non linear suspensions characteristics, tyre stiffness, aerodynamics and rider's attitude.

Linearization done symbolically

Braking Dynamics Linearization

The dynamics between braking torque and wheel slip has been considered.



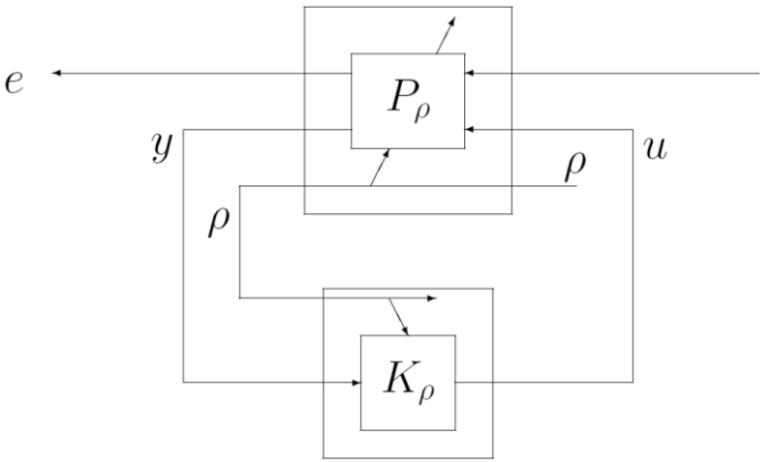


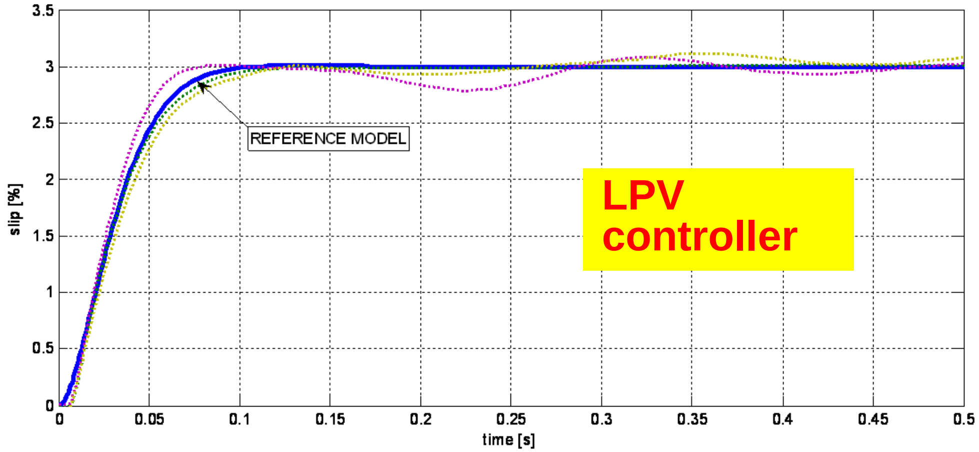
Out of the 28 modes only 7 are relevant to the considered dynamics: whic can be interpreted with the following in-plane dynamics:

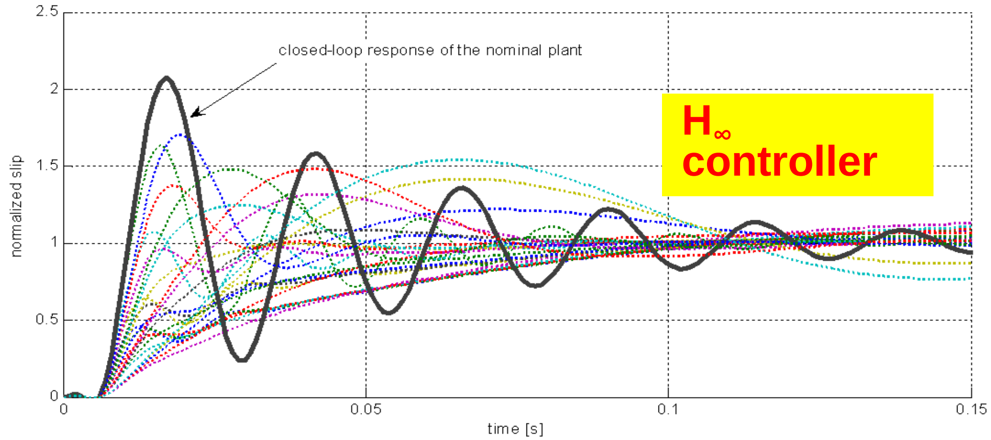
- one real pole: the wheel-slip pole also modeled by the single-corner model;
- one couple of complex poles: front wheel hop modes (15-17 Hz);
- two couples of complex poles: heave and pitch (2-3 Hz).

LPV Wheel-Slip Control Synthesis – main result

LPV techniques allow to explicity take into account parameter dependence in the controller synthesis (parameters: speed, slip)







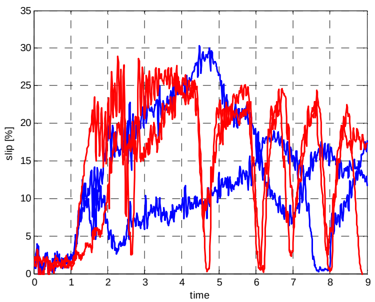
TC generations...

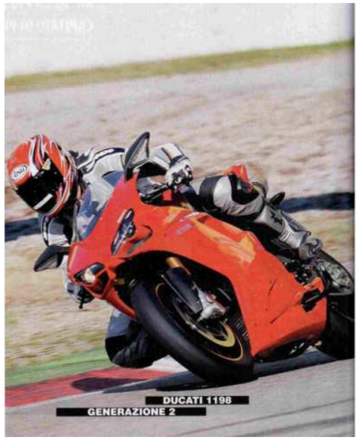
Generation 1

Mainly (only) safety-oriented

No ride-by-wire

Minumum sensors



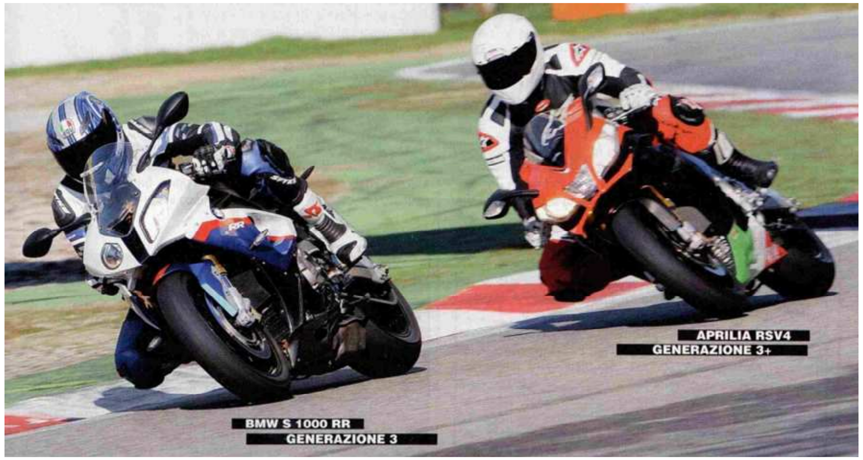


Generation 2

Performance-oriented!!!

Still no-ride-by-wire

Simple roll-angle detection



Generation 3

Ultimate-performances

Full roll-angle estimation

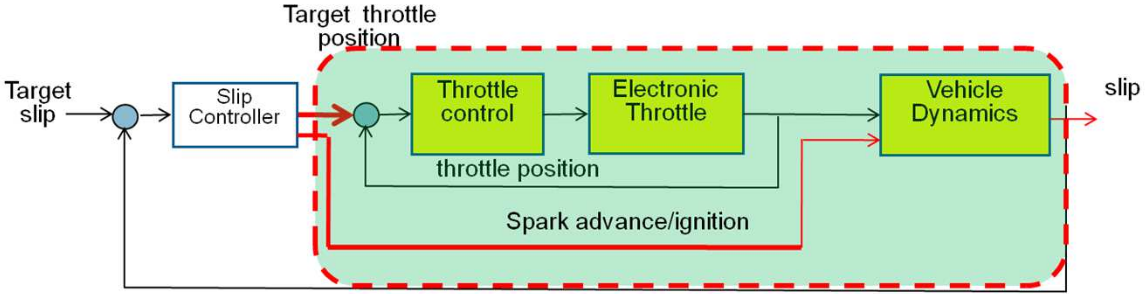
Ride-by-wire
Smooth feeling ("traction-control mode")

+ "Gadgets" (wheelie, launch...)

Appendix 3: Traction Control

Black-box identification of engine-to-slip dynamics for motorcycle traction control

Corno, M. and Savaresi, S.M.: Experimental Identification of Engine-to-Slip Dynamics for Traction Control Applications in a Sport Motorbike. European Journal of control, vol.16, no.1, p. 88-108, 2010.



The control variables taken into account are the **throttle set-point** and **spark advance**
The controlled variable is the **rear wheel slip**

Developing a first principles model of the dynamics would be very demanding as the dynamic is very complex (**engine, transmission, wheel dynamics, pitch and vertical dynamics ....**).

Approach: black-box modeling

Experimental set-up (I / O)

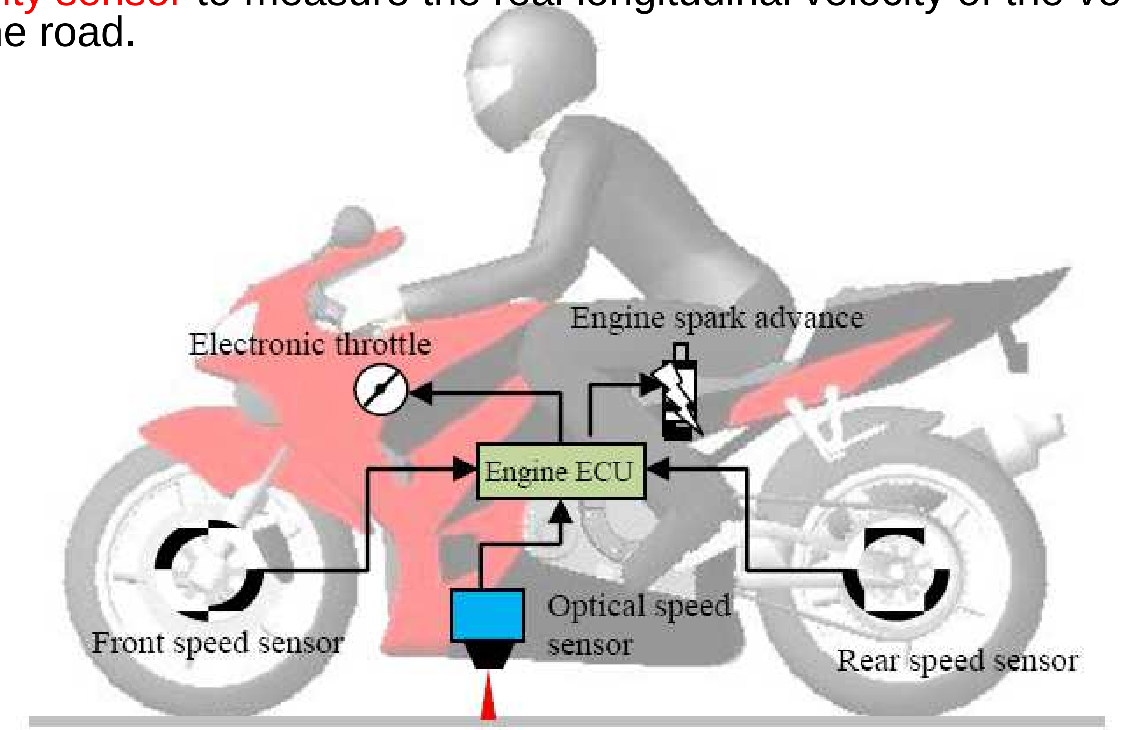
The experiments were performed on a World-championship SBK motorcycle (1000cc 4-stroke 4-cylinder engine, with more than 200 HP). The motorbike is equippedwith:

• an Electronic Throttle Body (ETB)

• an Electronic Control Unit (ECU) to control the throttle position and the engine spark-advance;

• two wheel encoders to measure the rotational speed of the wheels;

• an optical velocity sensor to measure the real longitudinal velocity of the vehicle chassis with respect to the road.

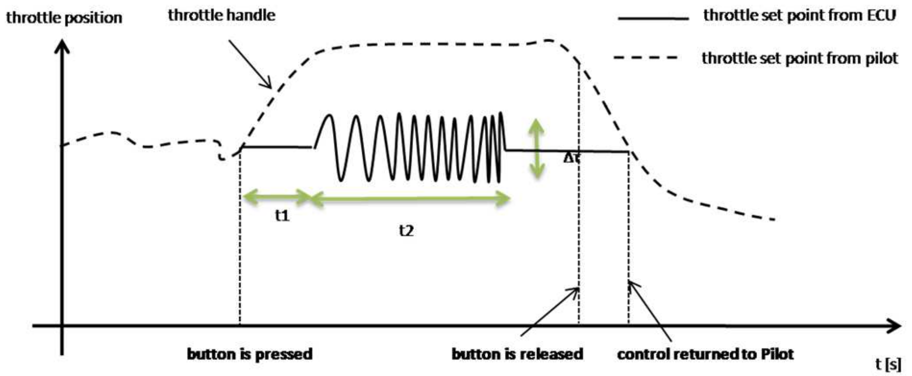


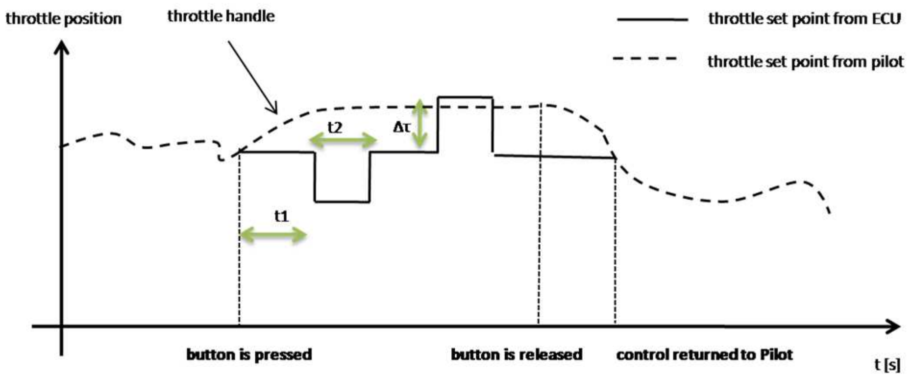
Design of experiments

Tests on a long (3.5 km) straight dry asphalt patch:

1) the rider is asked to Trim the motorcycle to constant speed
2) the test is trigged by the driver with a button: At that point the ECU completely command overrides the driver, and the excitation signal is applied around the neighborhood of the initial condition.

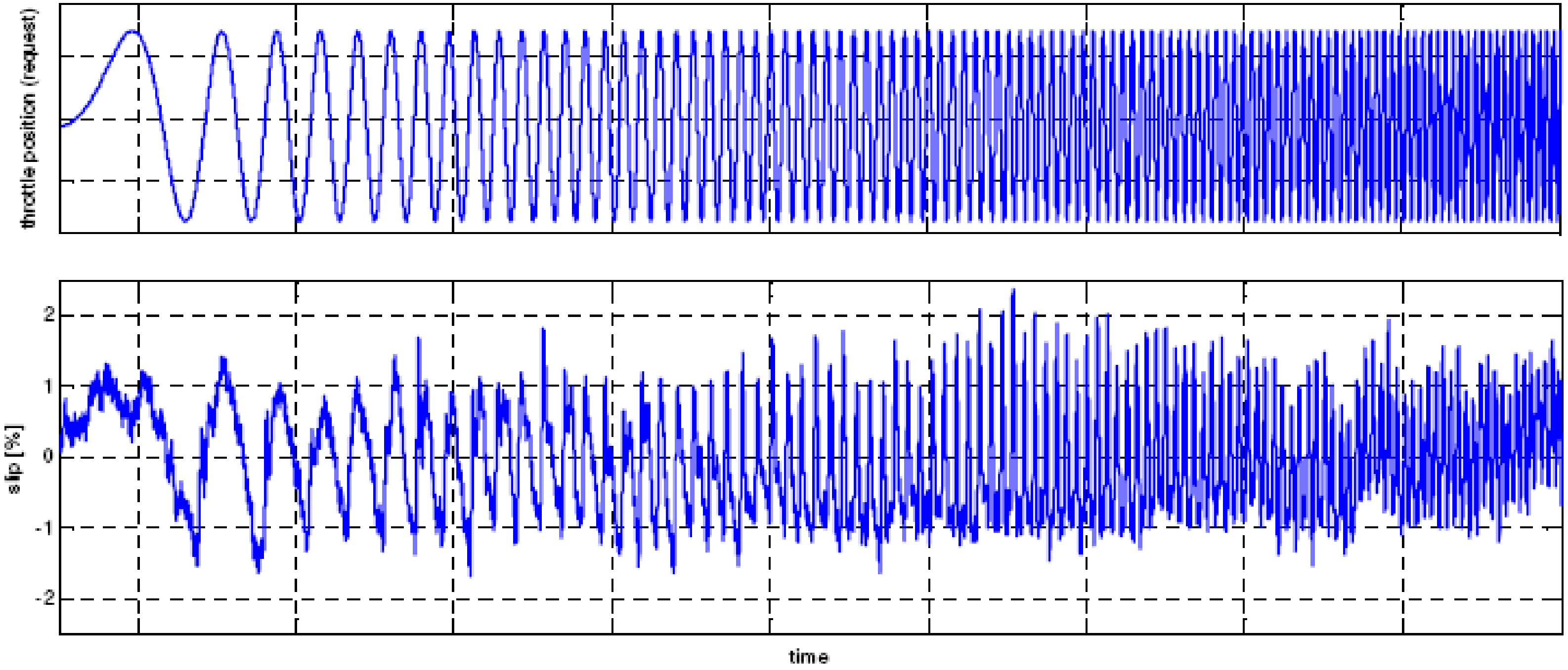
This experiment is non-trivial, but has the major advantage of **being repeatable and providing the real dynamic behavior of the motorbike** (and rider), on a real test-track (**whereas test-rig experiments are in general affected by non-realistic conditions)**.





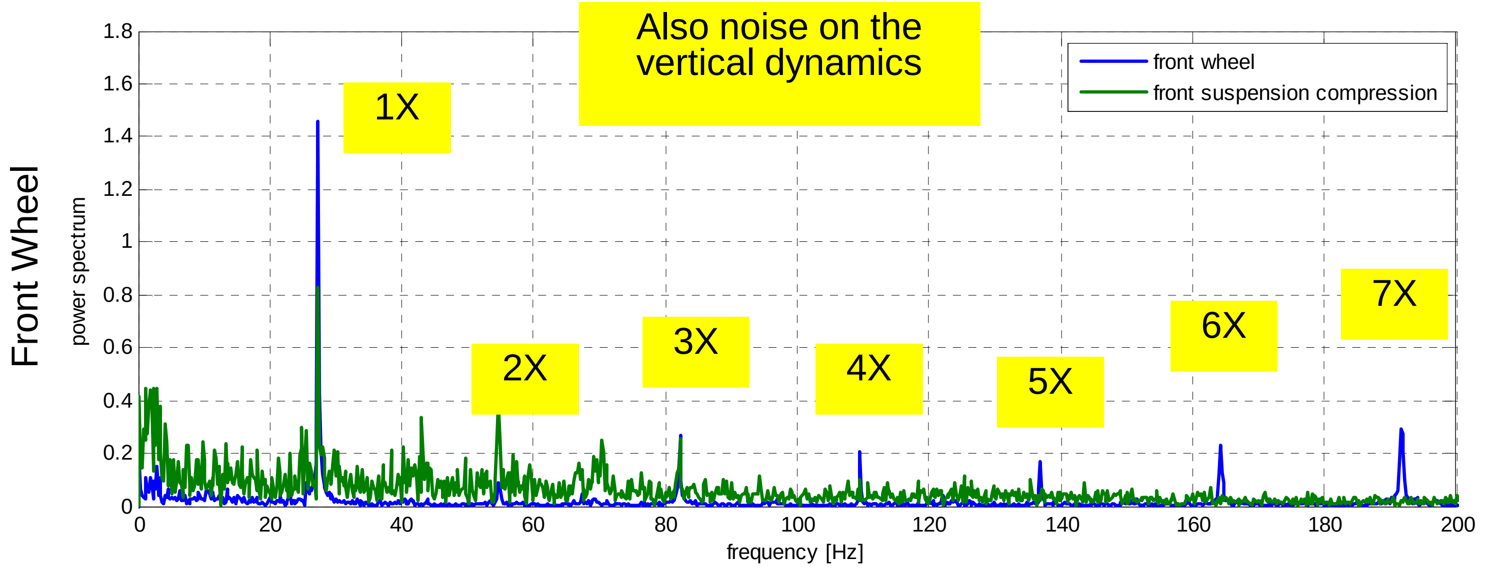
Two different excitations are considered: 1) sine sweep
2) sequence of steps

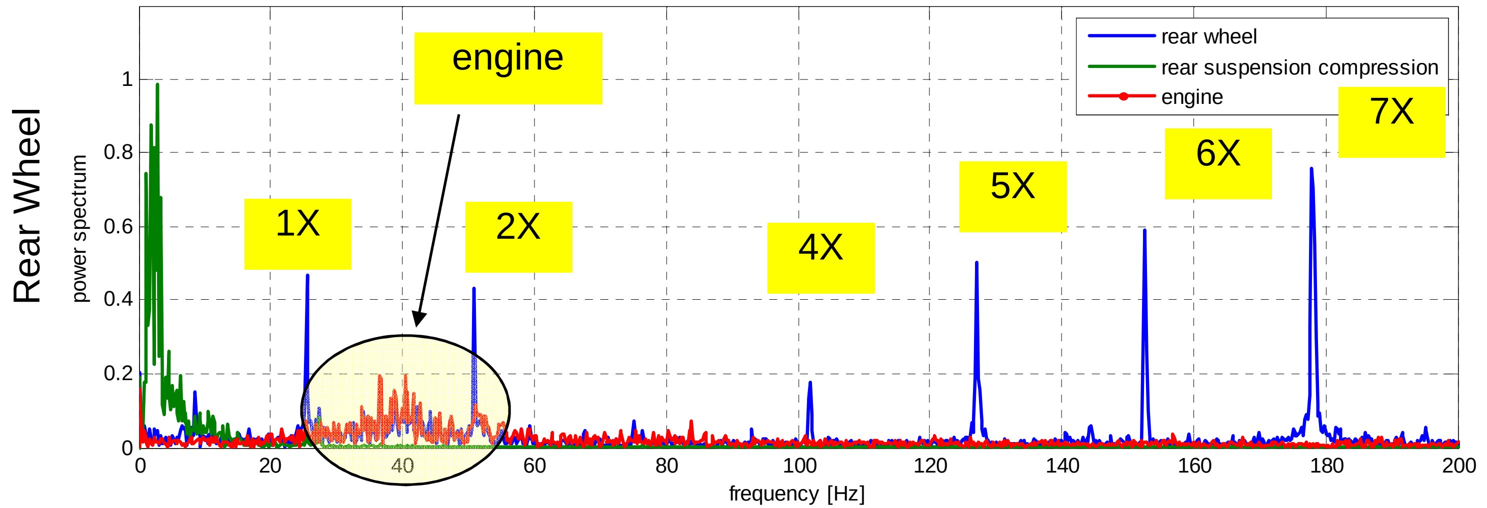
Tests Protocol - example



Example of a throttle sweep experiment. Top: requested throttle position; bottom: measured wheel slip.

Estimated slip - disturbances





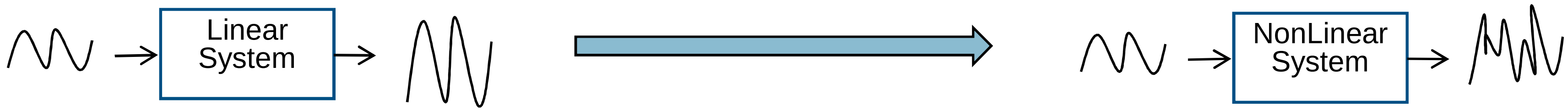
1X @ 182 km / h:

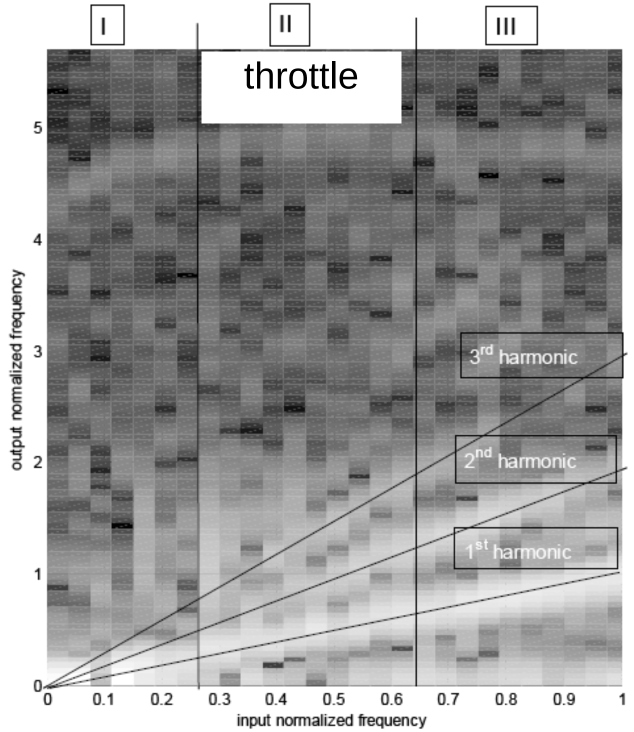
-27.4 Hz front

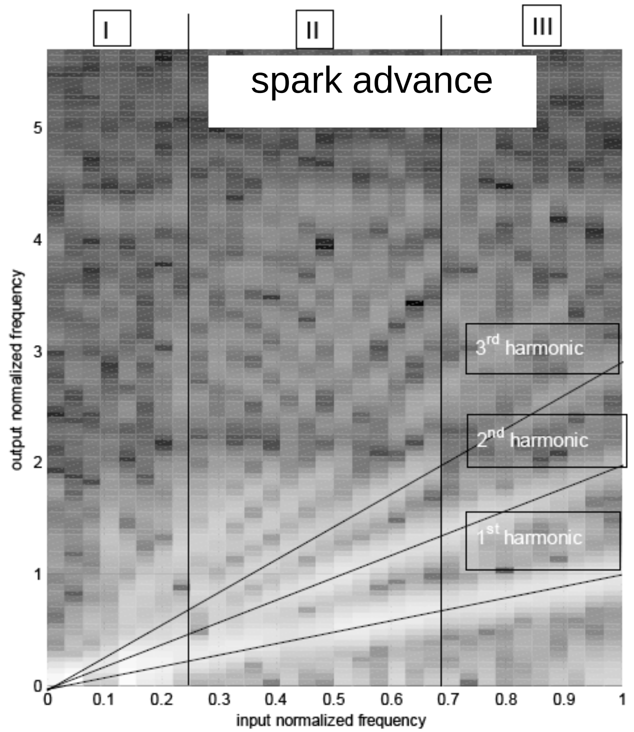
-25.5 Hz rear

Black-Box Identification - spectrograms

Sine sweeps provide an immediate way to quantify the system nonlinearities.

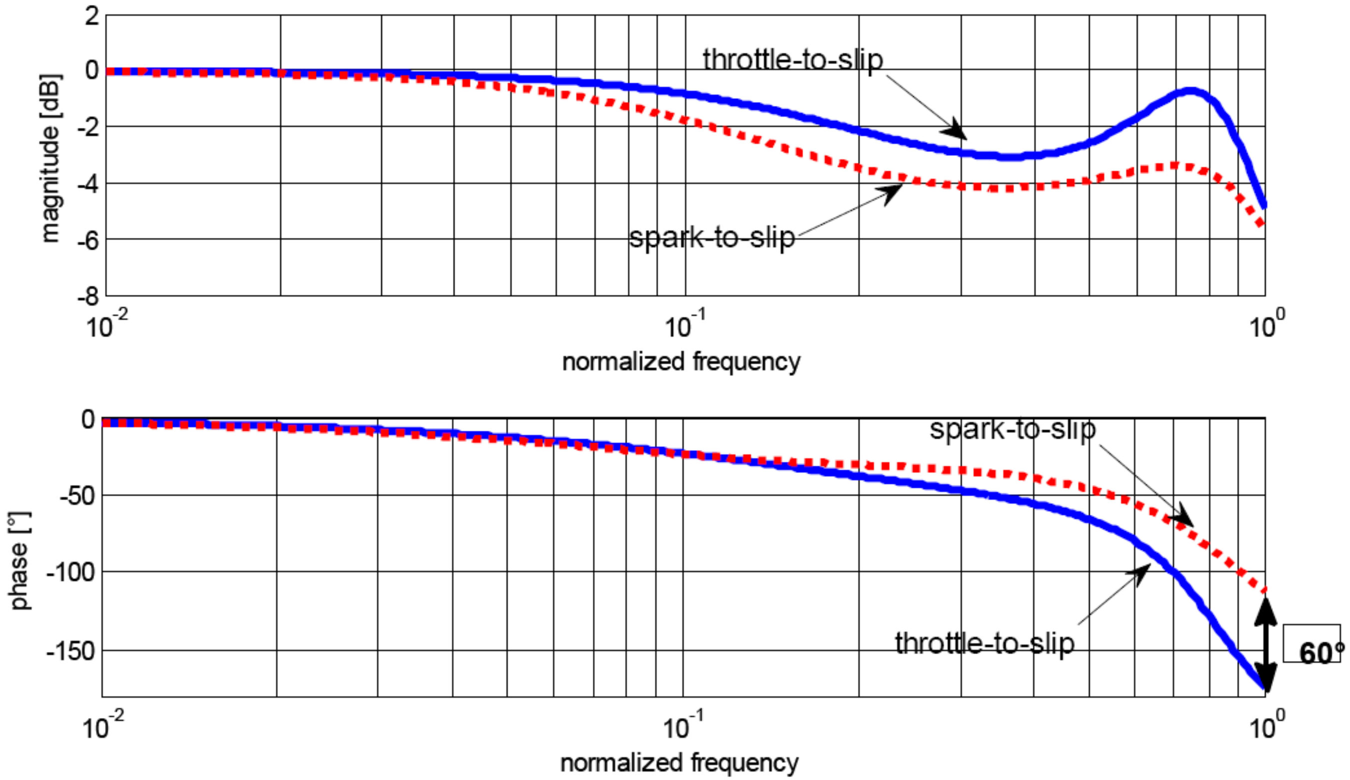






The system is strongly nonlinear

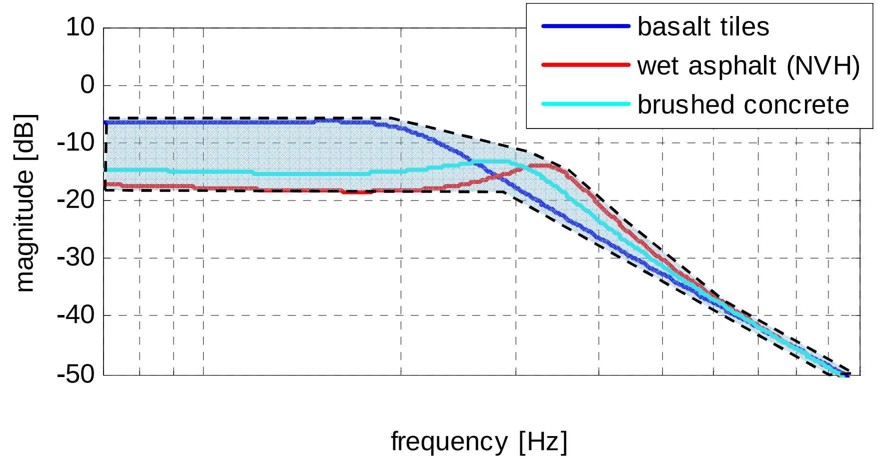
Black-Box Identification - Conclusions

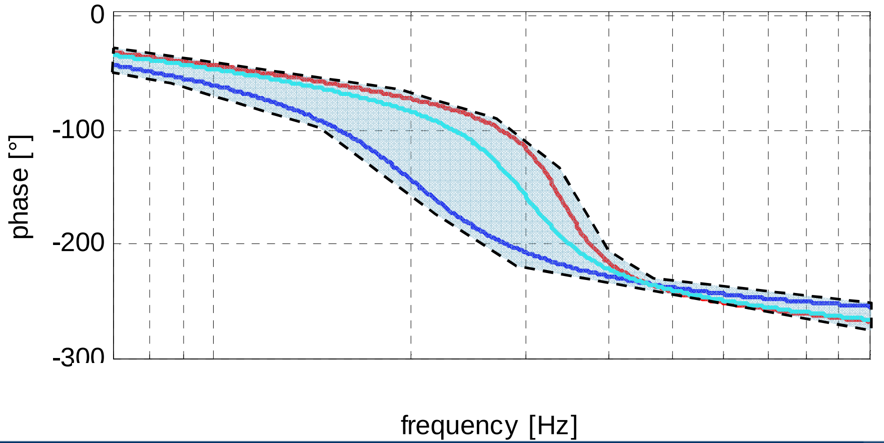


traction control via throttle is doable.

Using ALSO spark-advance enalrges the bandwidth of the traction-control loop

Longitudinal Wheel Slip Dynamics – sensitivity to road surface





1) There is a considerable spread in terms of **gain**
2) There is a considerable spread in term of **phase**
3) The **worst** conditions are those with **low friction** surfaces (worst phase loss)

Slip control

- **Remark: the closed-loop performance depend on the operating point**