An experimental study as reference for magneto-rheological damper modelling and control

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Agenda

- Teamwork
- Introduction
- Literature review on MR damper experimentation and modelling
- Experimental study on MR damper
- Results
- MR damper modelling
- Controllers for semiactive suspensions
- Conclusions and further work

Teamwork

Postgraduate Cooperation Program (PCP) between Mexico by CONACYT and France by CNRS

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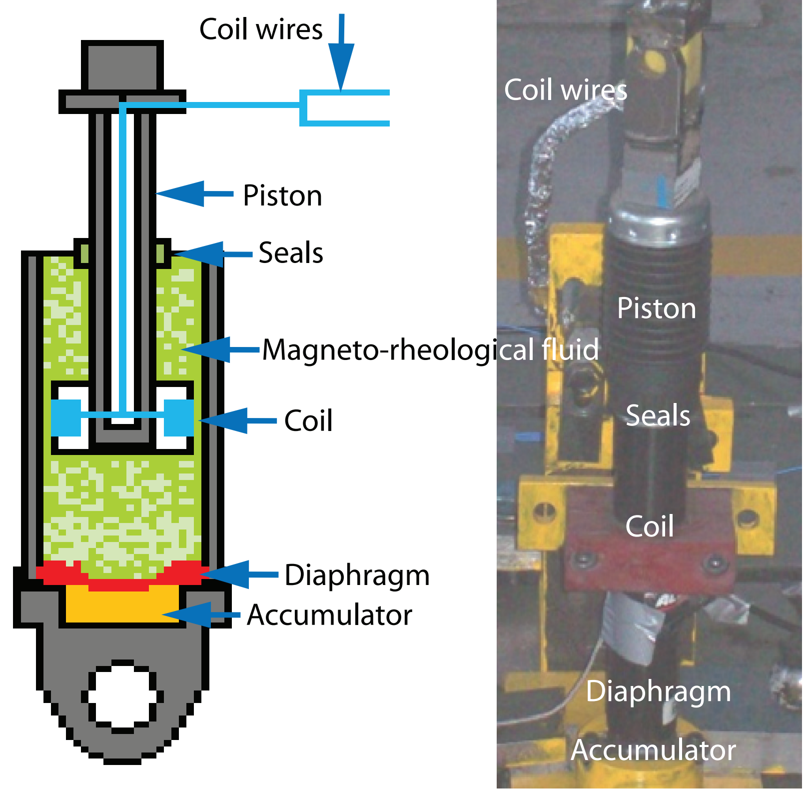
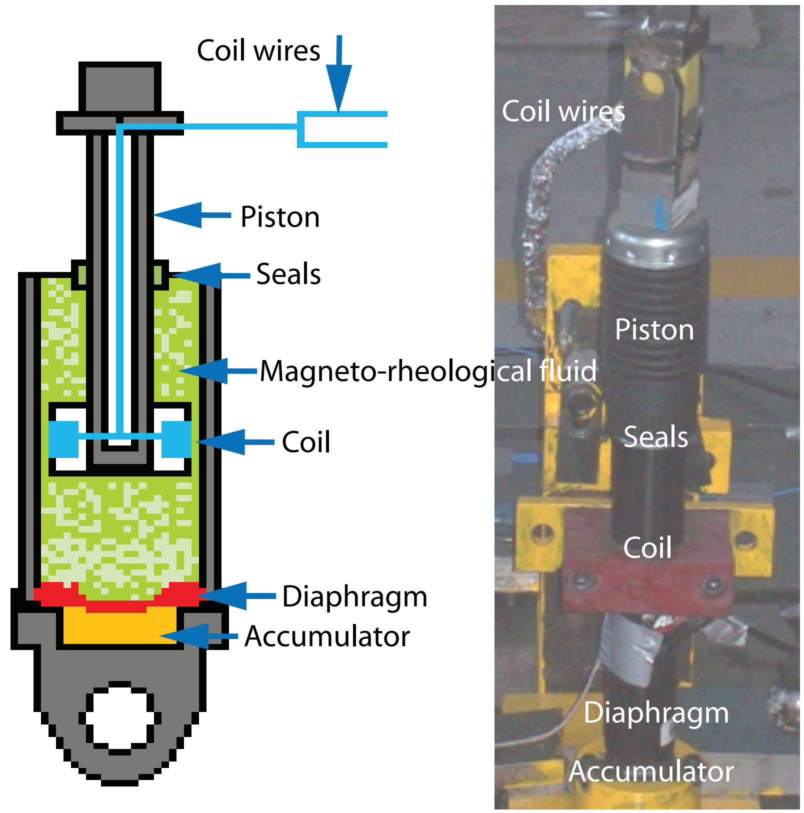
Magneto-rheological (*MR*) Damper

- The bigger the current in the coil, the bigger the dissipative force in MR damper.
- The device exposes a hysteresis with regard to the velocity of displacement.
- The relations of displacement, velocity and electric current changes and mechanical design of MR damper deliver a nonlinear damping force.



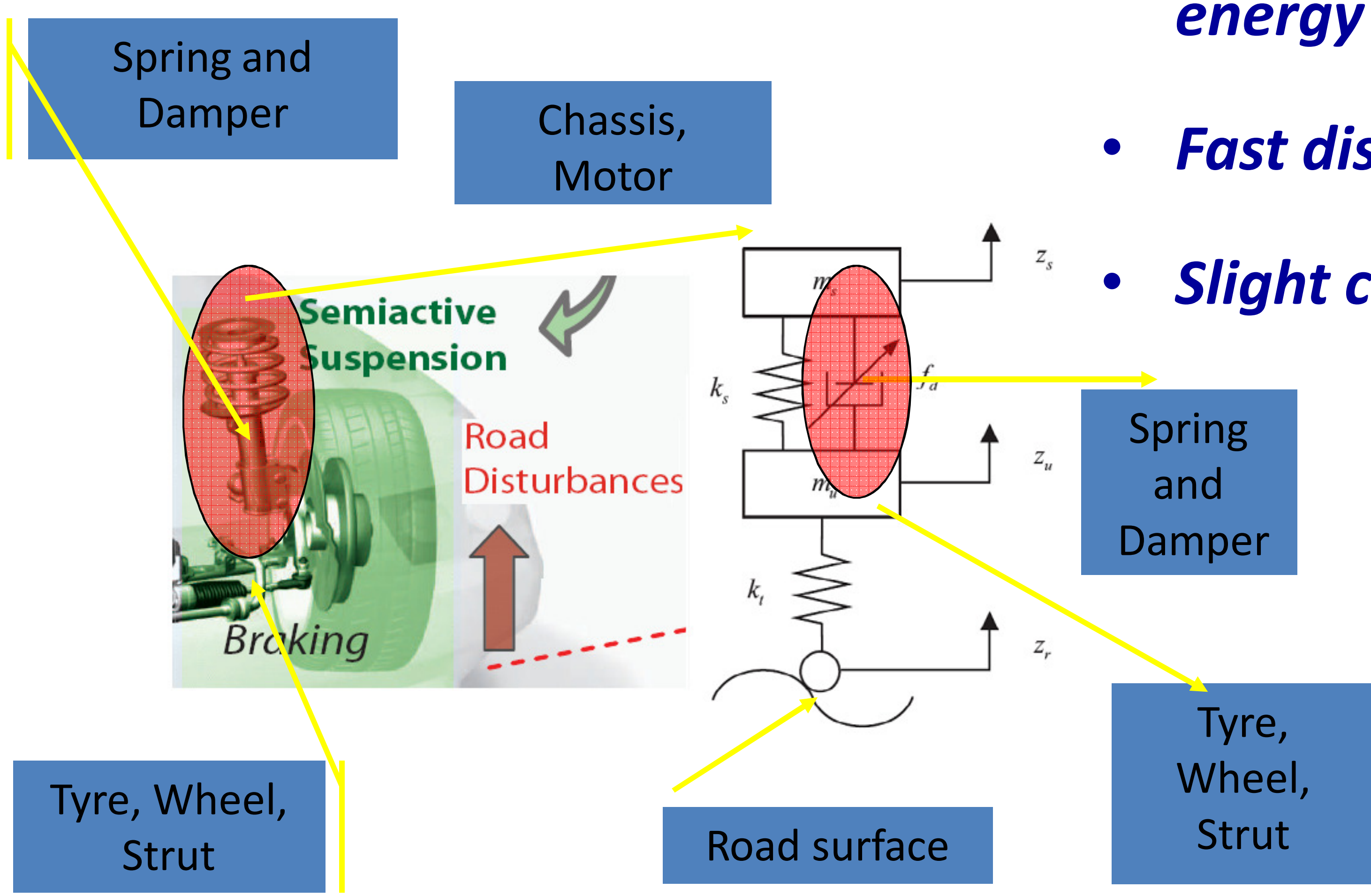
Magneto-rheological (*MR*) Damper

In an automotive suspension semiactive control, the controller manipulation generates the changes in the damping force required in order to succeed the predefined performance hence the MR damping force must be followed in an optimal and precise way.



Automotive semiactive suspension control keys are:

- ***An accurate and effective energy dissipation***
- ***Fast disturbance rejection***
- ***Slight computations***



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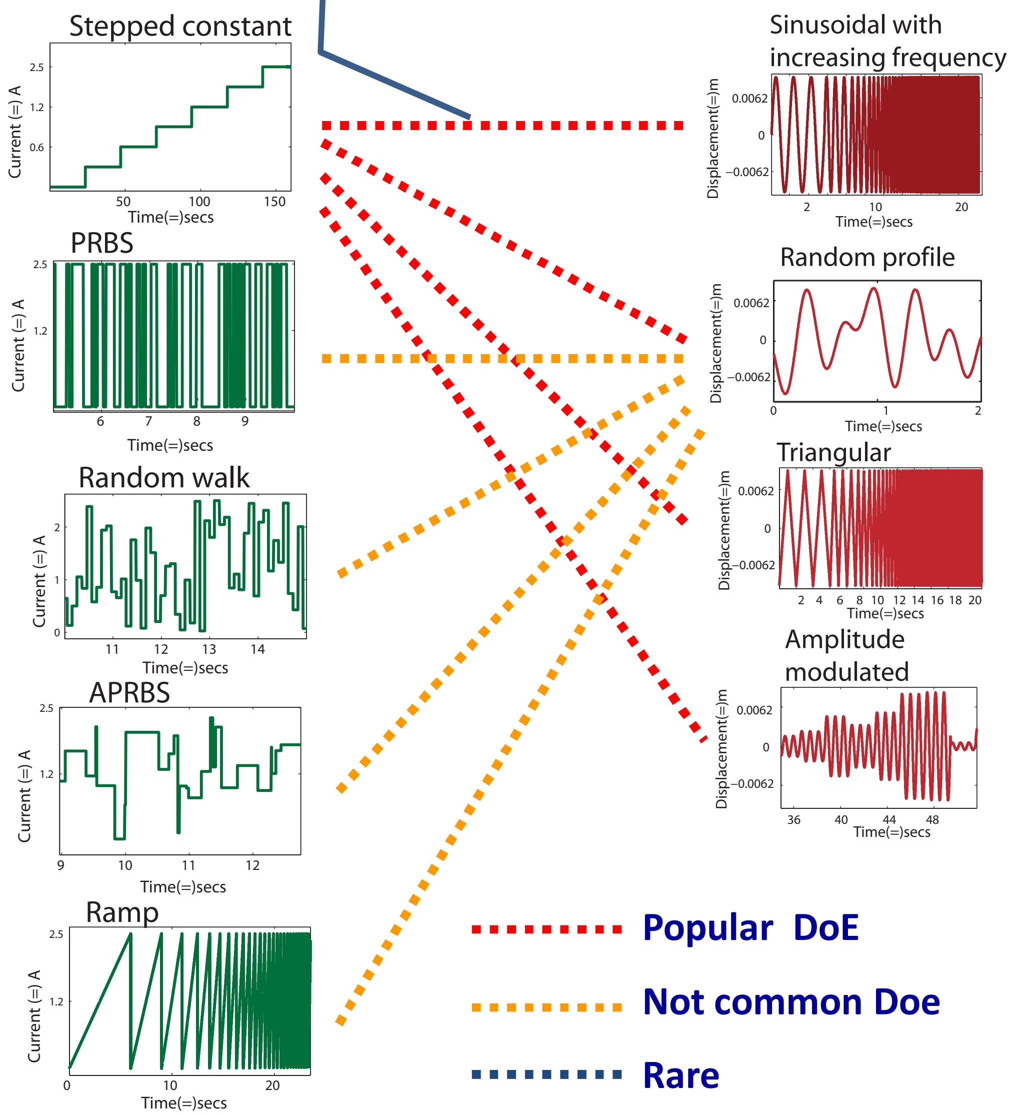
Literature review in Training Inputs Configuration (TIC)

For the red ones, the common factor are long duration, high cost, and operation of *MR* damper at functional limit.



Displacement and electric current reviewd features:

Frequency bandwidth, amplitude, discrete or continuous, shape of the signal (sinusoidal, white noise, sine-on-sine, constant), and duration

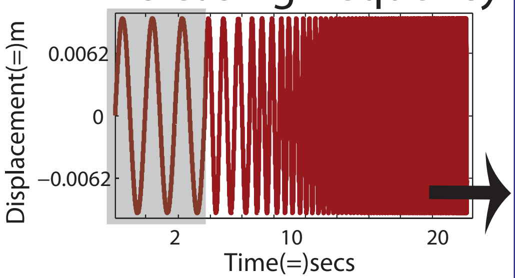
Opportunities:

1. The lack of standard experimentation
2. Proper exploration of hysteresis
3. The use of persistent current
4. The *DoEs* have not been properly focused on high frequency (8-20 Hz) properties of *MR* damper.
5. The derived MR damper models generally expose a lack of good hysteretic emulation.

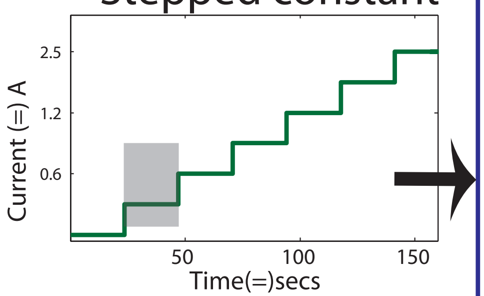
Literature review in MR damper modelling: Common practices

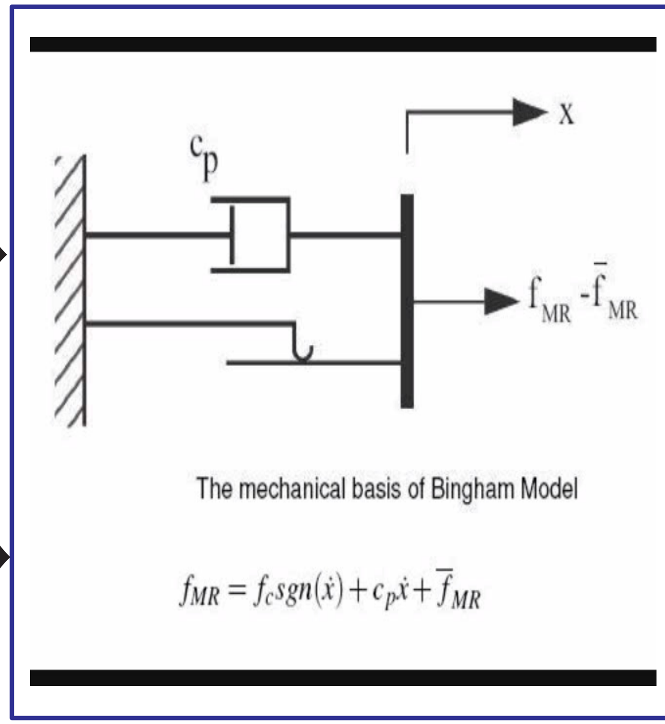
Parametric and Blackbox Models

Sinusoidal with increasing frequency



Stepped constant





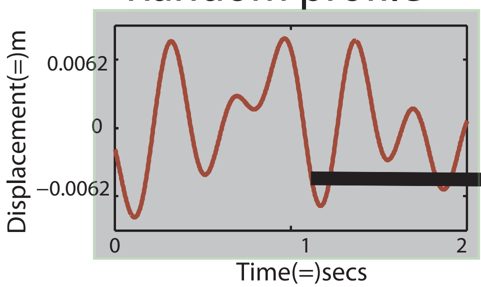
-Good estimation of the Force
-Excellent static charactetistic curves
-Transient response regarding to the electric changes are not emulated
-When submitted to persistent inputs in simulation, the prediction could be not accurate

-When the current is constant, the identification process is less complicated and well suited for the parametric approaches which commonly are nonlinear and with a number of parameters between 12-30.

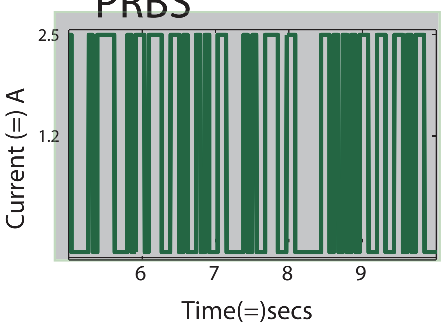
-The blackbox models are more precise than the parametric approaches

Literature review in MR damper modelling: Common practices

Random profile

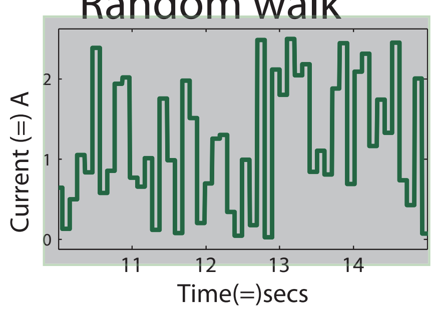


PRBS

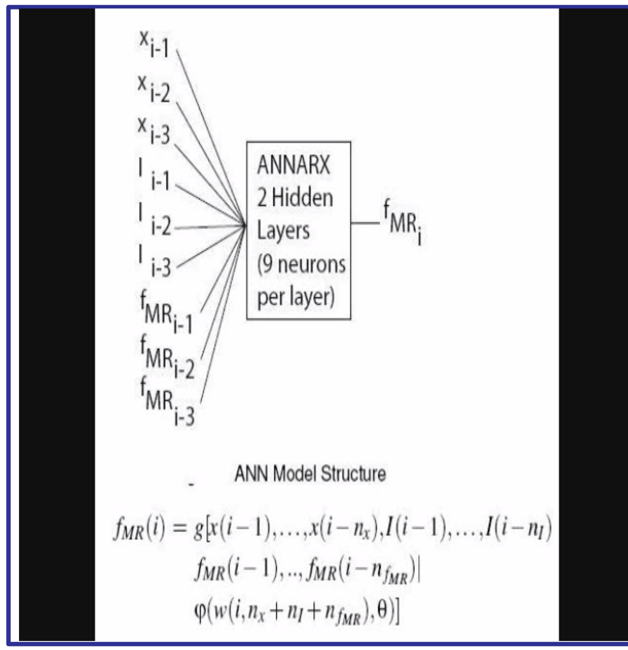


or

Random walk



Blackbox Models



- Good estimation of the Force
- Excellent static charactetistic curves
- Transient response regarding to the electric changes are emulated
- When submitted to persistent inputs in simulation, the prediction are accurate

-The nonlinear identification succeed the hysteresis and variables interaction for the MR damper force

Good practices in MR damping experimentation

1. Constant damper case T° (experimentation)

2. Same maximum displacement amplitude between experiments

3. For sine-on-sine displacements, the identified models are not generalized.

4. The *DoE with electrical current excitations to the MR* damper coil with a bandwidth equal to 0−10 Hz and displacements with a bandwidth equal to 0−15 Hz offers less experimentation time

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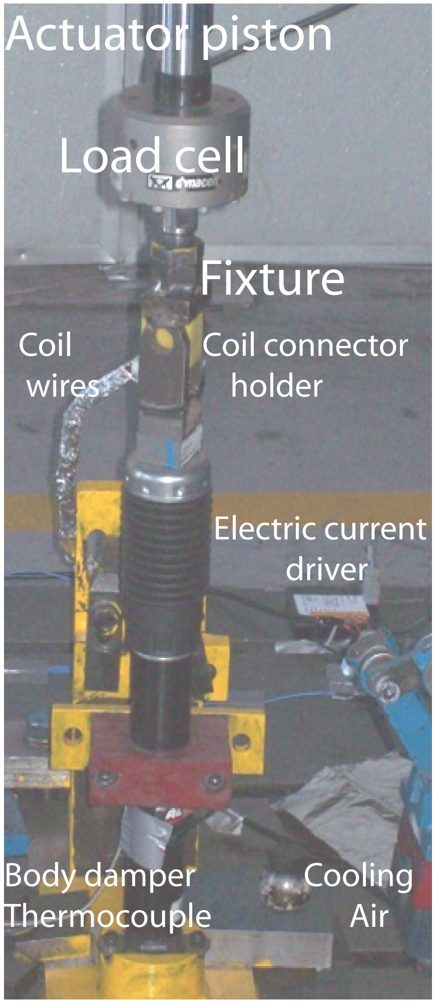
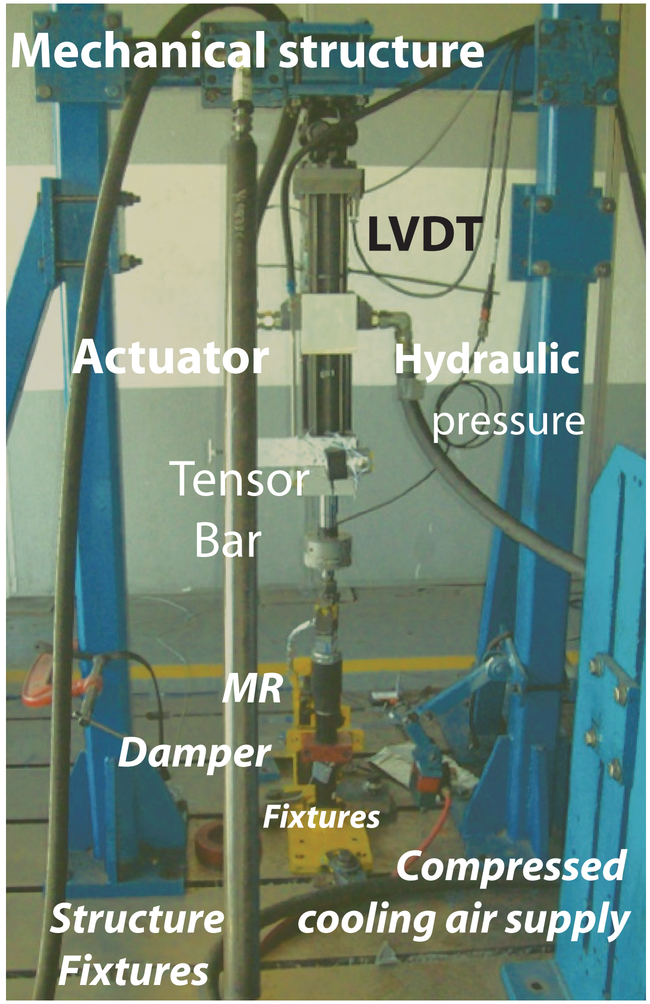
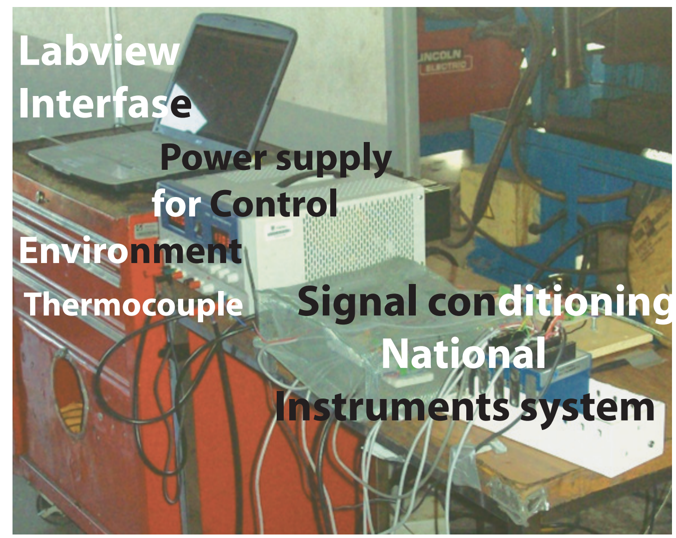
Objectives

- Applicability of the database in the developing of new *MR* damper control-oriented models.
- To establish for benchmarking on modelling for *MR dampers where* the academic community can use the same data in the model proposals.
- The observed phenomena will allow to enrich the feasibility on the *MR damper application.*

Testbed for MR damper



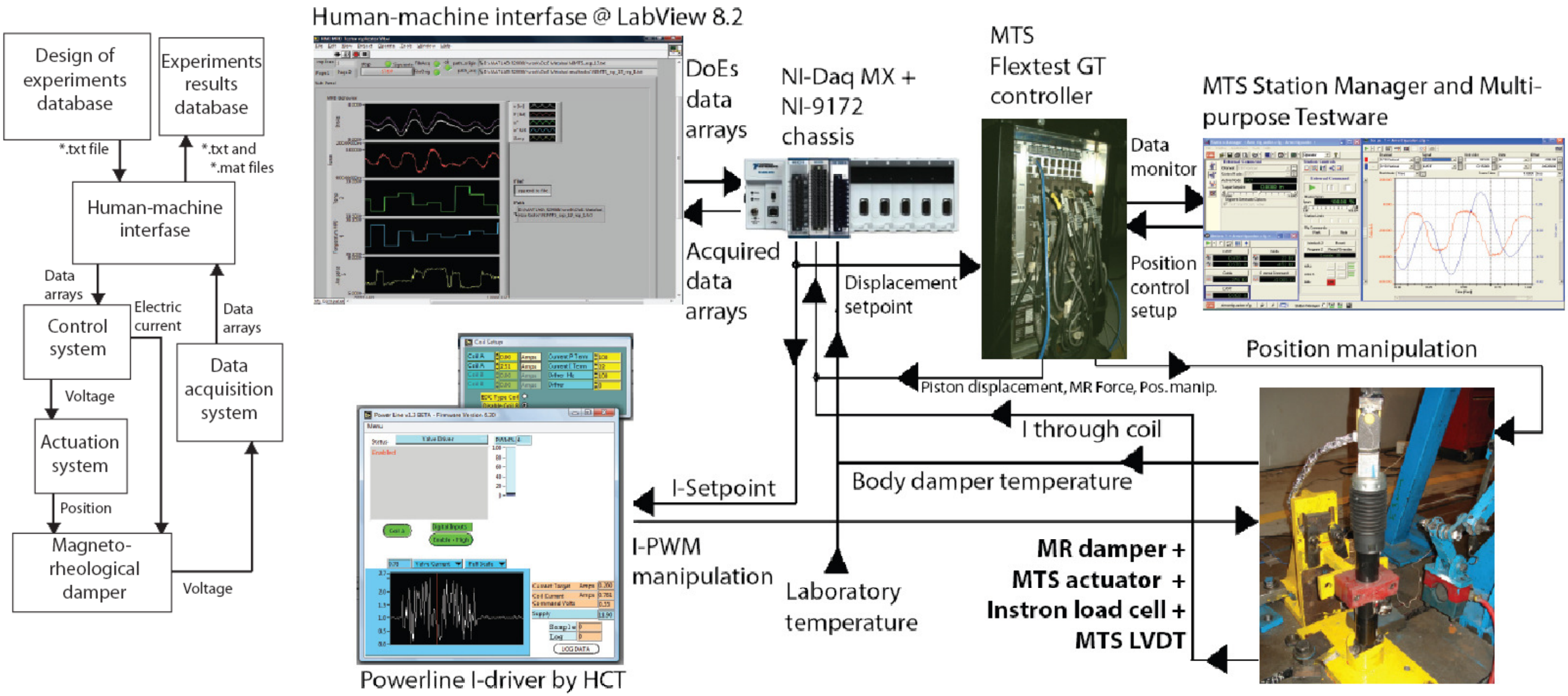




The selected specimen is a *ACDelco MR damper, component of* the *Magneride suspension, actual system on the Cadillac* vehicles.

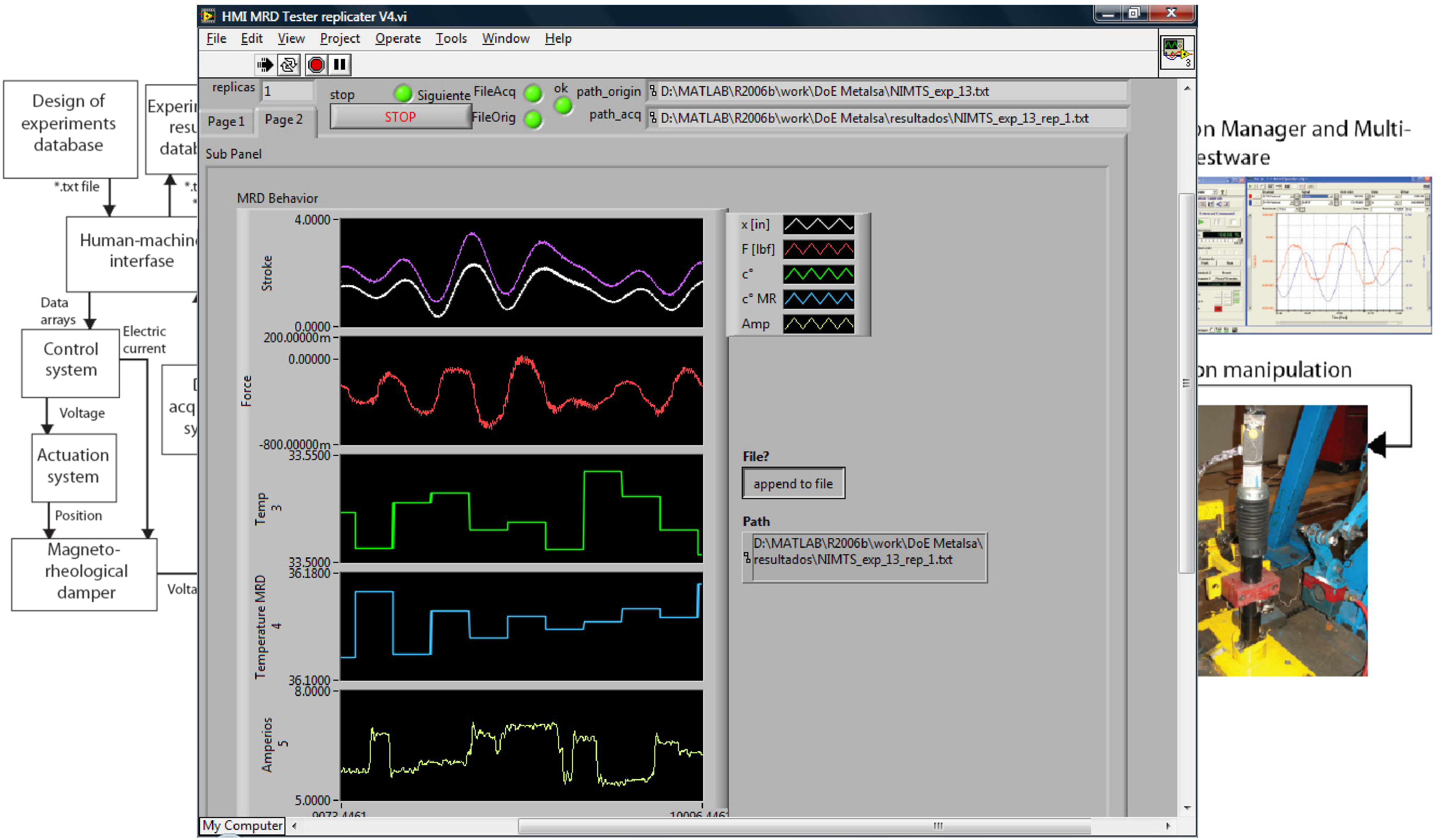
The professional automotive test laboratory is located at *Metalsa* (www.**metalsa**.com.mx)

Information flow and tasks

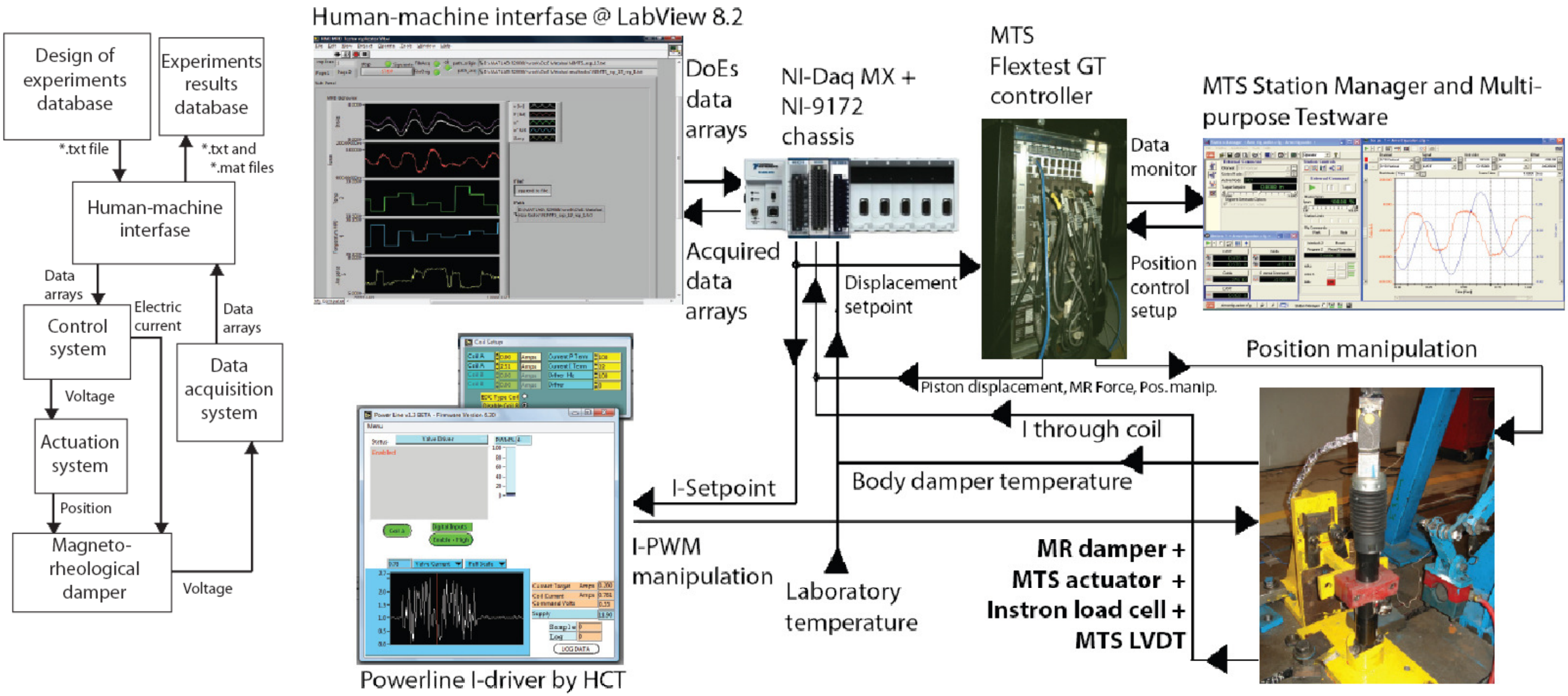


The piston deflection peak-to-peak is 12.5 mm. The maximum applied current is 2.5 A

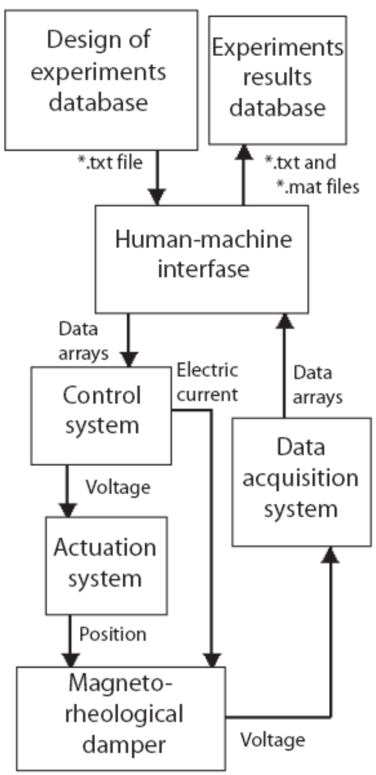
LabWindows data acquisition HMI

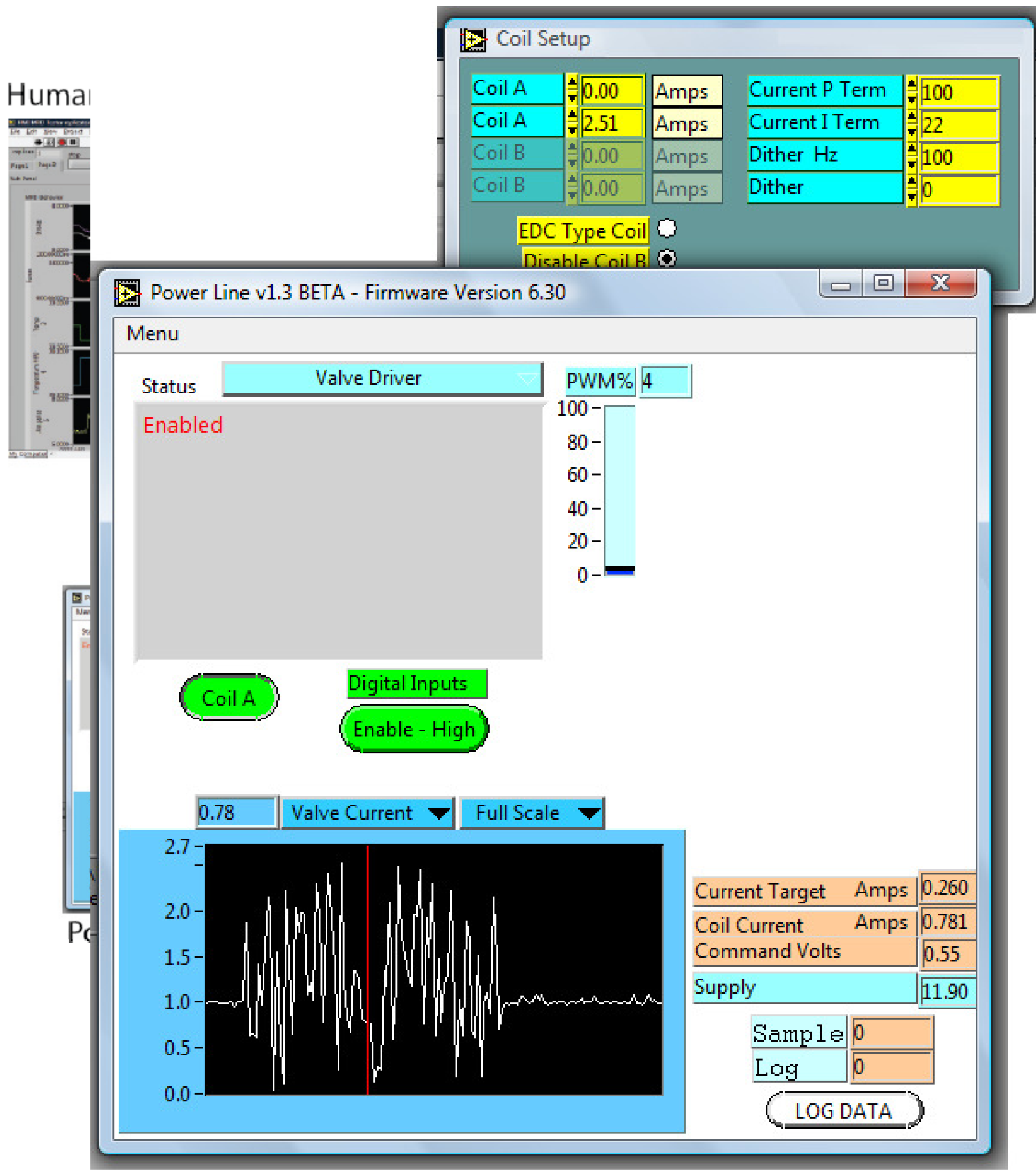


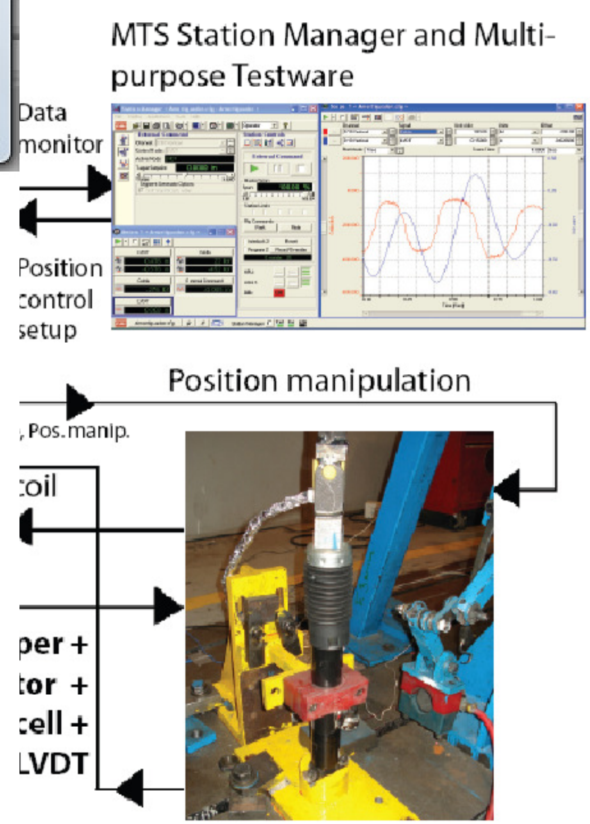
Information flow and tasks



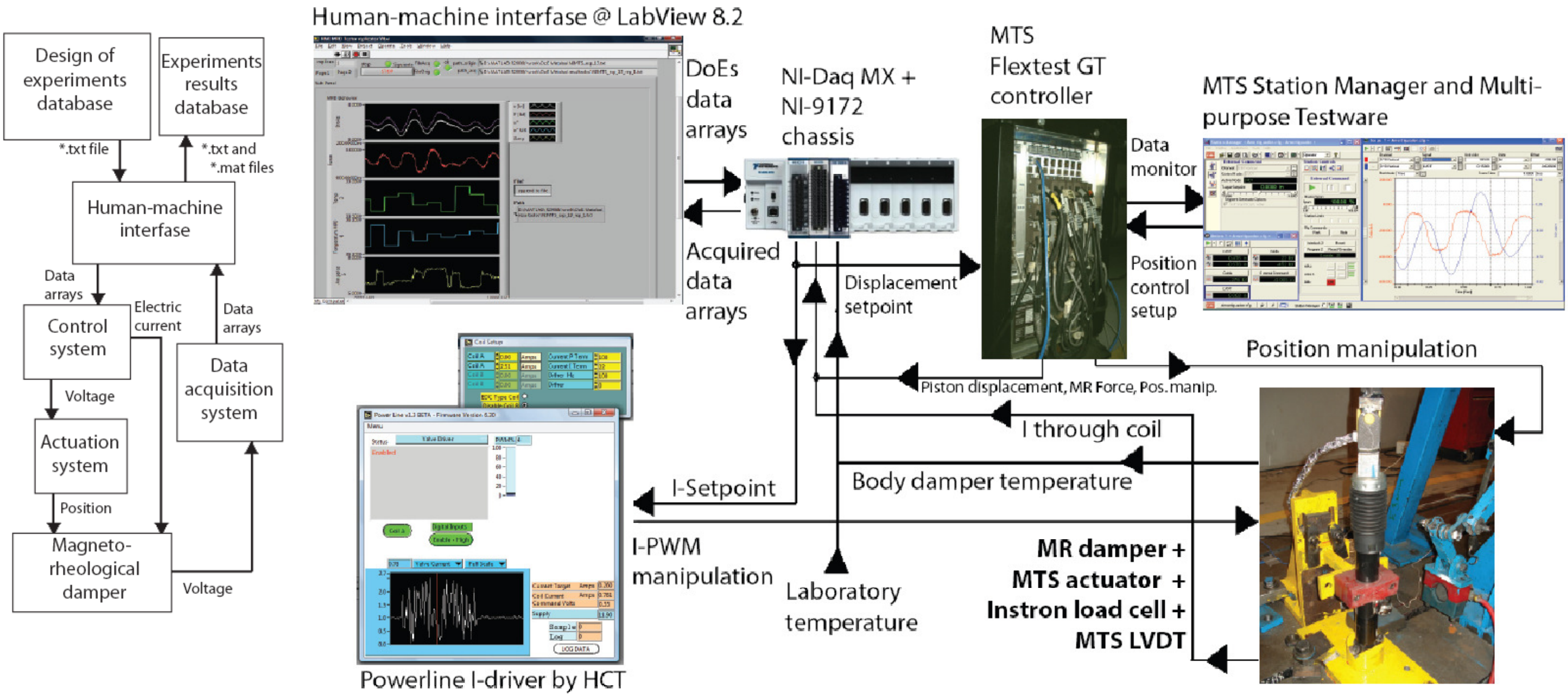
Current driver controller HMI



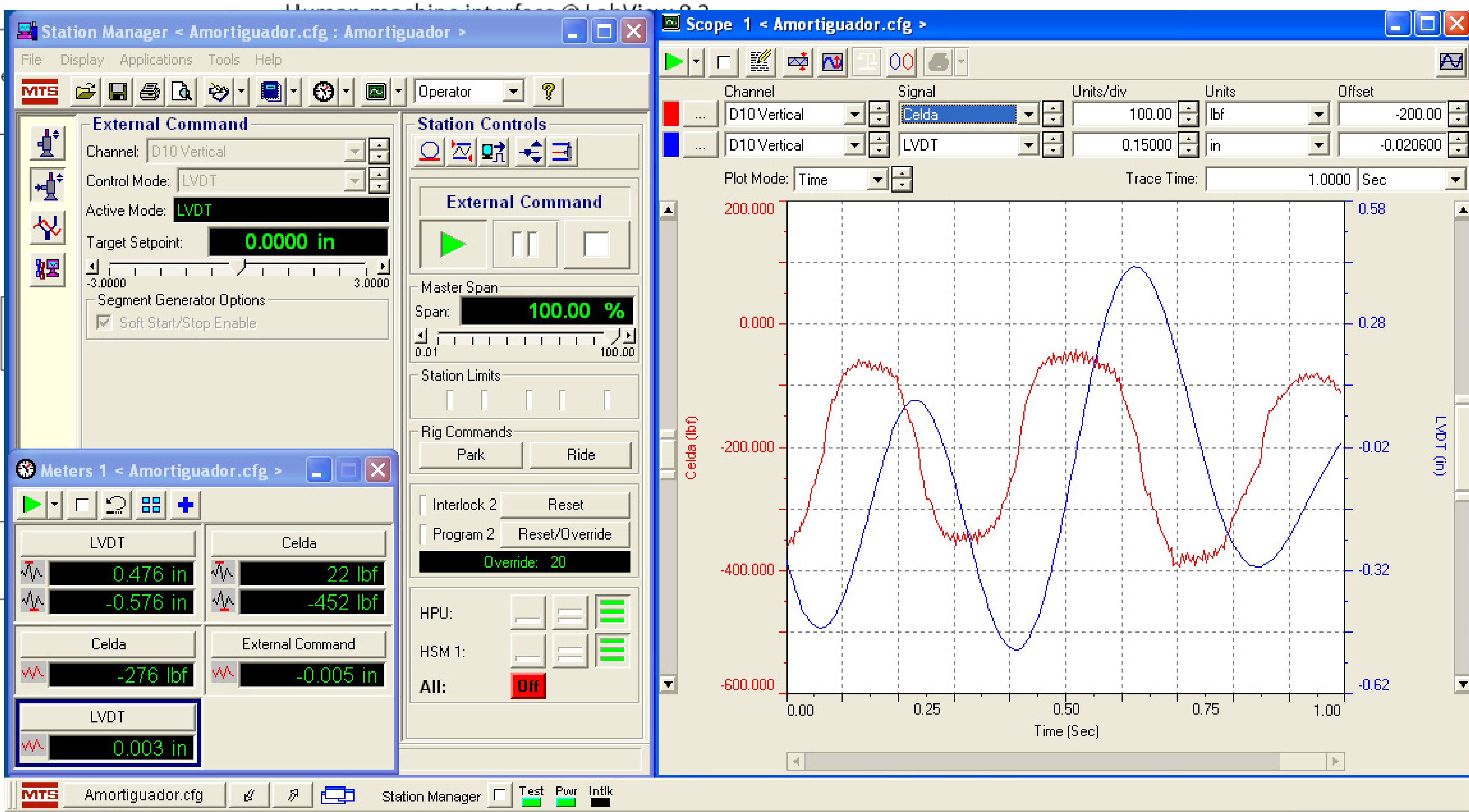




Information flow and tasks



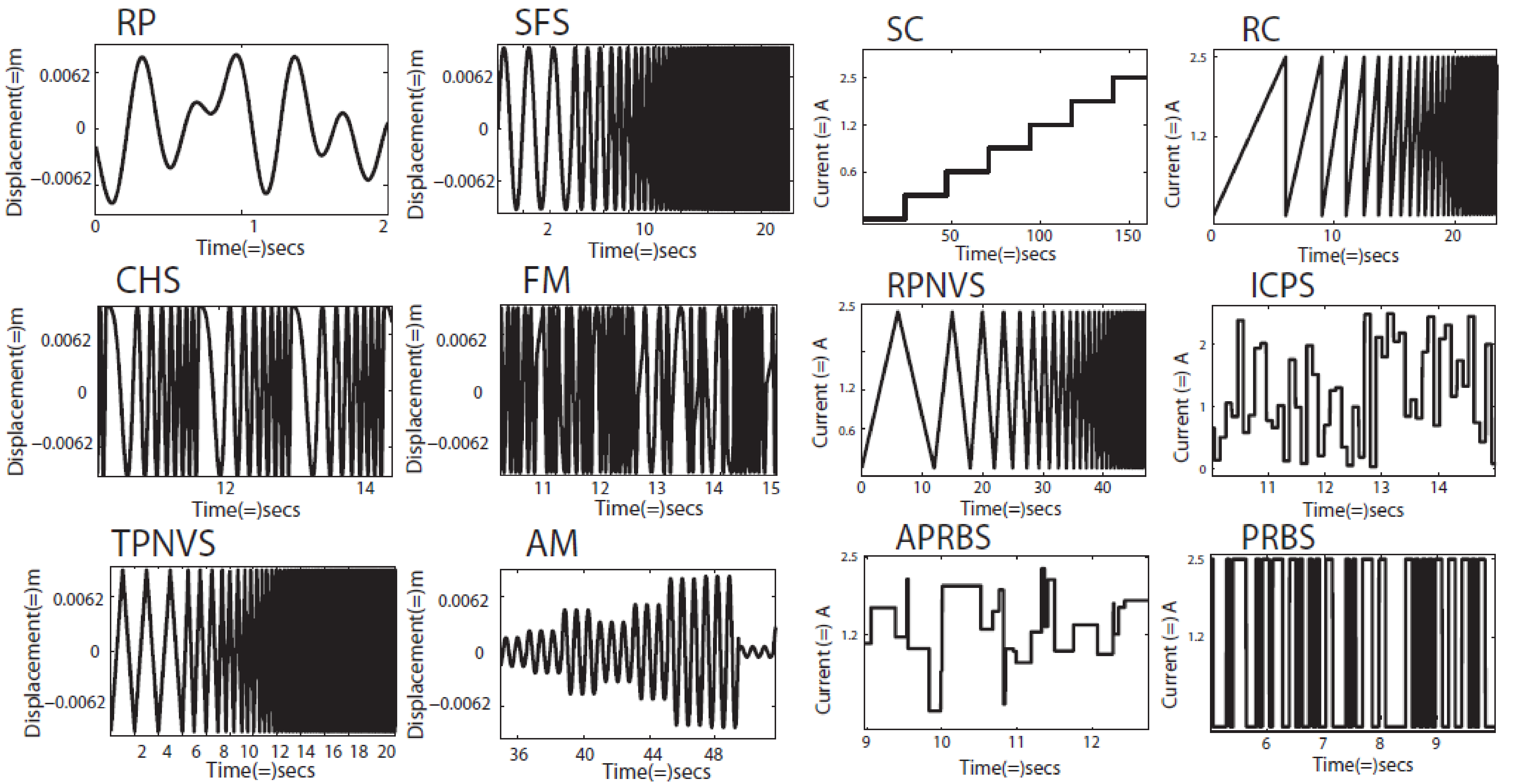
MTS^{MR} Control Station software



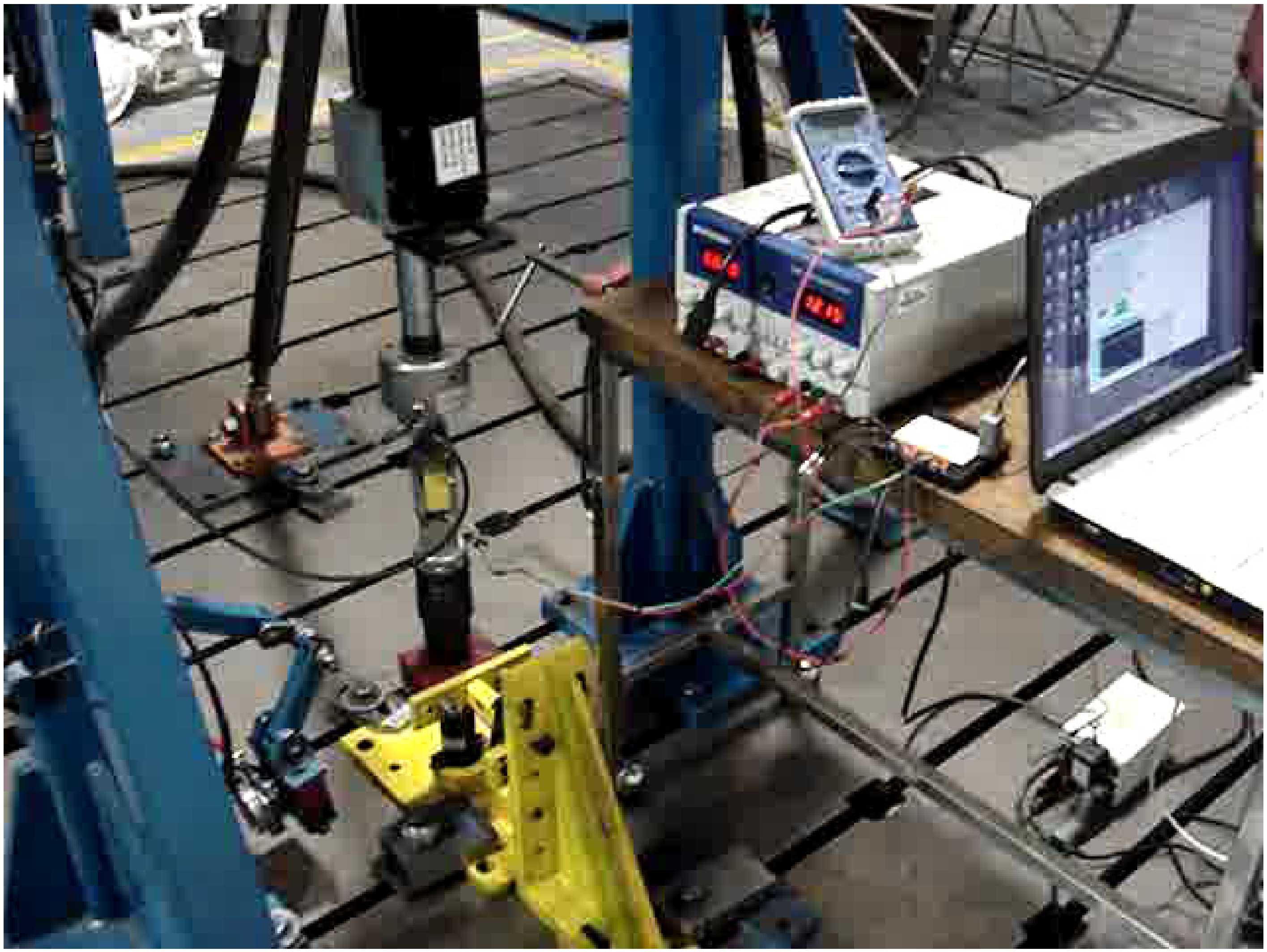
Displacement and electric current patterns for DoE

Displacement

Electric current



Experimental test-bed in action



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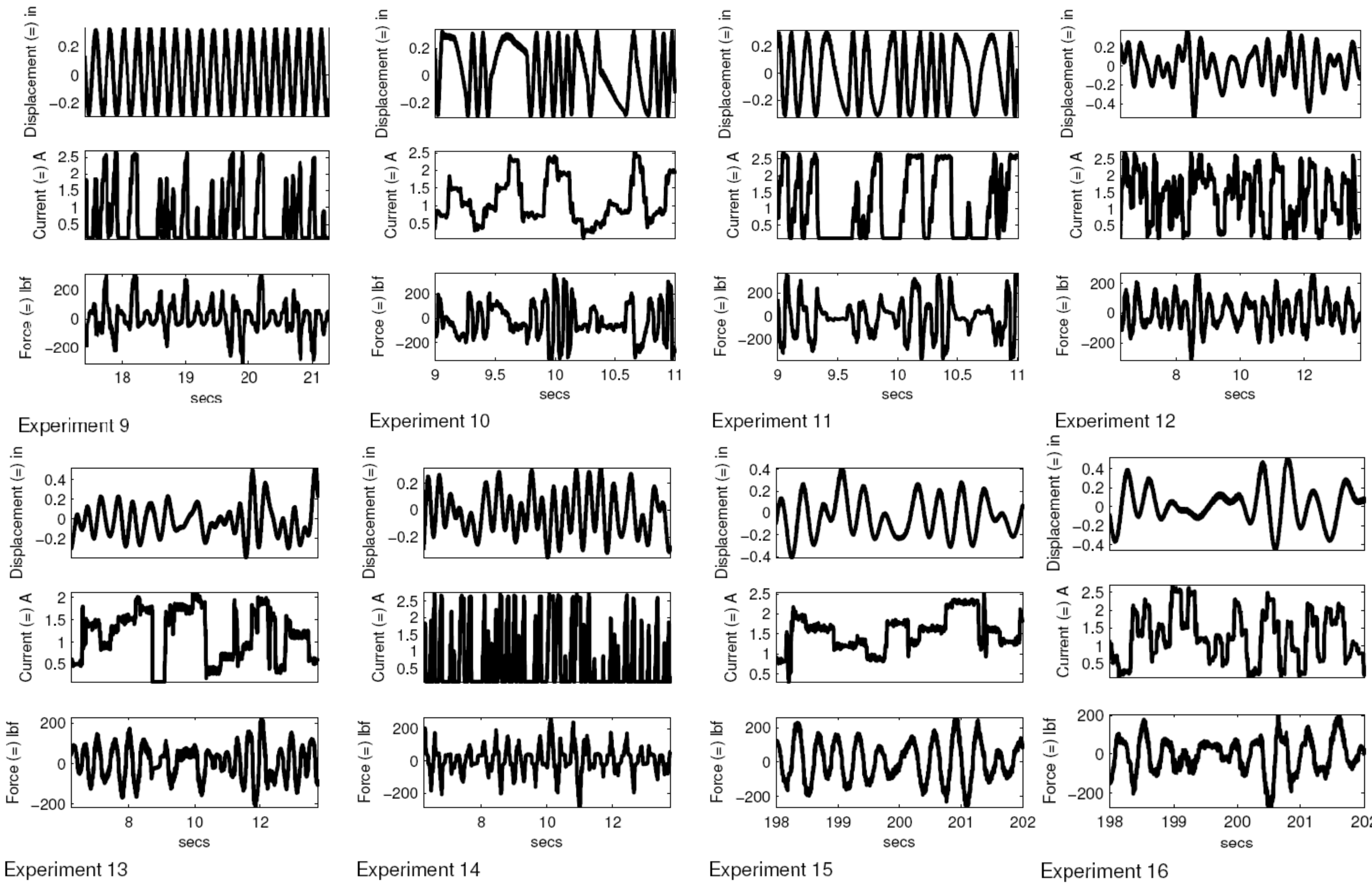
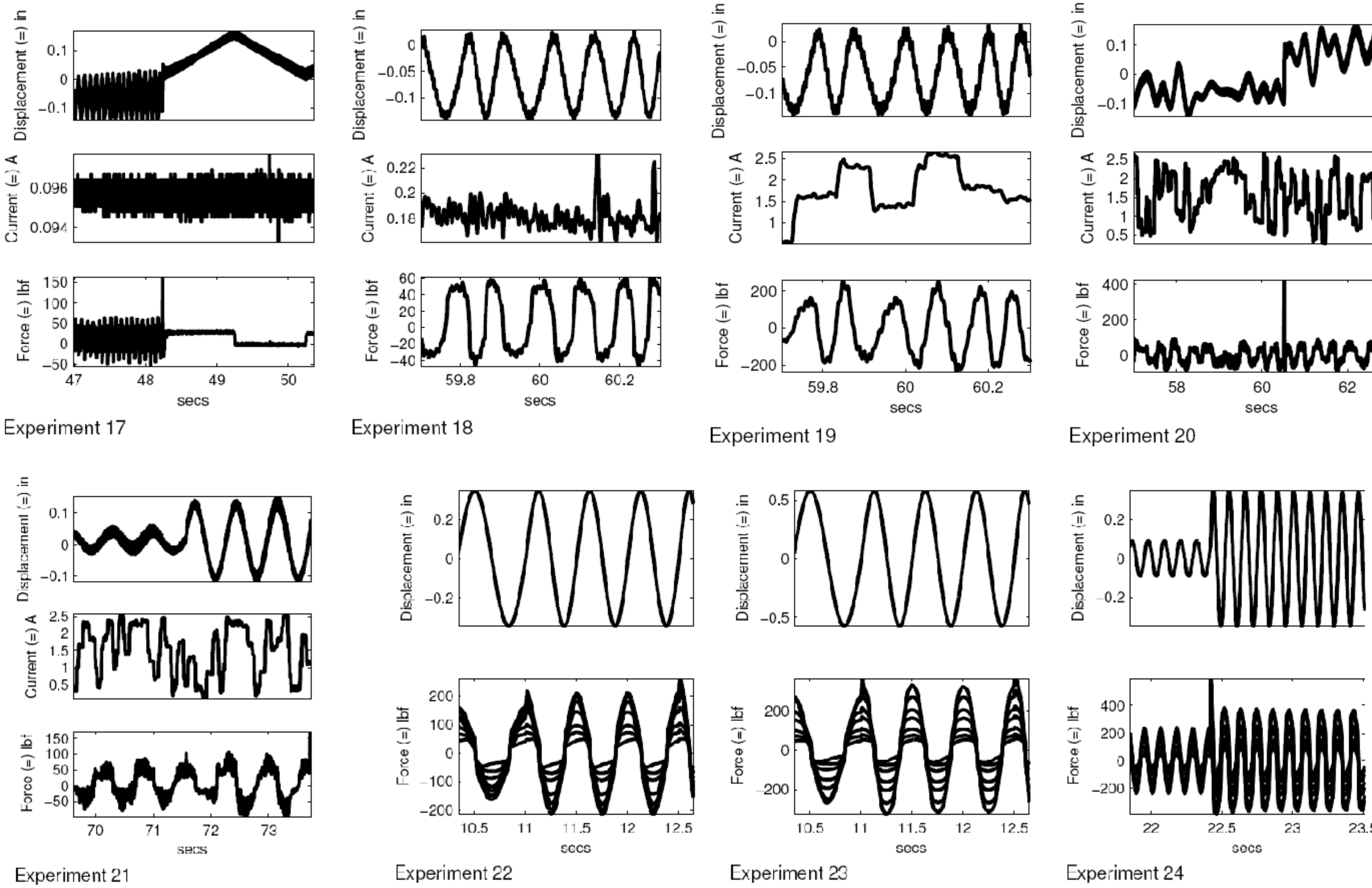
Results

- 21 experiments with several current and displacement patterns.
  - Each one has 10 replicates in order to assure the repeatibility of the system.
  - The experiments includes the measure of the damper body and the laboratory
- 8 experiments with several displacement patterns and each tested with 8 different constant current

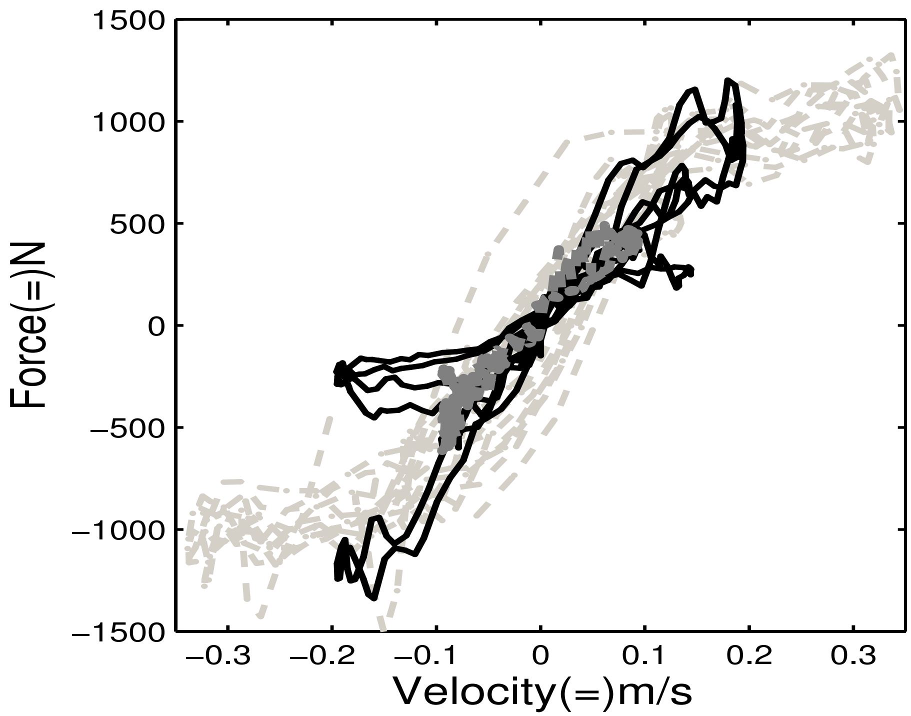
Experimental datasets 9-16

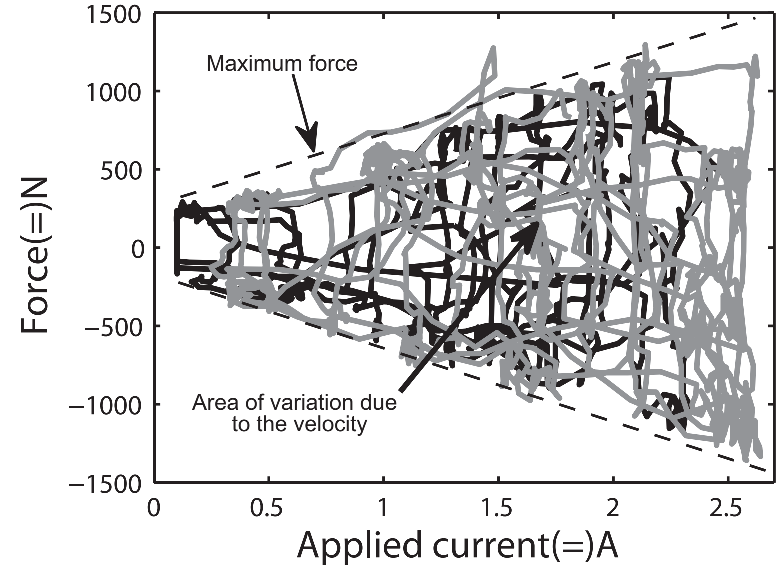


Experimental datasets 17-24

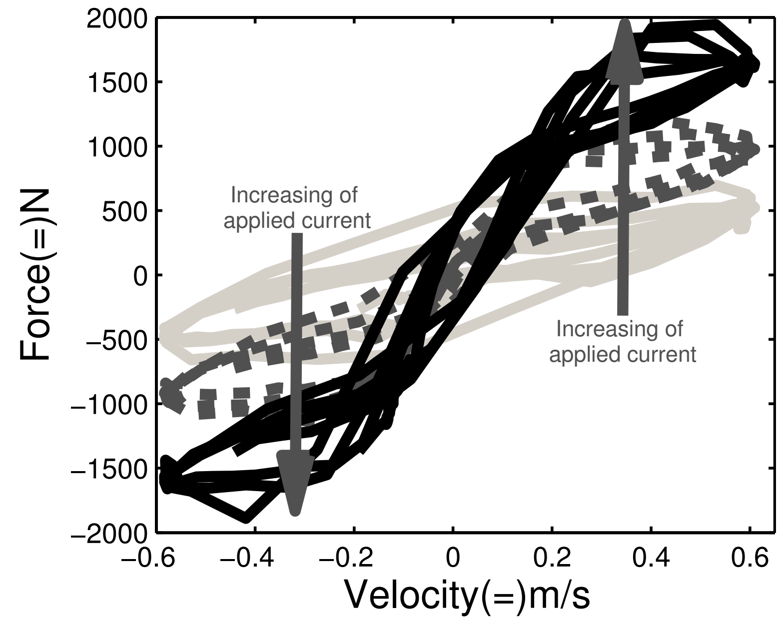


Observed phenomena: Frequency and current effects

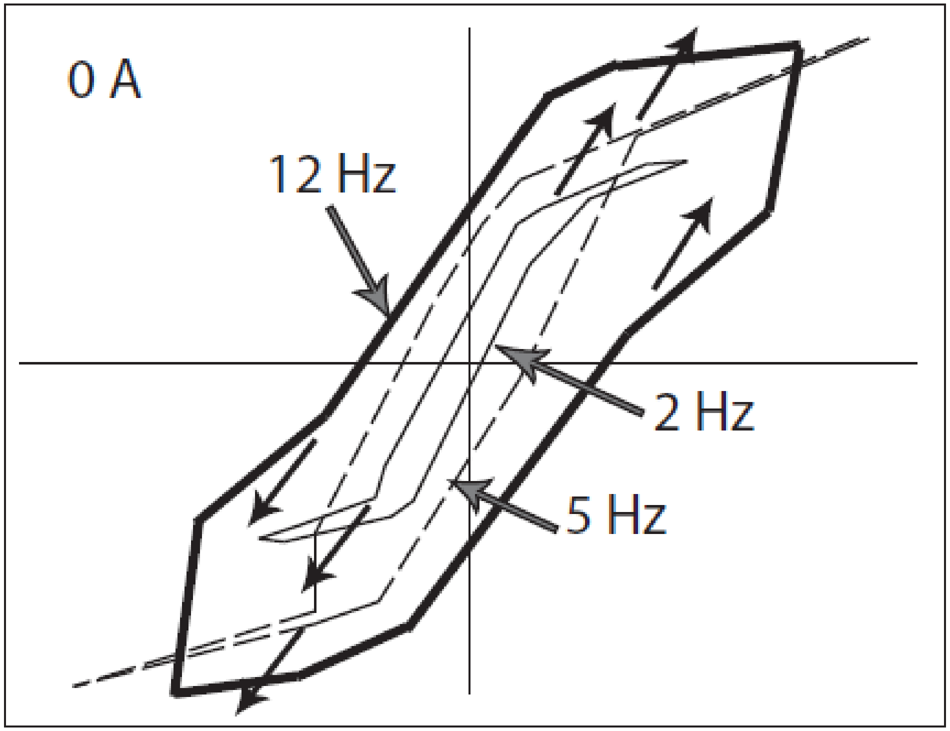


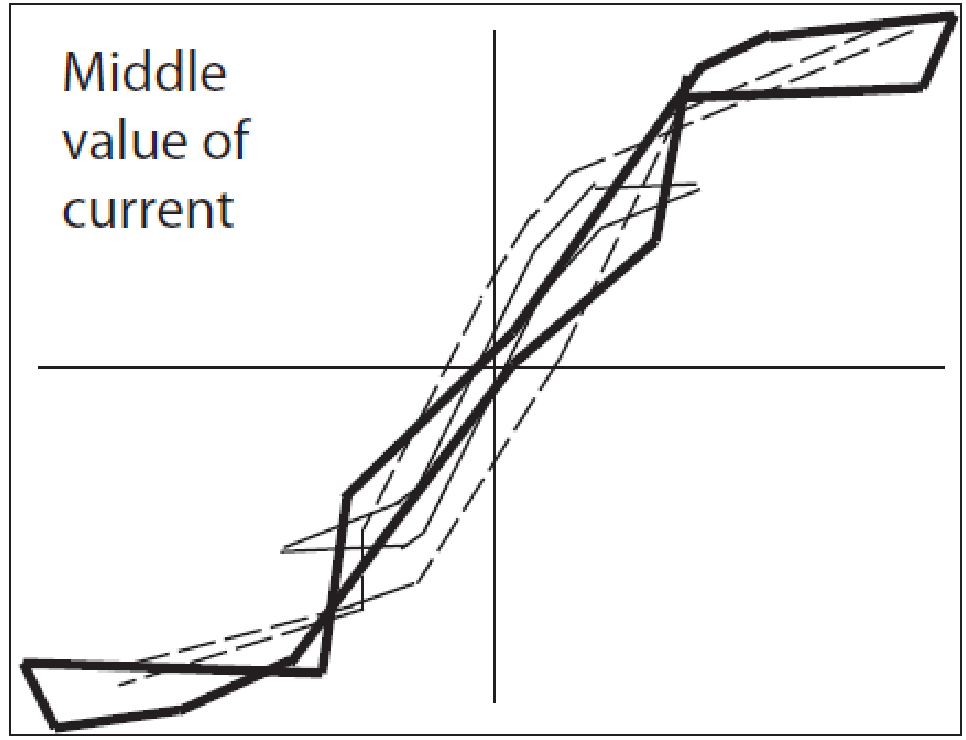


Force-velocity curve :
Exp. 21 2.8 Hz (dark grey), 5.6 Hz (black), and 9.7 Hz (grey)



Observed phenomena: Hysteresis on frequency and current



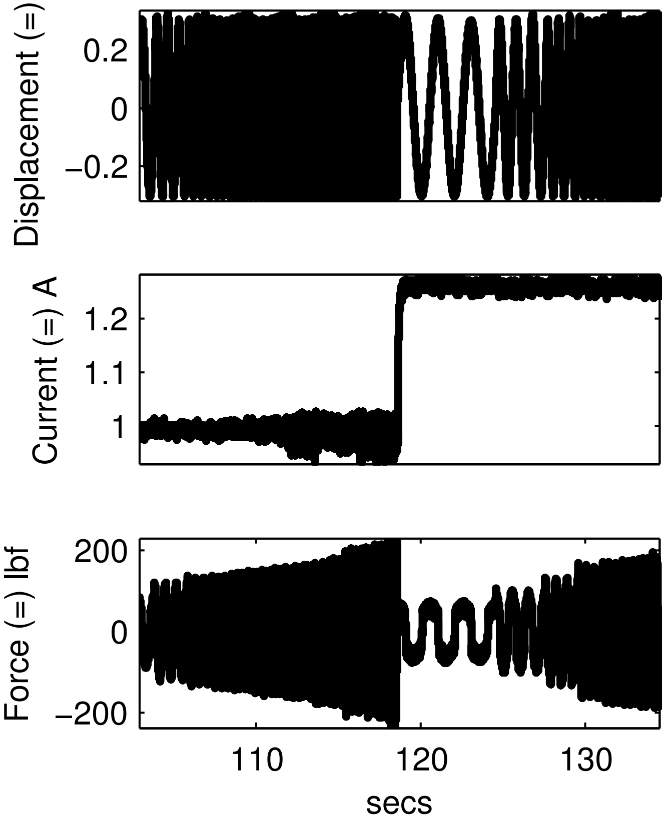


If the current is high, the magnetic links are stronger, hence the yield force is larger. If the yield force is larger, the hysteresis decreases at the maximum velocities. This phenomenon modifies the hysteresis phenomena discussed in the last subsection due to the yield point of the magnetic links in the oil

Key experiments

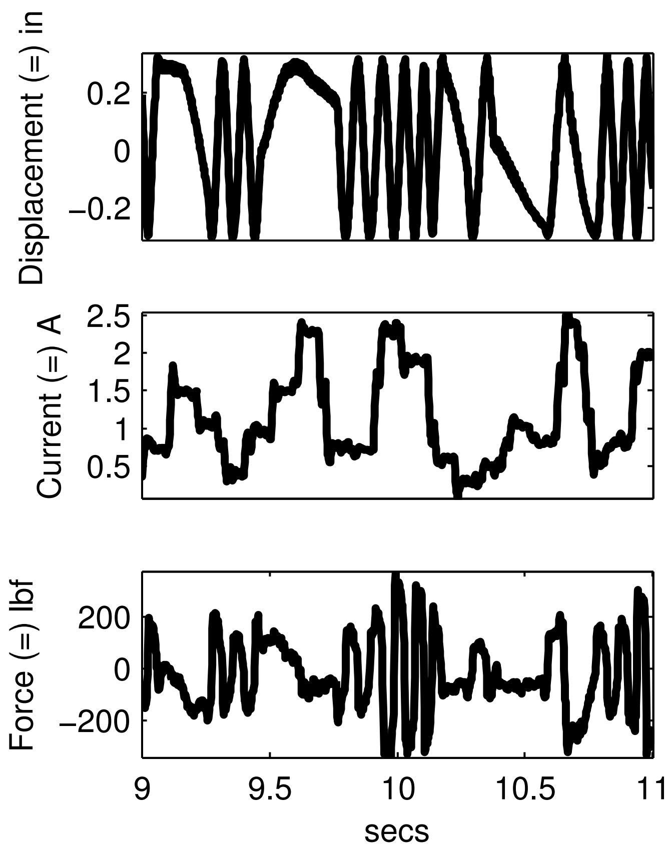
Classical

SFS + Electric Curr. Constant



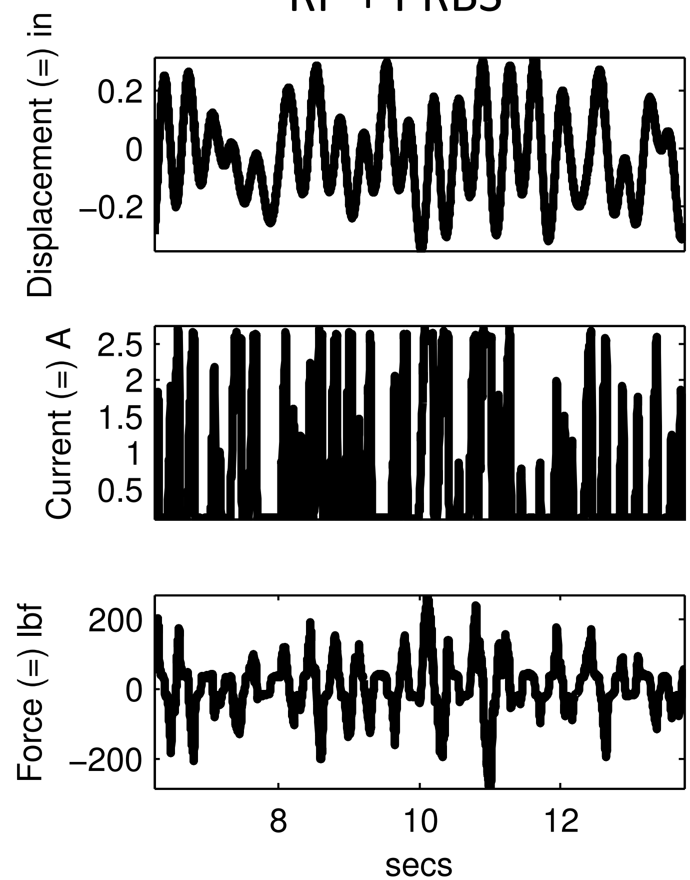
New proposal

FM + ICPS

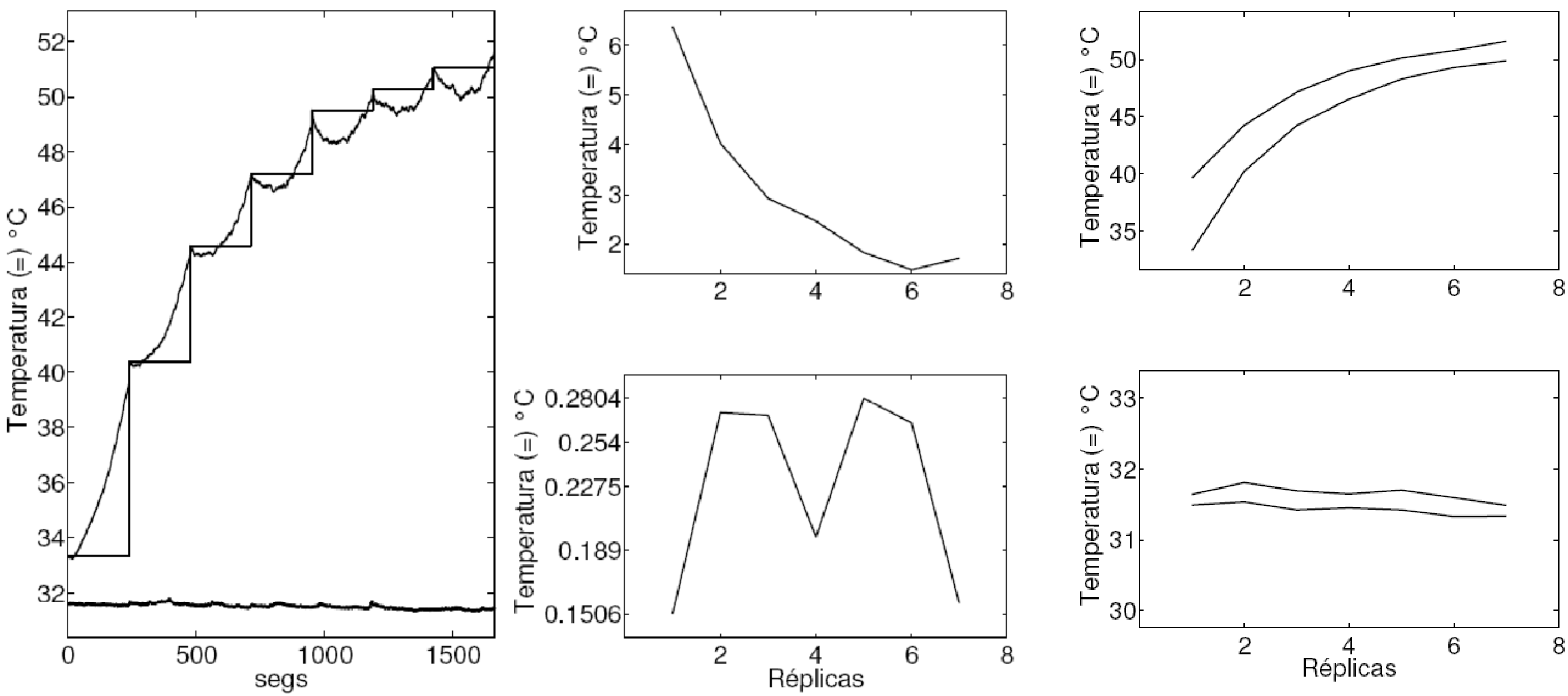


Realistic actuation

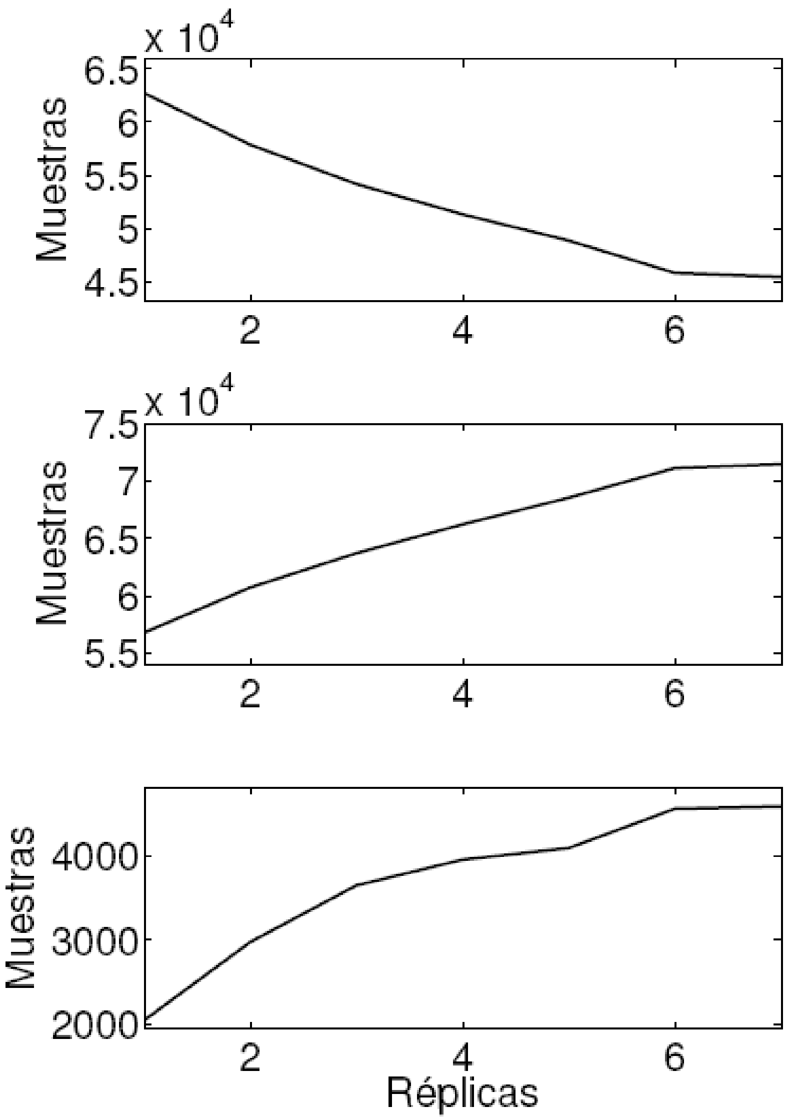
RP + PRBS

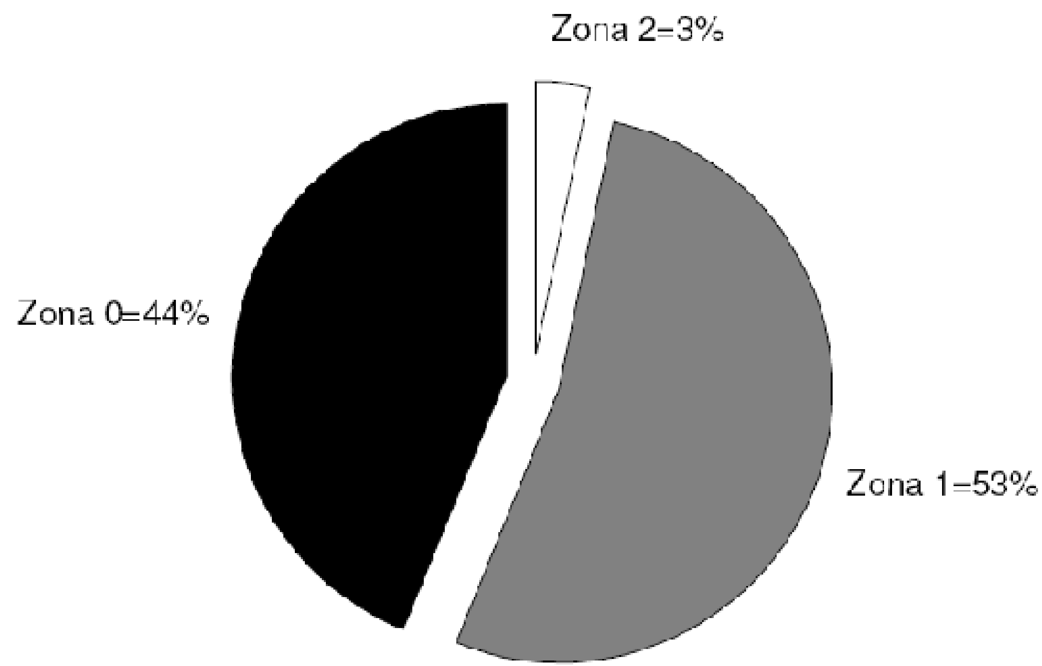


Example:Experiment 3



The MR damper force distribution changes with the temperature





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MR damper modelling **control-oriented**

A general *MR damper structure model can be described by* to two dampers in parallel: a damper with constant shear stress (passive) and a damper with variable-shear stress (semi-active) due to the variation of the applied current. The sum of the 2 components yields the *MR total damping force* .

$$f_{MR} = f_p(x, \dot{x}) + f_I(x, \dot{x}, I)$$
$$f_p = k_p x + c_p \dot{x}$$
$$f_I = y_f(I) \cdot g(\dot{x}, x)$$

Semi-phenomenological Model I-driven

A modified version of the model Guo et al 2006 is presented where the force of the damper is described by: (a) the force due to the spring effect of the gas accumulator, (b) the damping force of the oil, and (c) the *MR force due to the electrical* current.

$$f_{MR} = y_{MR} \cdot I \cdot tanh\left(c_{MR}\dot{x} + k_{MR}x\right) + c_p\dot{x} + k_p x$$

The maximum deflection velocity model

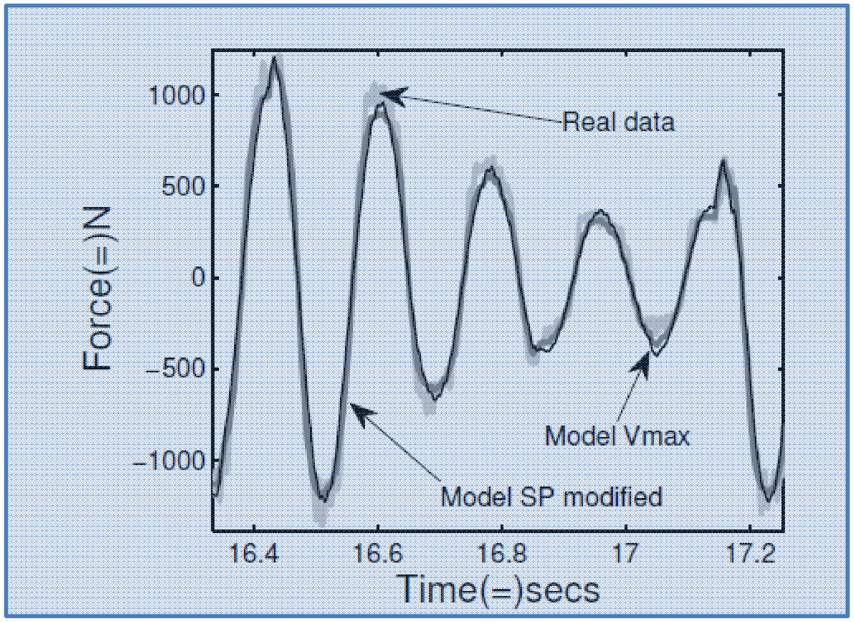
The model is based on the variation of the post-yield damping coefficient depending on the maximum deflection velocity. The maximum deflection velocity is a function of the maximum amplitude and the frequency of the deflection, [40], hence this measure can capture the dynamic behavior of the damping coefficient.

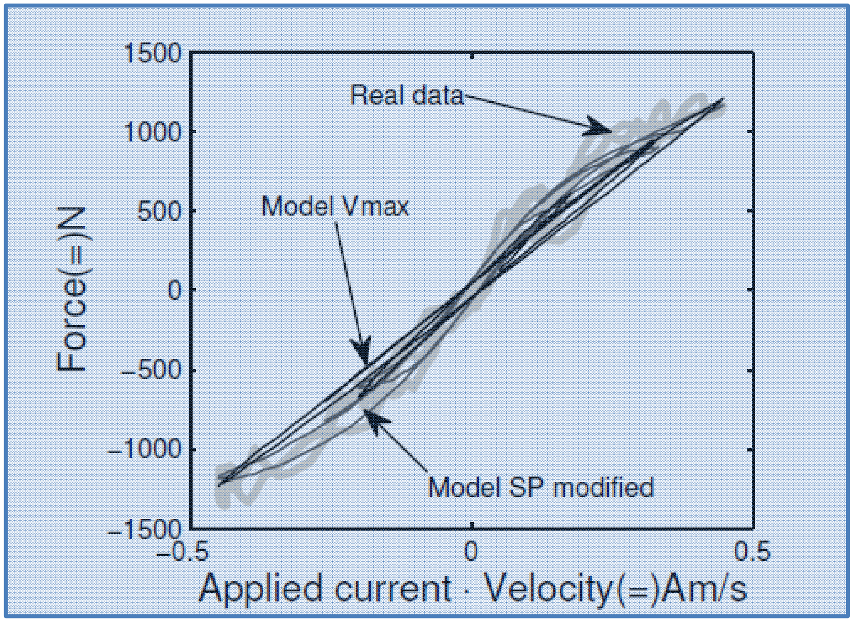
$$c_I = \frac{f_I}{\dot{x}} = \frac{y_f(I) \cdot g(\dot{x}, x)}{\dot{x}} \propto \frac{I \cdot c_{MR}}{|||\dot{x}|||_{\infty}{}_{i-k}^{i}}$$

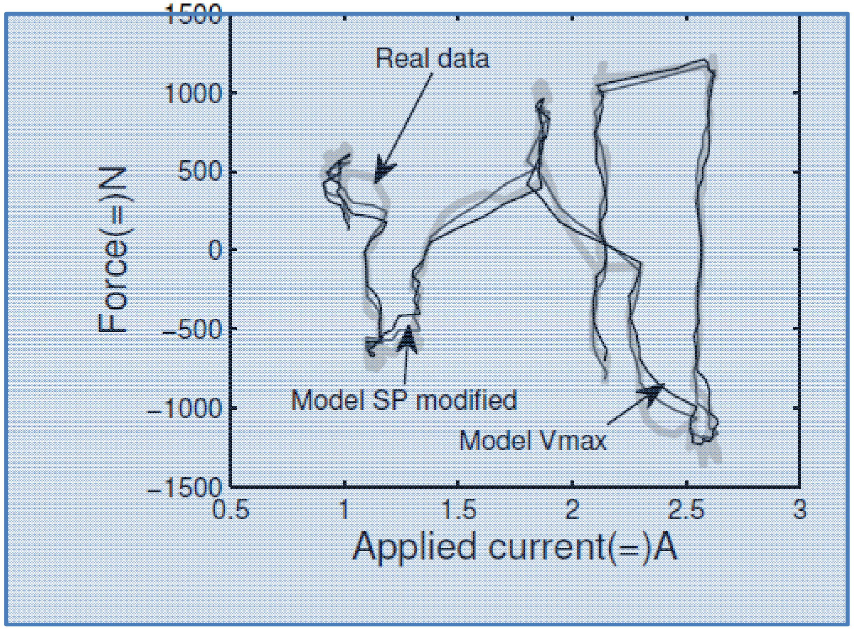
$$f_I = c_I \cdot \dot{x} \propto \frac{I \cdot \dot{x} \cdot c_{MR}}{|||\dot{x}|||_{\infty}{}_{i-k}^{i}} \longmapsto f_I$$

$$f_{MR} = I \cdot \dot{x} \cdot c_{MR} \cdot \frac{1}{|||\dot{x}|||_{\infty}{}_{i-k}^{i} + \varepsilon} + k_p x + c_p \dot{x}$$

Identification results







The models simulates the experimental data with few parameters and *quasi-linear structure*

Linear parameter varying (LPV) modelling, (Bruzelius 2004), for MR damper

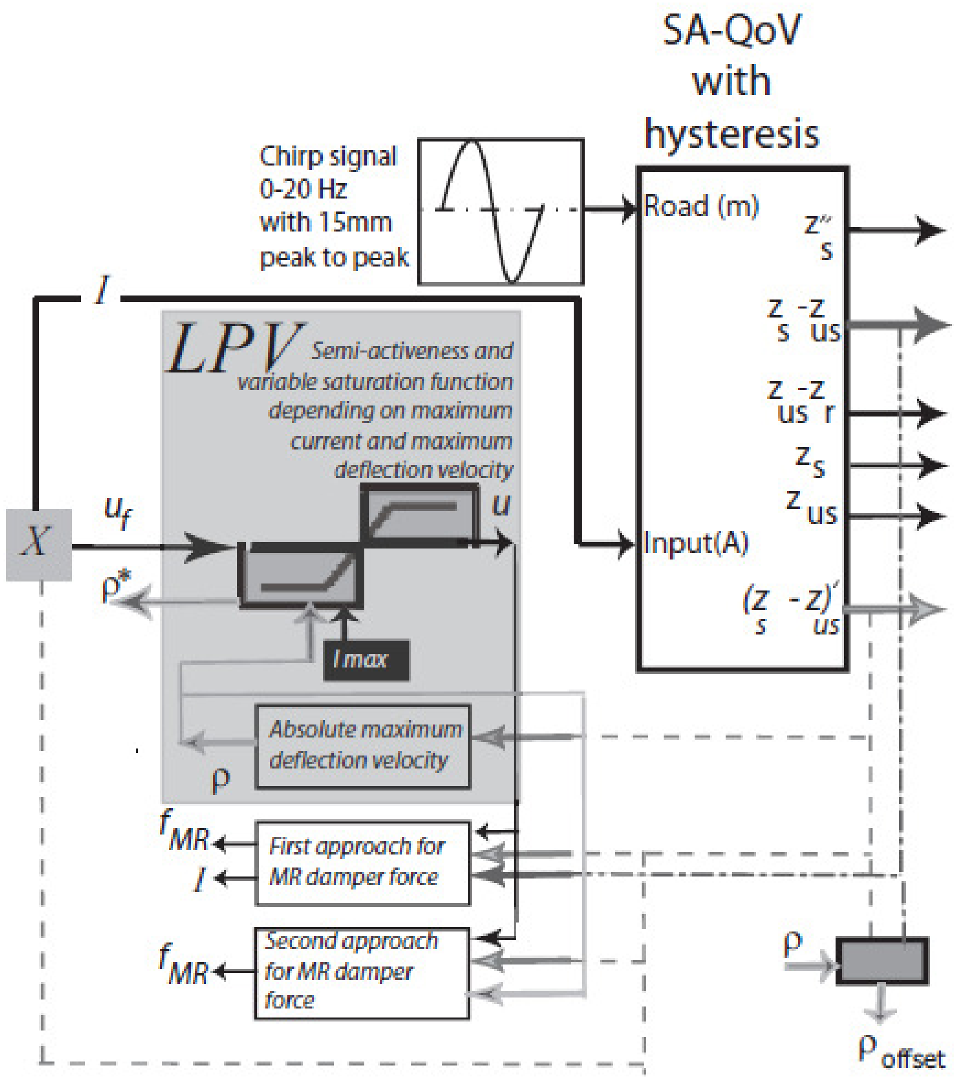
- The current inputs on the models in a linear manner, an important characteristic for controller synthesis.
- Both models have the same structure, the difference is the nonlinear function, hence
- The models can be expressed as linear parameter variable (*LPV) model:*

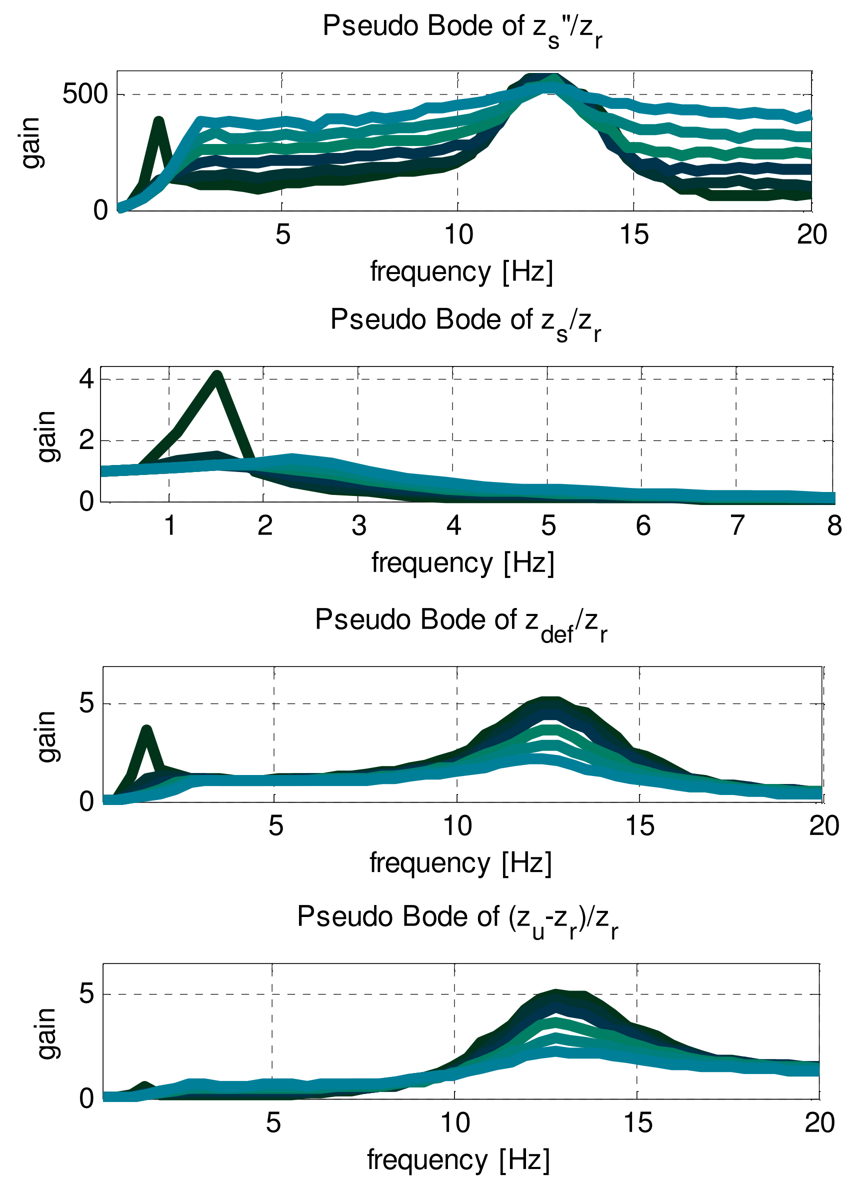
$$f_{MR} = a \cdot I \cdot (\rho) + c_p \dot{x} + k_p x$$

First proposed model: $\rho = tanh\,(c_{MR}\dot{x} + k_{MR}x) \ \in \{-1, 1\}$ and $a = y_{MR}$,

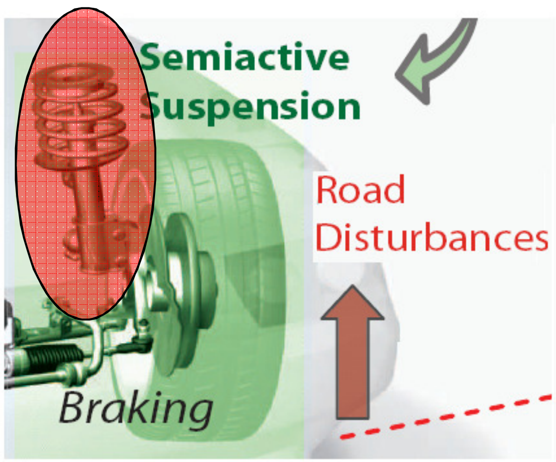
Second proposed model: $\rho = \dot{x} / \left(|||\dot{x}|||_{\infty}{}_{i-k}^{i} + \varepsilon \right) \ \in \{-1, 1\}$ and $a = c_{MR}$

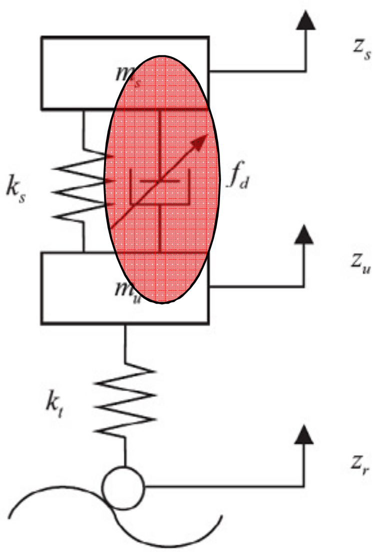
Open loop simulation using first proposed model

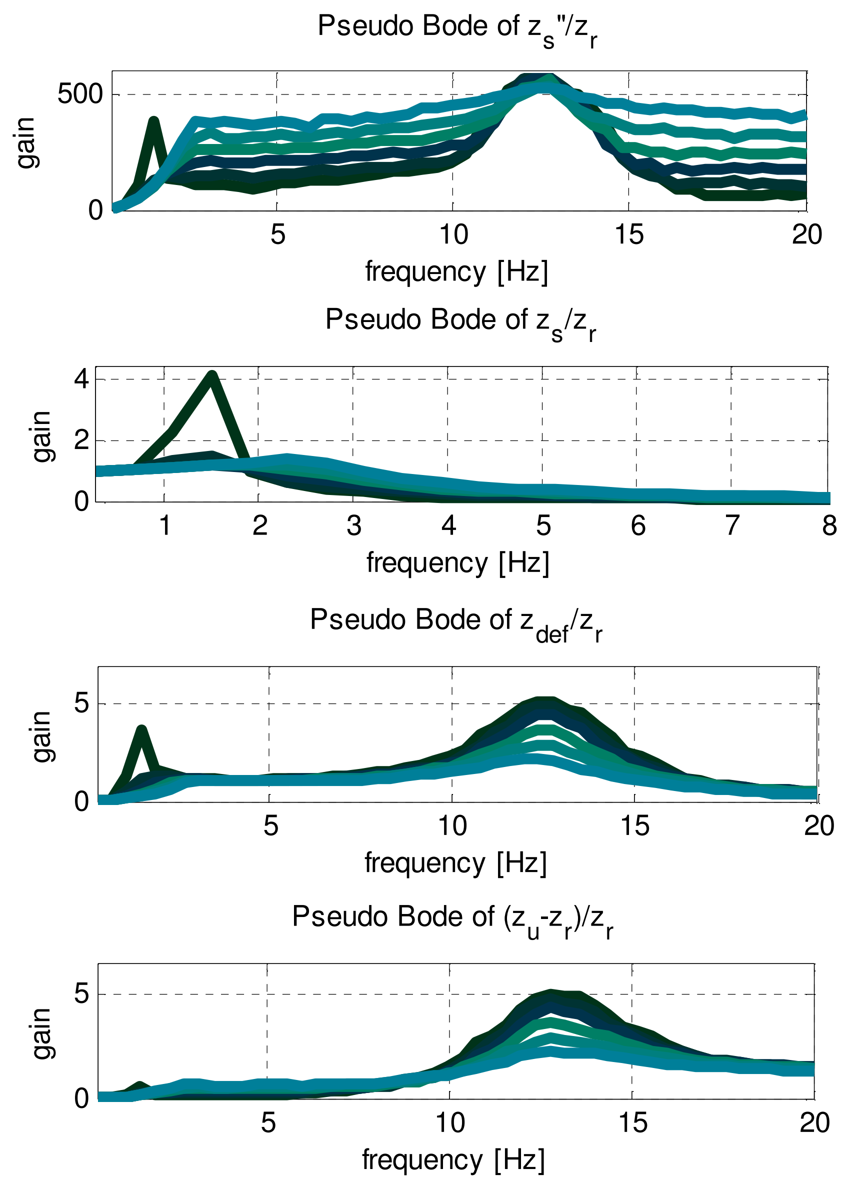




Open loop simulation using first proposed model







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Gain scheduling control for semi-active suspensions: LPV cases

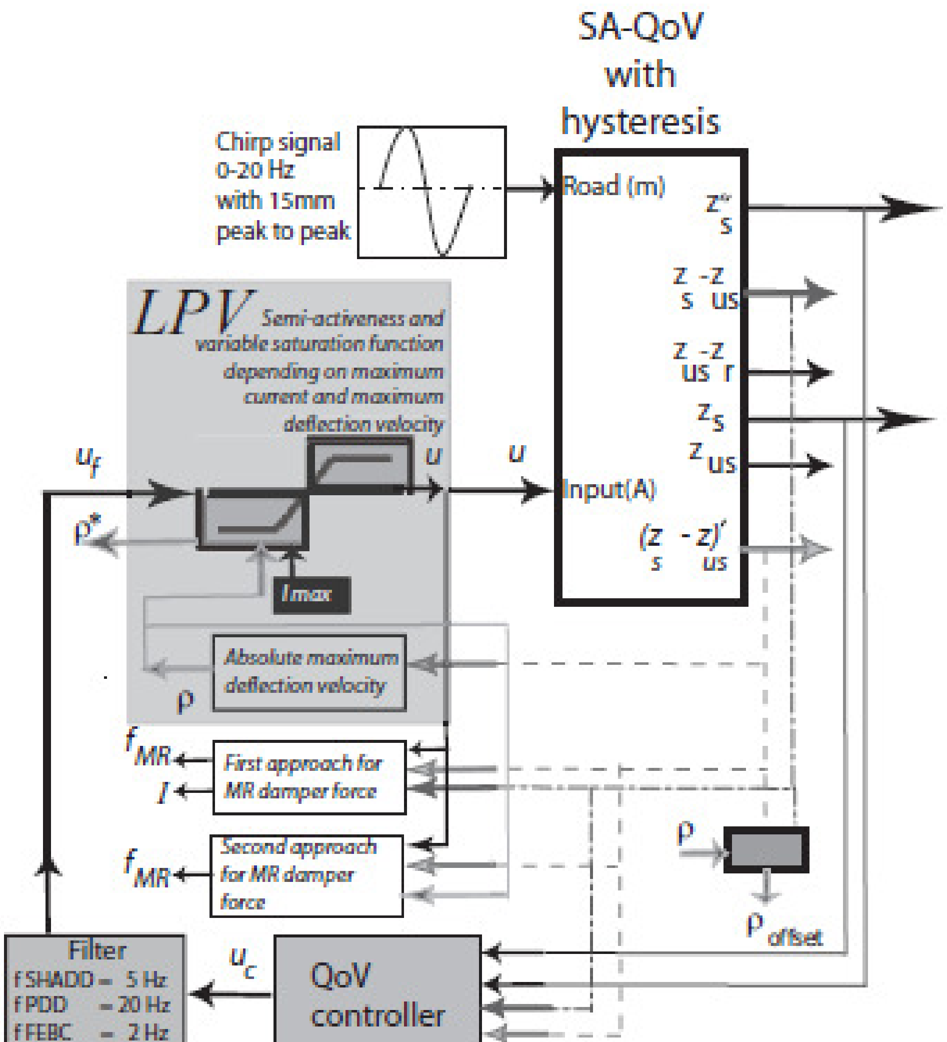
- The scheduling variable should capture the MR damper nonlinearity
- A gain scheduling controller is based on a linear time-invariant approximations to a nonlinear system
- The development involve robust linear control techniques
- The works presented here are extensions of the works by (Poussot-Vassal, 2008) and (Do et al, 2010)

Free model controllers

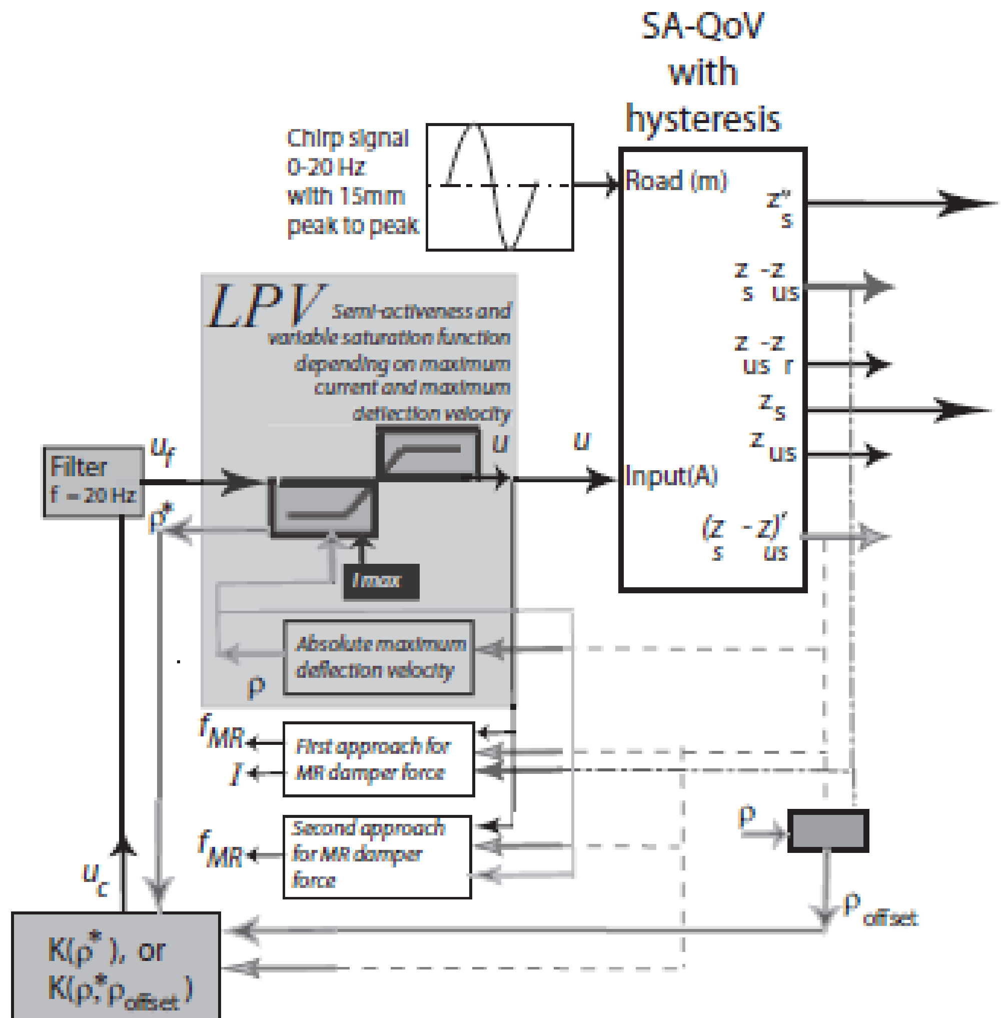
- Sky-Hook Acceleration Driven Damper (SH-ADD) (Savaresi 2007), free model controller, two sensors, comfort oriented.
- Power Driven Damper (PDD) (Morselli, 2008), the stiffness of the QoV is mandatory, two sensors, comfort oriented.
- Frequency-Estimation-Based Controller (FEBC)(Lozoya-Santos 2010), free model controller, one sensor, comfort and road holding oriented.

Closed loop controllers: Simulation schemes

Free Model Controllers

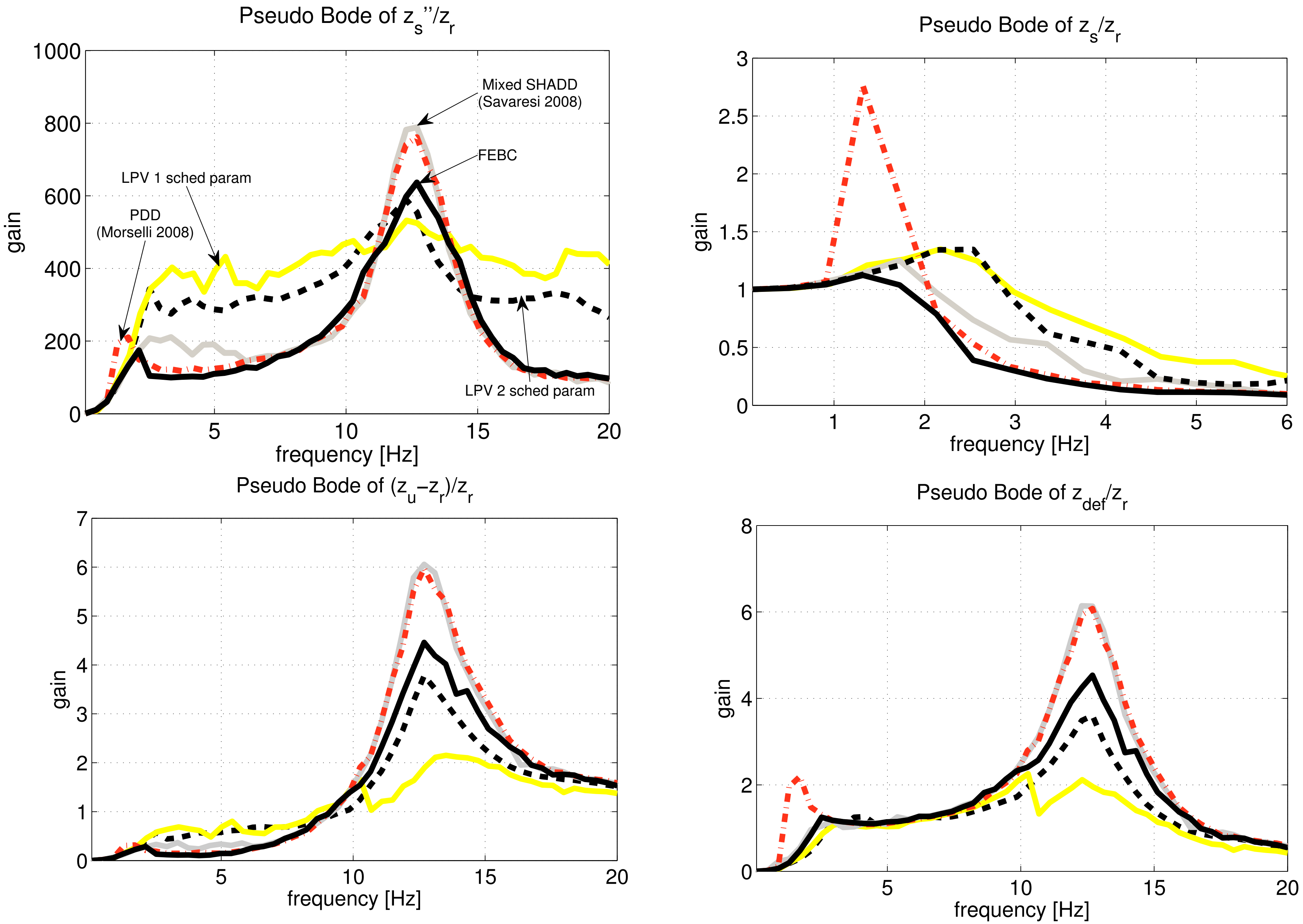


Gain Scheduling Controllers



The quarter of vehicle parameters corresponds to a Renault Megane Sedan, (Poussot-Vassal, 2008)

Frequency response of controllers based on experimental MR damper data



Advantages for practical implementation

- The control command is not force but the current, a slight advantage over other proposals
- Actual controllers are not convenient for both objectives, comfort and road holding; the proposed controllers states this possibility
- No on-line real time hard computations,
- The proposed control laws claims to be programmed in a standard micro-processor due to their simple numerical structure

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Conclusions

- A rich dynamic database for a MR damper is obtained for an academic benchmark.
- Two control oriented models of the device overpasses those present in the literature, by having few parameters, precise simulation and proper for controller synthesis.
- Through the observation of some experiments, three controllers are developed with practical implementation advantages

Further work

- The experimental validation on a quarter of vehicle of the proposed models and controllers.
- The study of the hysteresis effect on the controllers performances.
- To apply the proposed controllers into a full vehicle controller for comfort and road holding in order to implement in mass production.

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Website for MR damper Modelling Benchmark:

CALL FOR A BENCHMARKING ON MAGNETORHEOLOGICAL (MR) DAMPER MODELLING

http://www.jorgelozoya.mx/

mrdmodelling@jorgelozoya.mx

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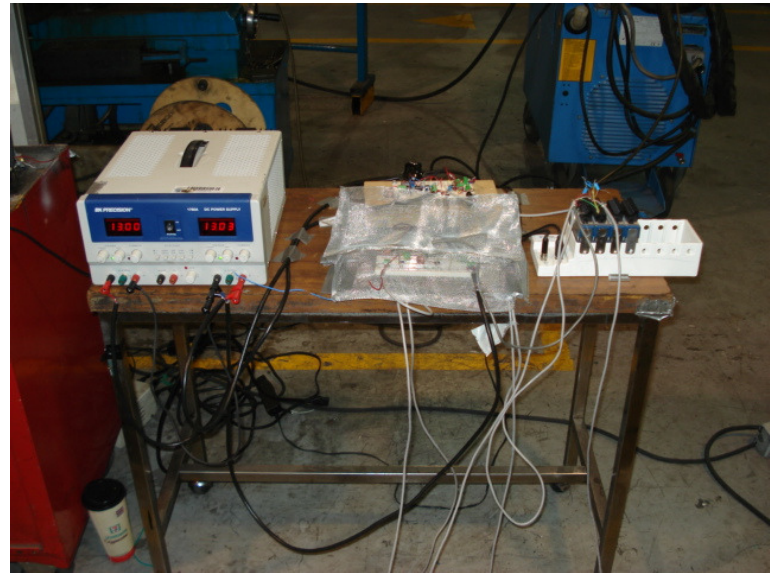
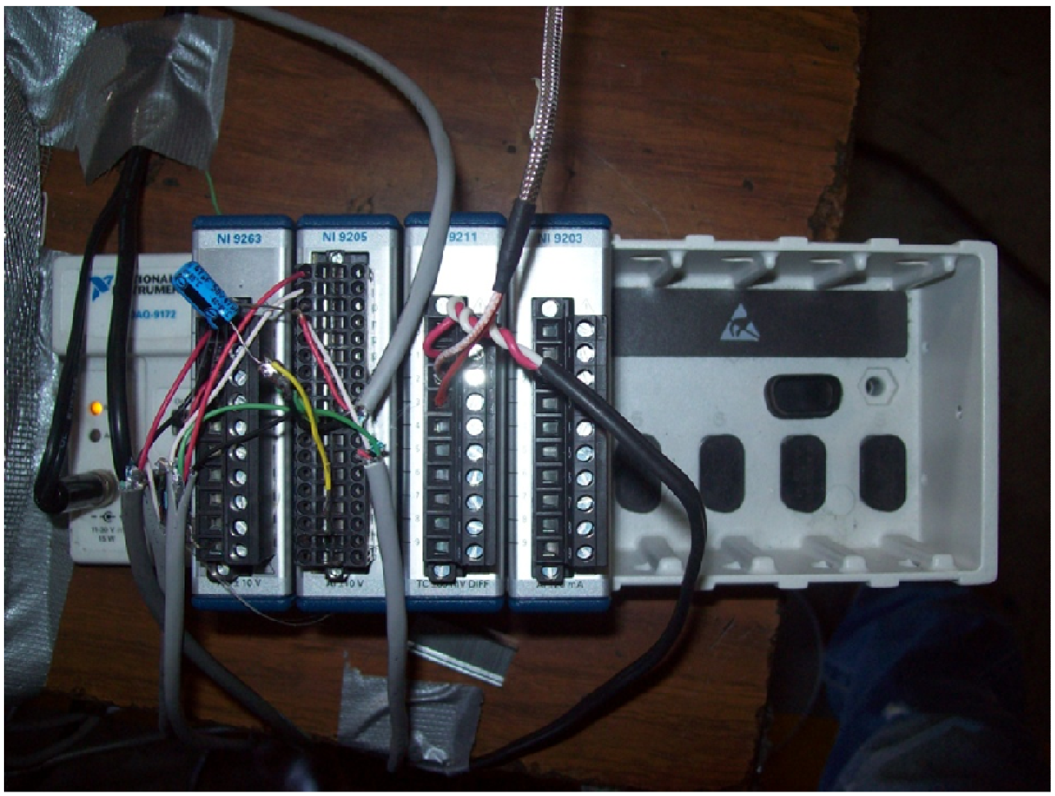
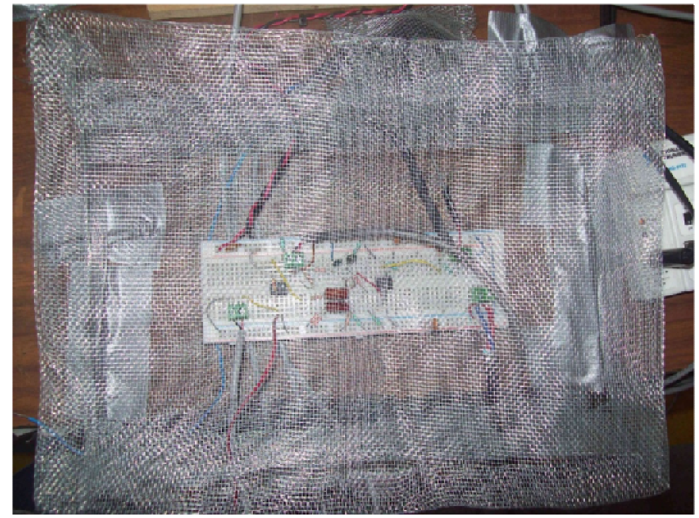
Nonlinearities of MR damper

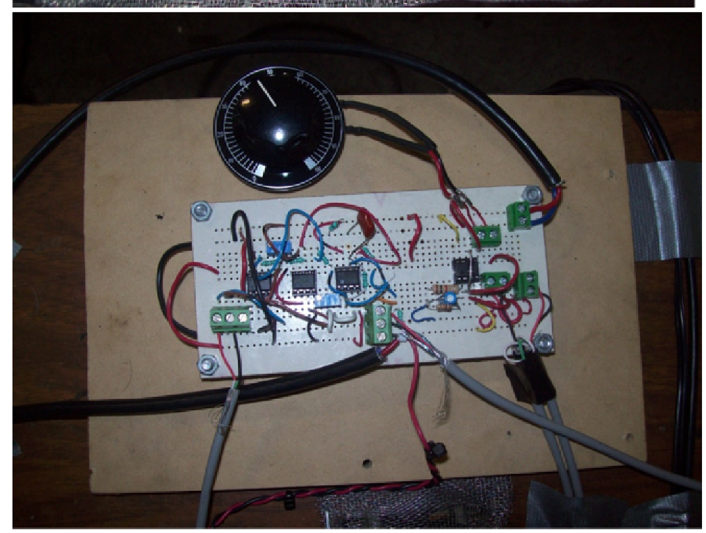
Facilities and equipment



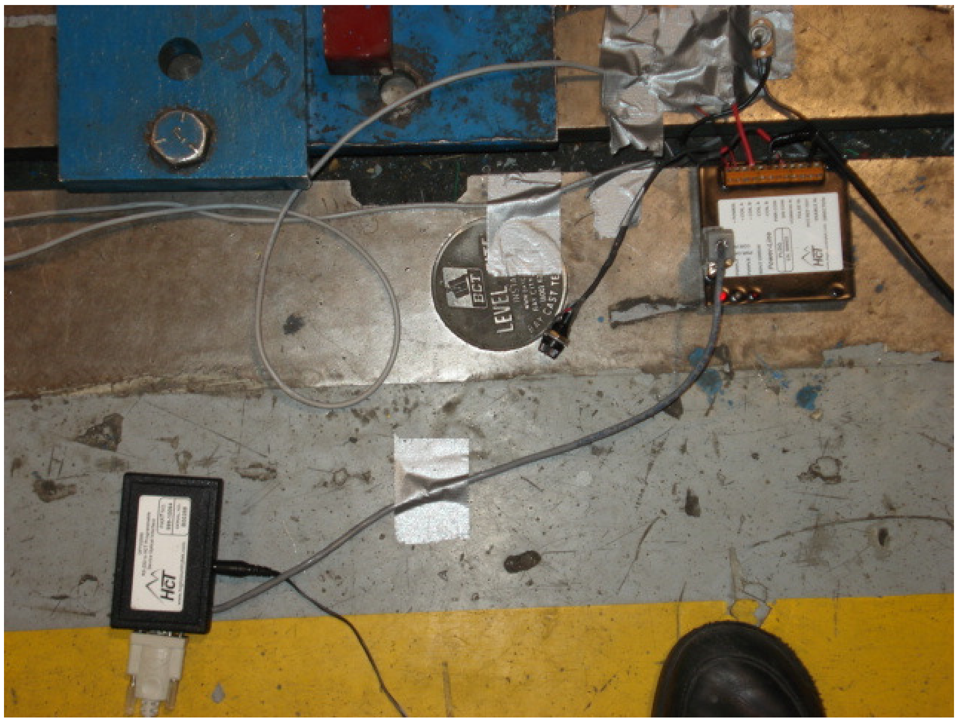
Hardware and data acquisition circuits

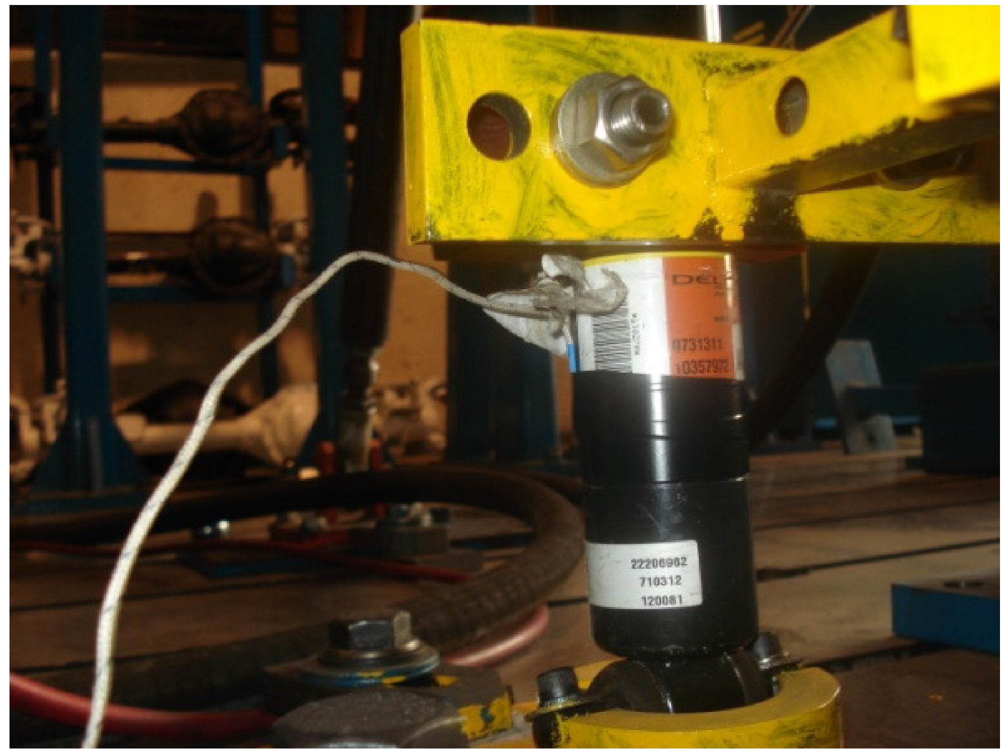




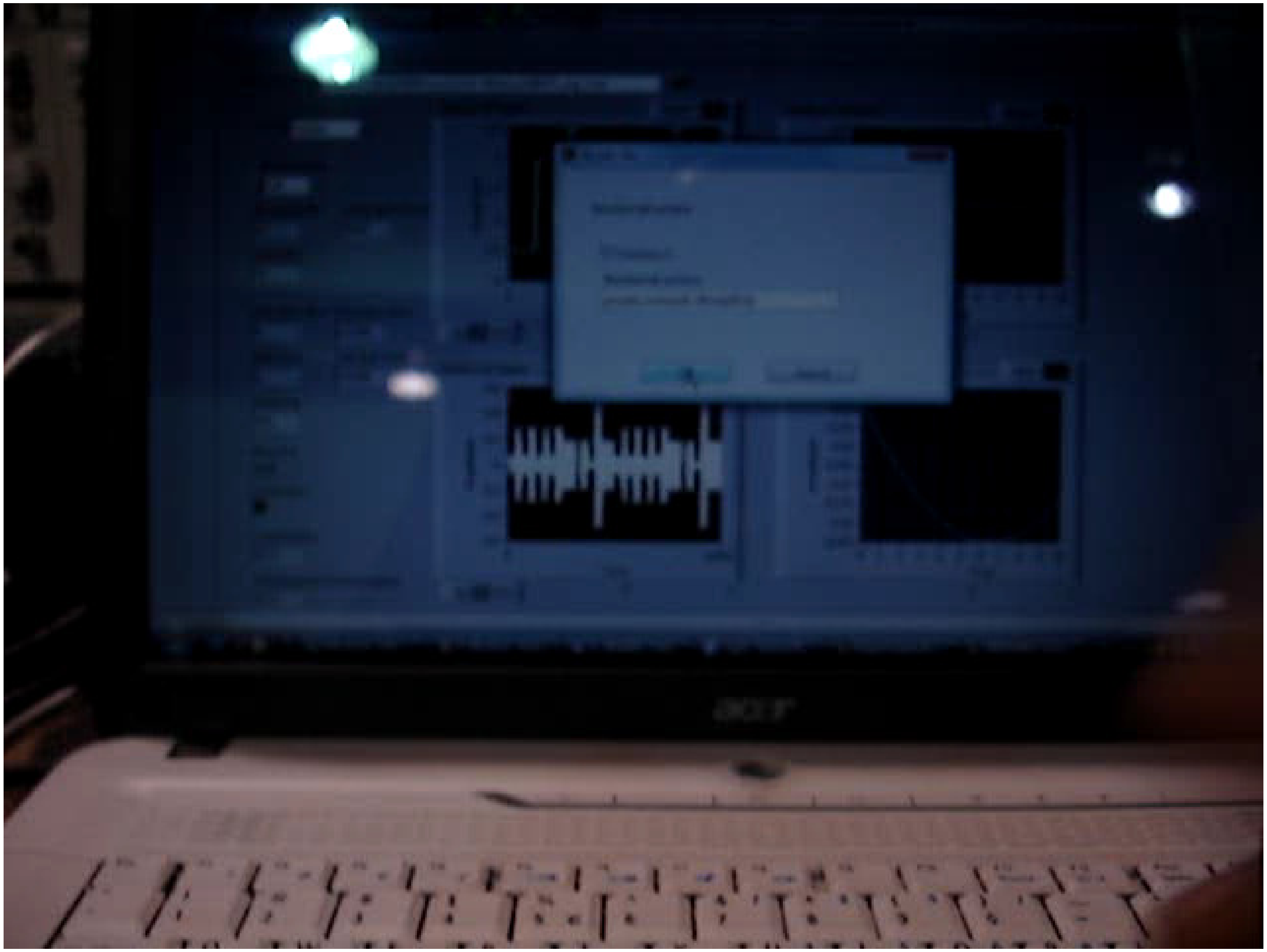


Current driver and thermocouples





Experiment example



Example of HMI running