



GIPSA – LAB
Control Department

**Benchmark on Adaptive Regulation:
Rejection of unknown/time-varying multiple narrow
band disturbances.**

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Version 1.1/ Oct. 13, 2009

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Benchmark on Adaptive Regulation: Rejection of unknown/time-varying multiple narrow band disturbances.

Results to be submitted to IFAC World Congress 2011, Milano, Italy

The scientific objective of the benchmark is to evaluate current available procedures which may be applied in the fields of active vibration control and noise control. The benchmark specifically will focus in testing: 1) performances, 2) robustness and 3) complexity.

The test bed is an active suspension using an inertial actuator and equipped with a shaker and a measure of the residual force. It is located at GIPSA-Lab, Grenoble (France) which has already experience on organizing benchmarks on test beds (see European J. of Control, no.2, 1995 and no.1, 2003).



The disturbances are unknown/time-varying multiple narrow band disturbances located in a given frequency region. The plant model is (almost) constant, but unknown. It should be identified by the participants from input/output data which will be provided (additional data can be provided upon specific demands from participants).

A “black box” discrete time Matlab Simulink simulator of the plant will be also provided. The participants should give a Simulink simulation including complete control scheme built around the “black box” model. The “test” protocol will be made available to the participants. The simulation should be compatible with the Matlab xPC Target environment, which will be used for real-time implementation on the test bed. Final evaluation will be performed on the basis of real-time results.

It is expected that the results will be presented at the IFAC World Congress 2011 in Milano, Italy. Therefore the schedule is as follows:

September 2010: Papers with preliminary results

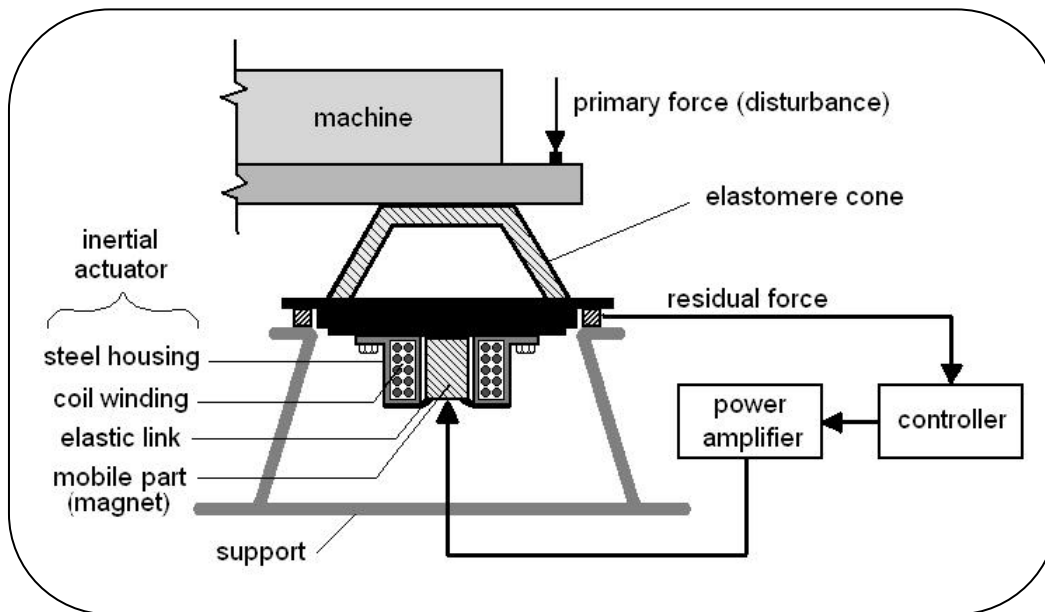
March 2011: Papers with final results

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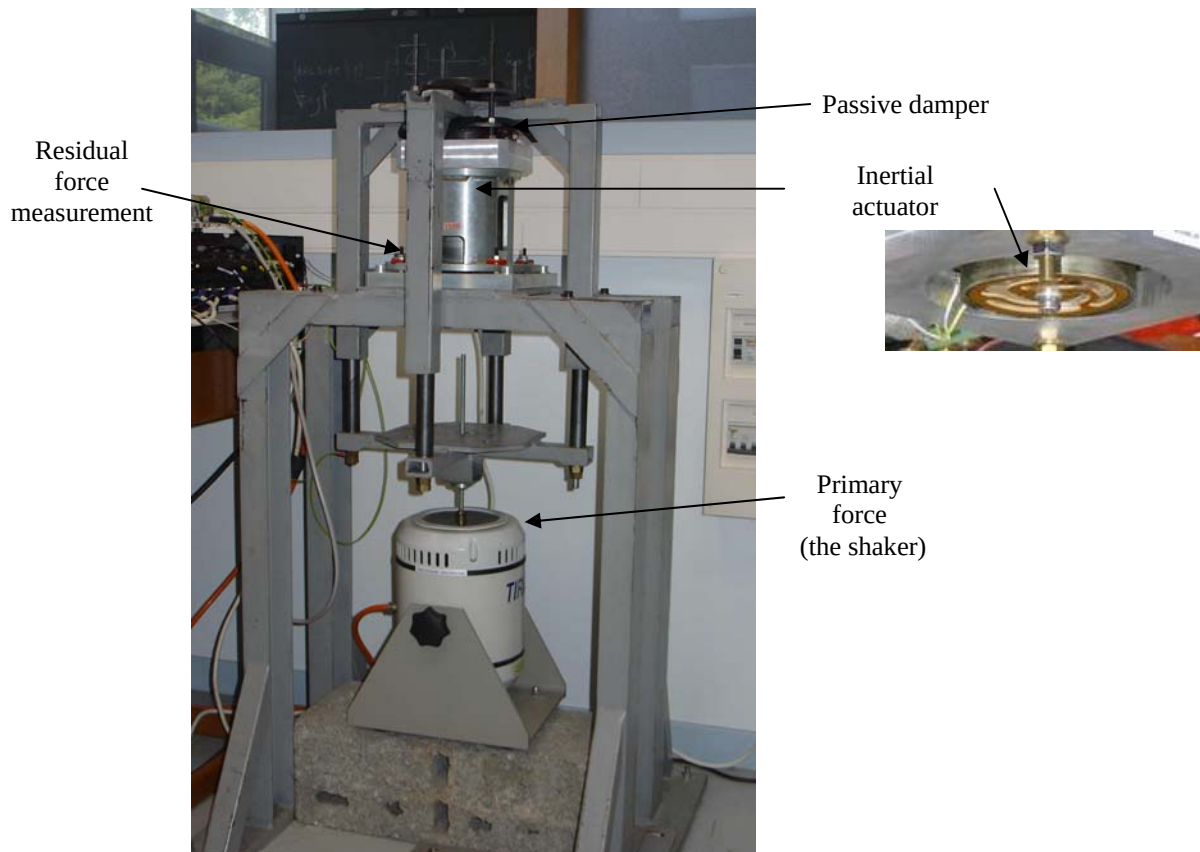
SYSTEM DESCRIPTION



An active suspension system is used for attenuation of unknown/time varying narrow band disturbances. The figure above shows the scheme of the active suspension. The main parts of the active suspension are:

- 1 an elastomer cone (passive suspension)
- 2 an inertial actuator
- 3 a measure of the residual force
- 4 a power amplifier
- 5 a controller (computer generated control signal)
- 6 a shaker which generates the disturbances

A view of the active suspension is shown below.



The mechanical construction of the load is such that the vibrations produced by the shaker, fixed to the ground, are transmitted to the upper side of the active suspension.

The output of the system is the measured voltage corresponding to the residual force. The control input drives the inertial actuator through a power amplifier. The transfer function between the excitation of the shaker and the residual force is called the **primary path**. The **secondary path** is defined as the transfer function between the control input and the residual force.

Both the **primary path** and the **secondary path** are characterized by the presence of a double differentiator (since the input in the actuator is proportional to a position and the output is proportional with the acceleration).

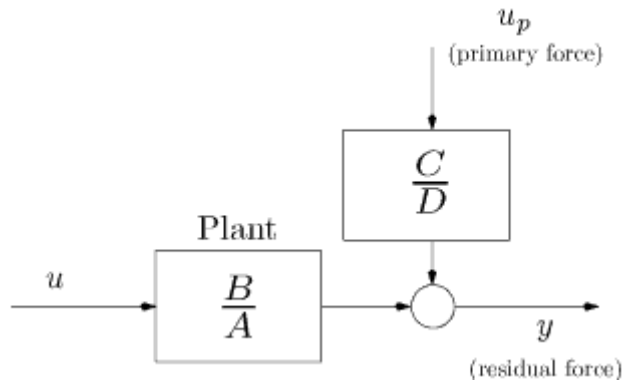
These transfer functions have to be identified from input/output data provided (additional input/output data can be provided on demand). The sampling frequency is 800 Hz.

Under appropriate control the inertial actuator will provide the forces for the compensation of the mechanical disturbances, therefore leading to the absorption of the vibrations.

The control objective is to reject the effect of unknown narrow band disturbances on the output of the system (residual force), i.e. to attenuate the vibrations transmitted from the machine (the mechanical structure fixed on the active suspension and excited by the shaker) to the support via the active suspension.

A discrete time “black box” Matlab Simulink simulator of the plant can be downloaded. (see section Simulator)

SYSTEM IDENTIFICATION



The block diagram of the active suspension system is presented in the above figure. Two models for the system can be identified, corresponding to the primary and secondary path. Here u_p denotes the input of the primary path (excitation of the shaker), u is the input of the secondary path (proportional to the inertial actuator input) and y is the system output (residual force). The sampling frequency for data acquisition is $F_s = 800$ Hz.

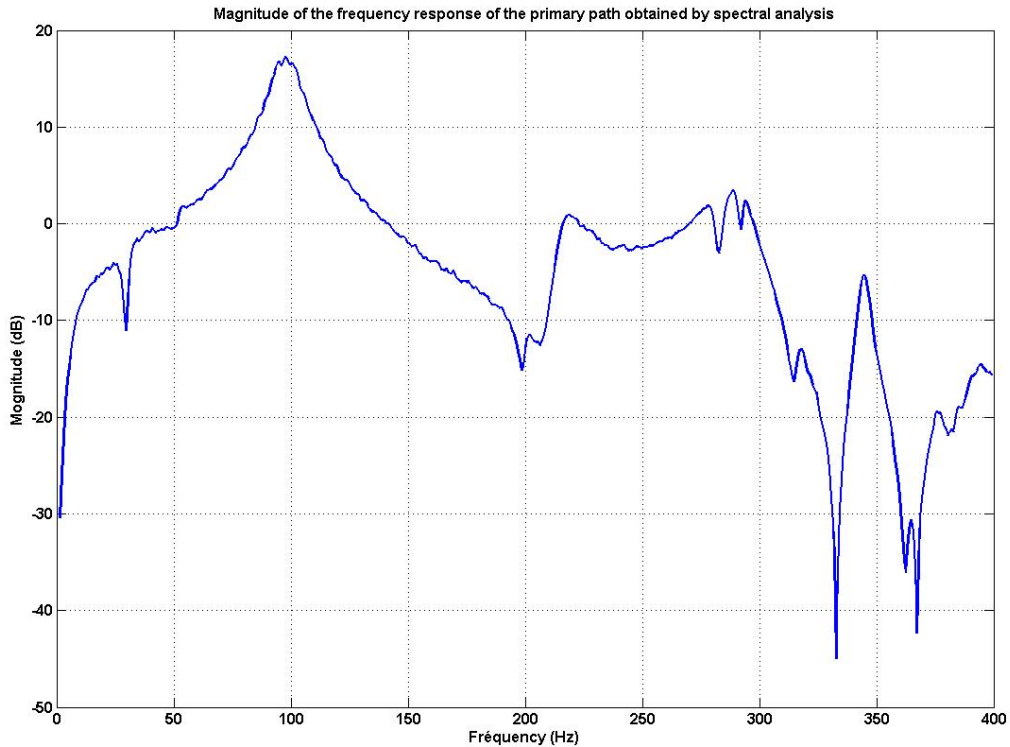
Identification of the Primary path model

To identify the primary path model the shaker is excited by a PRBS. Several files are available:

data_prim1.mat : PRBS input generated by a 10-bit shift register, with a clock frequency of F_s , input magnitude : 0.2V, data length:10000:

data_prim2.mat : PRBS input generated by a 10-bit shift register, with a clock frequency of $F_s/2$ input magnitude : 0.2V, data length:4096:

A non parametric model of the primary path can be identified by the spectral analysis method. This analysis shows that the model contains several high-resonant modes. The magnitude of the model frequency characteristic is given in the figure below.



The magnitude of the model frequency characteristic has been calculated with the following M file: **freq_resp_cal.m** using the file **data_prim1.mat**

Identification of the Secondary path model:

To identify the secondary path model several input/output files are available:

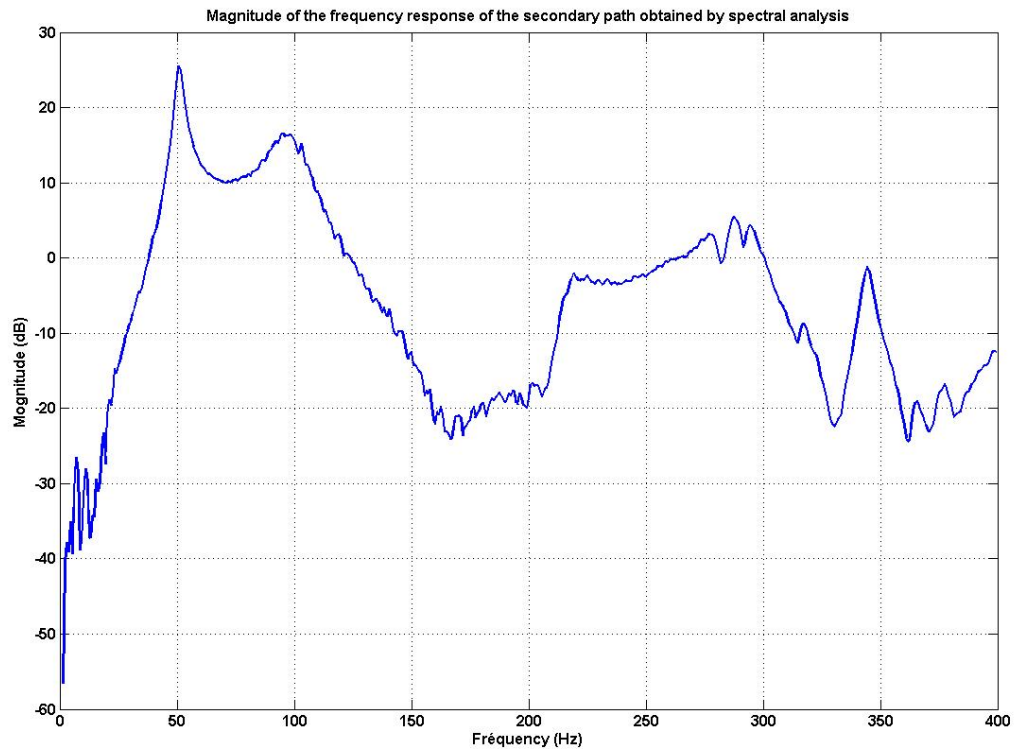
data_sec1.mat: PRBS input generated by a 10-bit shift register, with a clock frequency of F_s input magnitude: 0.2V, data length: 10000:

data_sec2.mat : PRBS input generated by a 10-bit shift register, with a clock frequency of $F_s/2$, input magnitude: 0.2V, data length: 2048:

data_sec3.mat : PRBS input generated by a 10-bit shift register, with a clock frequency of $F_s/2$, input magnitude: 0.2V, data length: 4096:

A non parametric model of the primary path can be identified by the spectral analysis method. This analysis shows that the model contains several high-resonant modes. The magnitude of the model frequency characteristic is given in the figure below

The magnitude of the model frequency characteristic has been calculated with the following M file: **freq_resp_cal.m** using the i/o data file **data_sec1.mat**



Continuous-time model

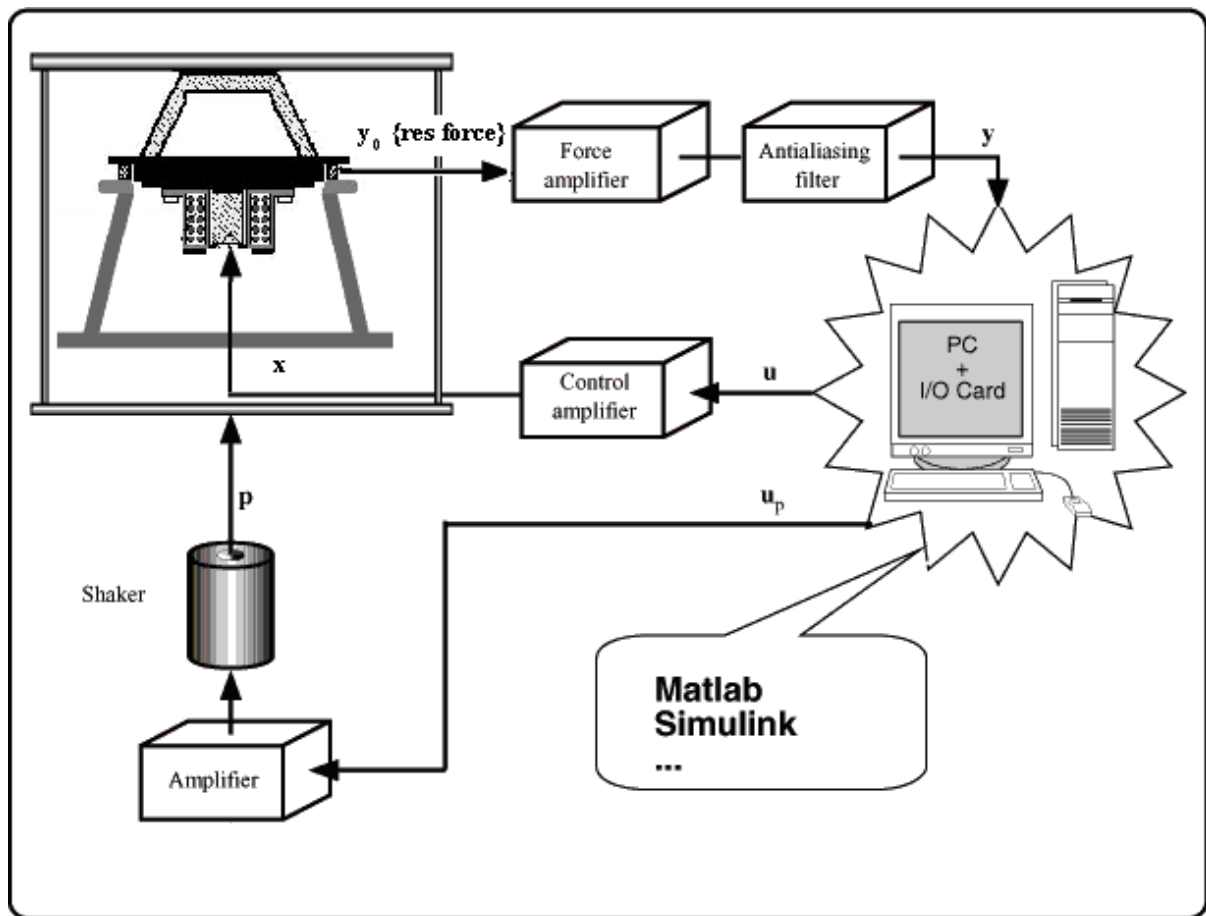
Approximate continuous continuous-time models of the plant can be obtained by conversion of discrete-time identified models using the zero-order hold method or from the estimated frequency characteristics

The real-time data acquired on the system are available in the **data acquisition** section.

A compressed version of all files is available in the file: **data.zip**. The routines are available in the compressed file: **functions.zip**

DATA ACQUISITION

The block diagram of the data acquisition system is given in the figure bellow:



Open-loop operation

The real-time experiments have been performed with different PRBS signals, for the primary and secondary path. The sampling frequency was $F_s = 800$ Hz. The characteristics of the data obtained and the name of the files are given below:

Primary path

data_prim1.mat : PRBS input generated by a 10-bit shift register, with a clock frequency of F_s , input magnitude : 0.2V, data length:10000:

data_prim2.mat : PRBS input generated by a 10-bit shift register, with a clock frequency of $F_s/2$ input magnitude : 0.2V, data length:4096:

Secondary path

data_sec1.mat: PRBS input generated by a 10-bit shift register, with a clock frequency of F_s input magnitude:0.2V, data length: 10000:

data_sec2.mat :PRBS input generated by a,10-bit shift register, with a clock frequency of $F_s/2$, input magnitude: 0.2V, data length: 2048:

data_sec3.mat : PRBS input generated by a, 10-bit shift register, with a clock frequency of $F_s/2$, input magnitude: 0,2V, data length: 4096:

A compressed version of all files is available in the file: **data.zip**.

Other data can be acquired on demand.

CONTROL SPECIFICATIONS

The non parametric models of the primary path and of the secondary path obtained by the spectral analysis method shows that there are several resonance modes. The most significant are those near 50 Hz (secondary path) and 100 Hz (primary and secondary paths).

The narrow band disturbances are located in the range 45 to 105 Hz. It is important to take in account the fact that the secondary path (the actuator path) has no gain at very low frequencies and very low gain in high frequencies near 0.5 Fs. Therefore the control system has been designed such that the gain of the controller be very low (or zero) in these regions (preferably 0 at 0.5Fs). Not taking in account these constraints can lead to undesirable stress of the actuator.

It is suggested that participants to the benchmark consider first a linear control design in order to assess the particularities of the secondary path. This design should consider the attenuation of one, two or three sinusoidal disturbances located between 45 and 105 Hz with the objective to introduce attenuation over 45 db at the disturbance frequencies and very little amplification at other frequencies.

The control objectives can be expressed as follows:

Level 1

Rejection of a **single** time varying sinusoidal disturbance within 45 and 105 Hz under three protocols:

1. Step changes in frequencies. Time domain performances

An upper bound for the duration of the adaptation transient is imposed (2 sec) since the time separation between the steps in frequencies will be between 2 and 3 sec. However, the transients will be further evaluated in terms of maximum value and duration.

2. Evaluation in steady state operation at the frequencies considered above (after adaptation settles).

Test 1: The steady state performance in time domain will be evaluated by measuring the mean square value of the residual force

Test 2: Power spectral density performances

For a constant frequency disturbance, once the adaptation transient is over, the attenuation with respect to the open loop will be measured (using function: **spectre_psd_rms.m**)

The imposed performances are as follows:

- attenuation of the disturbance (with respect to the open loop) of at least 45 db
- amplification at other frequencies (with respect to the open loop) case should be less than 6dB

3. Chirp changes in frequency. Time domain evaluation

A linear time varying change between two situations will be made. The maximum value of the residual force during the chirp will be measured as well as the mean square value of the residual force

The loop is closed before the disturbances are applied for all the above tests.

Supplementary tests

The operation of the system should remain stable if three sinusoidal disturbances are applied simultaneously.

The operation of the loop should remain stable if the disturbance is applied simultaneously with the closing of the loop

Level 2

Rejection of **two** time varying sinusoidal disturbances within 45 and 105 Hz under two protocols:

1. Step changes in frequencies. Time domain performances

An upper bound for the duration of the adaptation transient is imposed (2 sec) since the time separation between the steps in frequencies will be between 2 and 3 sec. However, the transients will be further evaluated in terms of maximum value and duration.

2. Evaluation in steady state operation at the frequencies considered above (after adaptation settles).

Test 1: The steady state performance in time domain will be evaluated by measuring the mean square value of the residual force

Test 2: Power spectral density performances

For a constant frequency disturbance, once the adaptation transient is over, the attenuation with respect to the open loop will be measured (using function: **spectre_psd_rms.m**)

The imposed performances are as follows:

- attenuation of the disturbance (with respect to the open loop) of at least 45 db
- amplification at other frequencies (with respect to the open loop) case should be less than 6dB

3. Chirp changes in frequency. Time domain evaluation

A linear time varying change between two situations will be made. The maximum value of the residual force during the chirp will be measured as well as the mean square value of the residual force

The loop is closed before the disturbances are applied for all the above tests.

Supplementary tests

The operation of the system should remain stable if three sinusoidal disturbances are applied simultaneously.

The operation of the system should remain stable if only one sinusoidal disturbance is applied. The operation of the loop should remain stable if the disturbances are applied simultaneously with the closing of the loop

Level 3

Rejection of **three** time varying sinusoidal disturbances within 45 and 105 Hz under two protocols:

1. Step changes in frequencies. Time domain performances

An upper bound for the duration of the adaptation transient is imposed (2 sec) since the time separation between the steps in frequencies will be between 2 and 3 sec. However, the transients will be further evaluated in terms of maximum value and duration.

2. Evaluation in steady state operation at the frequencies considered above (after adaptation settles).

Test 1: The steady state performance in time domain will be evaluated by measuring the mean square value of the residual force

Test 2: Power spectral density performances

For a constant frequency disturbance, once the adaptation transient is over, the attenuation with respect to the open loop will be measured (using function: **spectre_psd_rms.m**)

The imposed performances are as follows:

- attenuation of the disturbance (with respect to the open loop) of at least 40 db
- amplification at other frequencies (with respect to the open loop) case should be less than 9dB

3. Chirp changes in frequency. Time domain evaluation

A linear time varying change between two situations will be made. The maximum value of the residual force during the chirp will be measured as well as the mean square value of the residual force

The loop is closed before the disturbances are applied for all the above tests.

Supplementary tests

The operation of the system should remain stable if only one or two sinusoidal disturbances are applied.

The operation of the loop should remain stable is the disturbances are applied simultaneously with the closing of the loop

The transients for the case when the disturbances vanish will be tested and measured for all the levels.

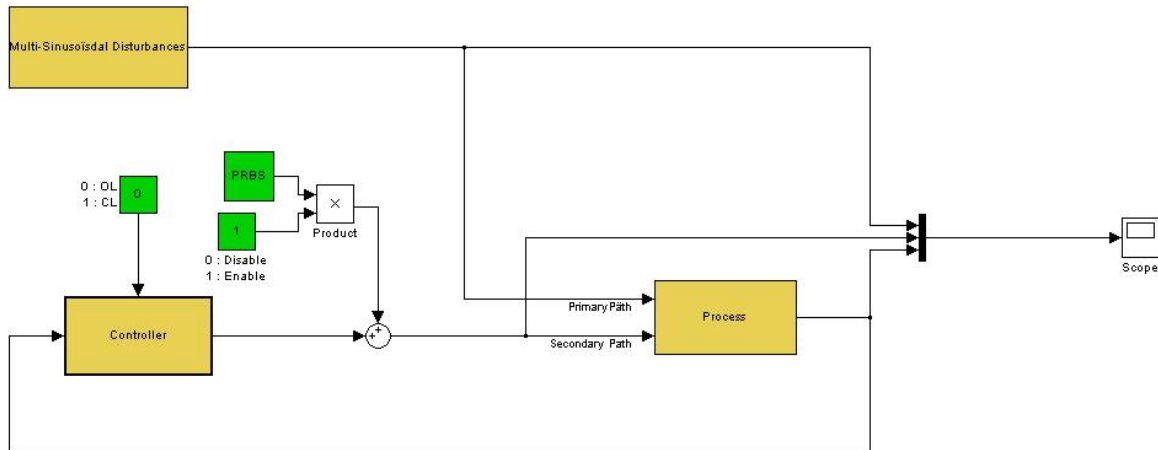
Testing protocols will be provided (disturbances).

For the final tests the values of the frequencies of the disturbances will be chosen randomly within the given range. (see evaluation section)

SIMULATOR

A « black box » discrete time simulator of the active suspension built on matlab simulink (Matlab 2007) can be downloaded: **bench_sim.zip**

The main simulation scheme is given below :



The zip file contains the folder : **bench_sim** which includes 3 files :

init_simulator_bench.m; bruitbench.mat; simulator_bench.mdl

The sampling frequency is 800 Hz.

The primary path and the secondary path are indicated.

A generator for the PRBS is included in the scheme as well as the generator for the disturbances (up to three sinusoids)

A sample of the system noise in open loop is added to the simulation (a record of 10000 samples).

The saturation of the actuator is included in the simulator. The corresponding input saturation level is 0.7 V (for both paths).

The control scheme(Controller) should be built around the given simulator using the actual “black box” model or an identified one. However the organizers will test the scheme using the given “black box” model before its implementation on the real system.

To start the simulator one should run the **init_simulator_bench.m**

REAL TIME IMPLEMENTATION

The real time implementation use the Matlab xPC Target environment (2007). The PC for program development is a Dell Optiplex 760. The PC target (Dell Optiplex GX270 with Pentium4 at 2.86 GHz) is equipped with I/O data acquisition, A/D and D/A converters

The procedure will compile the algorithms directly from the Simulink scheme.

It is therefore strongly recommended that a test on a xPC target environment be done in order to be sure that compilation is complete.

One should check also the execution time which should be less than 1.25 ms

For the real time experiments (**data acquisition** and **controller evaluation**) the participants should ask for a registration code.

The authors are advised to design and test their control scheme using the simulator because **the number of experiments on the real system** will be limited.

Those who would like to participate to the experiments should contact the organizers.

EVALUATION OF THE ADAPTIVE CONTROLLER

The Simulink control scheme provided by the participants will be firstly evaluated on the simulator using the given sequences of disturbances.

The step changes in the frequencies of the disturbances can be generated with the block “multi sinusoidal disturbances” already included in the Simulink Simulator. The description of these sequences can be found in the file **step_tests.pdf**.

The chirp change in the frequencies of the disturbances can be generated with the Simulink block “**test_chirp**” given in the file **test_chirp.zip**. The description of the chirp tests are given in the file **chirp_test.pdf**

Provided that the basic requirements are satisfied we will proceed to the next step i.e.: compilation using xPC Target. If compilation problems occur, these will be indicated to the contributors for making appropriate modifications.

Once the compilation is OK the scheme will be tested on the real system

The tests will be done with the sequences of disturbances described in the files **step-tests.pdf** and **chirp_tests.pdf** as well . Once these tests are achieved, test on similar sequences of disturbance but with values of frequencies chosen randomly (within the given range) will be done.

For the calculation of the power spectral density one use the function: **spectre_psd_rms.m**

For measurement of performances in the time domain, both transients and steady state will be evaluated.

The transients will be compared in terms of maximum value and duration.

The steady state performance in time domain will be evaluated by measuring the mean square value of the residual force

For chirp disturbances, the maximum value of the residual force during the chirp will be measured as well as the mean square value of the residual force (during the chirp)

Complexity of the control scheme will be evaluated in terms of execution time. (the organizers are aware that this is not a fully objective criterion – any suggestion is welcome).