# A PC-based multi purpose test bed environment for structural testing and control

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**Abstract:**

*The aim of the following paper is to give an overview of a test bed set up for a rail car body to compare different concepts to suppress structural vibrations. It is demonstrated, that such a complex measurement and actuation task can be easily implemented on a single laboratory PC using standard software like Matlab/SIMULINK®. With the help of this PC standard engineering tasks like measuring, identification of transfer functions, as well as controller design and their implementation in real time can be carried out easily. Additionally, the utilization of Matlab/SIMULINK® enables the realisation of a sophisticated virtual instrumentation system.*

## 1 Introduction

A growing number of measurement as well as actuation devices used in technical applications increases the complexity of the measurement system. Therefore, simple, standardised, and low-cost components and standard software programs are desired for the implementation of the measurement system.
In the paper at hand the application is a test bed for a 1:10 scaled railway vehicle car body, which has been built to investigate different concepts to suppress structural vibrations by active damping. In contrast to pure measurement applications the implementation of closed loop control schemes requires both actuators with suitable amplifiers and a fast and versatile realisation of the control unit. A software solution for a short development cycle from design to simulation and finally implementation of a control scheme is therefore necessary.
In the remainder of the paper the test bed, the measurement and actuation devices, as well as the implementation in Matlab/SIMULINK® are described.

## 2 Test bed

In Figure 1 the test bed with the applied components is shown schematically. The test bed mainly consists of the test stand, the flexible structure of the scaled car body and all the components used for actuation and measurement (see Figure 2).
The car body model is made from aluminium sheet metal which is adhered with a 2 component, structural metal adhesive and was designed with FE methods to exhibit dense lying eigenfrequencies. Some design aspects are given in [1]. The car body is suspended in the test bed by a defined elastic attachment between test stand and model via 4 coil-springs. Point of application on the model is the relative position of the secondary damping elements

in reality. With this connection the model is mechanically comparable to a free running beam. To ensure minimal disturbances caused by test stand-vibrations the springs have a very low natural frequency. In addition, base-foundation consist of heavy steel-reinforced concrete plates. Welded steel profiles establish the basic structure of the test stand.

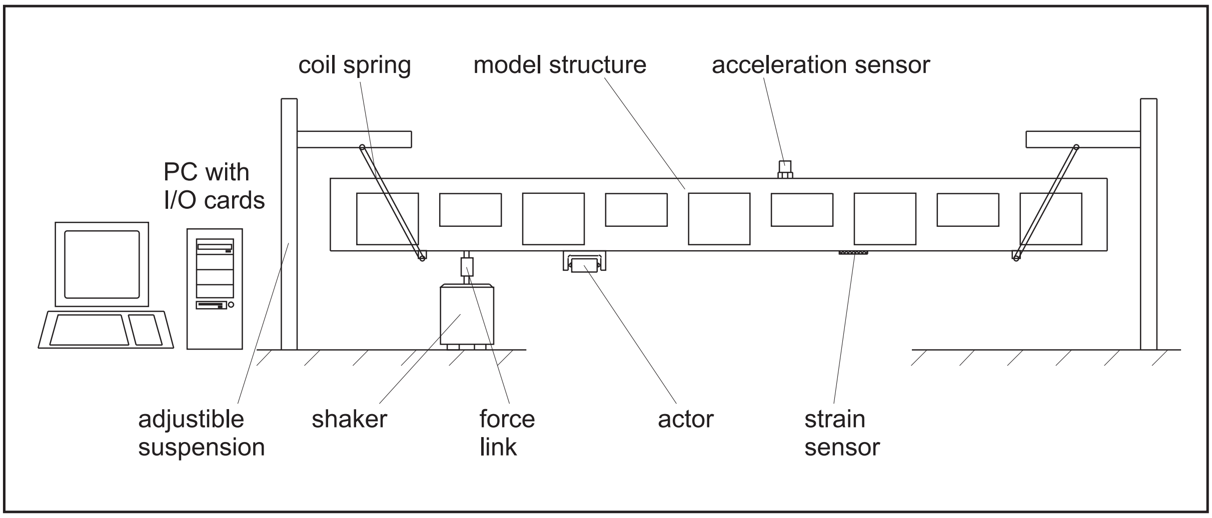


**Figure 1: Sketch of the multi purpose test bed**

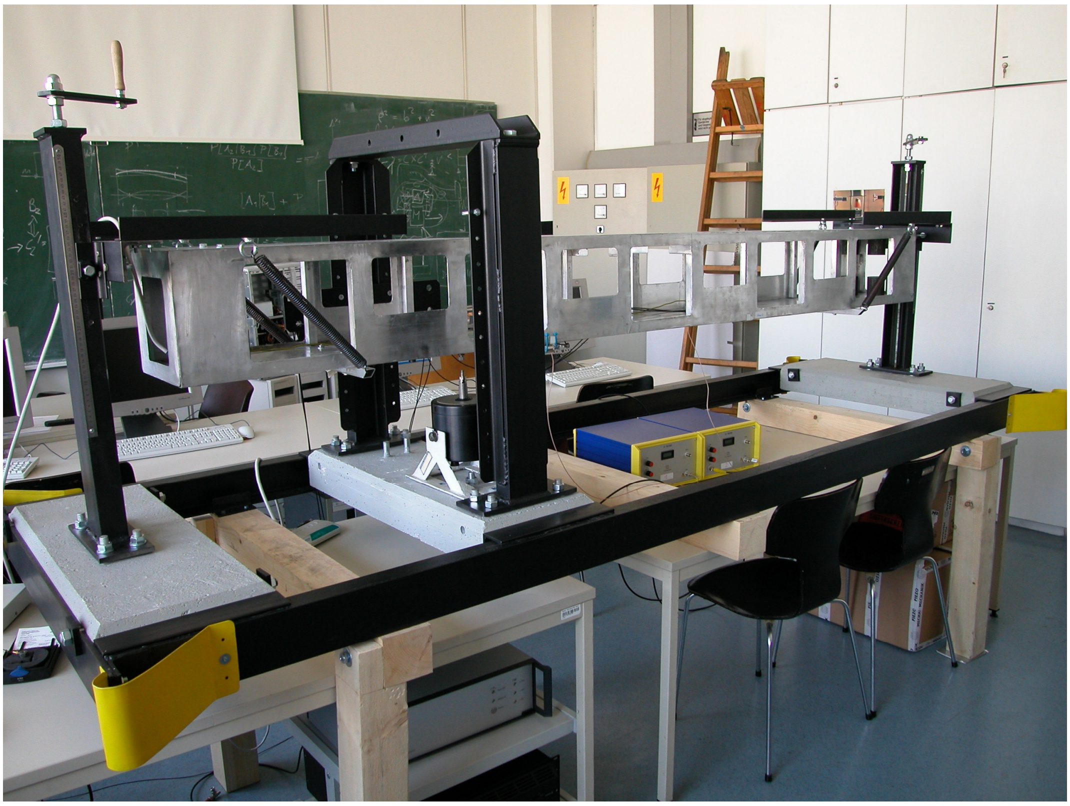

**Figure 2: Test bed bodywork in the laboratory**

# 3 Measurement equipment

### *3.1 Measurement devices*

In Figure 1 also the measurement and actuation devices are shown, respectively. Basically, three types of measurement devices are used. There is an acceleration sensor (Brüel & Kjaer 4383, piezoelectric charge accelerator), a force link (Kistler 9173B, SlimLine Quarz Force Link), connecting shaker and structure, as well as two strain type probes (SMART MATERIAL MFC M2814 P2). All sensor types are based on voltage generation, proportional to the measured quantities, by the piezoelectric effect. The strain type probes are used for control signal generation, whereas the actual performance variable to be controlled is the acceleration along the side members of the car body. Finally, with the help of the force link the force actually transmitted from the shaker to the structure can be measured directly. This is useful for the identification tasks.
The usage of different sensor types also gives rise to the necessity of different measurement signal amplifiers and signal pre-processing, respectively. Therefore, charge amplifiers are used for acceleration and force signals, whereas the voltages produced by the strain elements are directly (not amplified) used as control signals. Nevertheless, for signal quality enhancement differential amplifiers are used. A customized measurement system type MAS-10 which consist of a 19 inch rack housing contains the above mentioned charge amplifiers as well as signal pre-treatment devices such as the above mentioned low-pass-filters and differential amplifiers.

### *3.2 Actuation devices*

To simulate realistic vibration excitations generated by track irregularities a vibration exciter (Brüel & Kjaer 4809, Vibration Exciter) is used. Despite that there is only one but variable point of excitement all eigenfrequencies of interest can be excited (compare [1]).
For the implementation of different control concepts 2 piezo stack actuators (Piezomechanik, PSt 150/14/40 VS20) mounted in a specially designed console are used.
Using such consoles makes it possible to apply bending moments to the structure by using linear actors. The mounting of the actuator and the shape of the console together with some preliminary control results for a simple flexible beam structure are described in [2].

# 4 Software and PC implementation

Data-acquisition and -storage are carried out using only one PC with I/O hardware. The signals generated by the acceleration- and the force-probe are first filtered by a low-pass-filter to eliminate measurement noise and then are passed on to the measurement card (NI PCI 6052E) implemented in the PC along with the strain measurements. These signals, which are proportional to strain, require no filtering but a differential amplification to be capable of eliminating interference which can easily occur using such high resistance sensor types.

Actuator signals e.g. for control purposes as well as excitation signals applied to the shaker are generated with the help of the measurement PC and fed to the according devices (high voltage amplifier type Piezomechanik LE 150/100) via an analogue output card (NI PCI 6703).

On the PC Windows XP® is installed, which is the basic operating system for Matlab/SIMULINK®, a standard application for technical engineering. Matlab/SIMULINK®

is used for simulation and design of control systems, measurement, identification purposes and also real-time applications. In the presented case the Matlab/SIMULINK® Real-Time Windows Target Toolbox is used for control purposes that enable one to easily and fast implement a soft real-time system. Figure 3 shows a SIMULINK® model which was used for measurement, actuation, and control purpose.

An implementation with the help of the Real-Time Windows Target Toolbox is much more convenient than an implementation in the xPC Target Toolbox (e.g. [3]), that enables one to achieve hard real-time. Nonetheless, the compatibility of both available PCI cards makes it possible using the Real-Time Windows Target Toolbox as well as the xPC Target Toolbox, on the same PC.

With the so defined test bed rapid prototyping becomes very efficient. The central control is easily adaptable, scalable, and very fast to update. Additionally, the data processing (e.g. filtering), post-processing (e.g. FFT) and storage can be carried out directly on the PC with the help of Matlab/SIMULINK®. Thus, virtual instrumentation which considerably reduces the hardware requirements becomes easily and fast available.

Another advantage of the chosen system is its scalability regarding the number of necessary analogue input- and output-channels, which makes it possible to connect all standardised measurement- and actuating devices. Currently, both cards provide in combination 16 single ended analogue input- and 18 analogue output-channels as well as further digital I/O´s which are not yet in use.

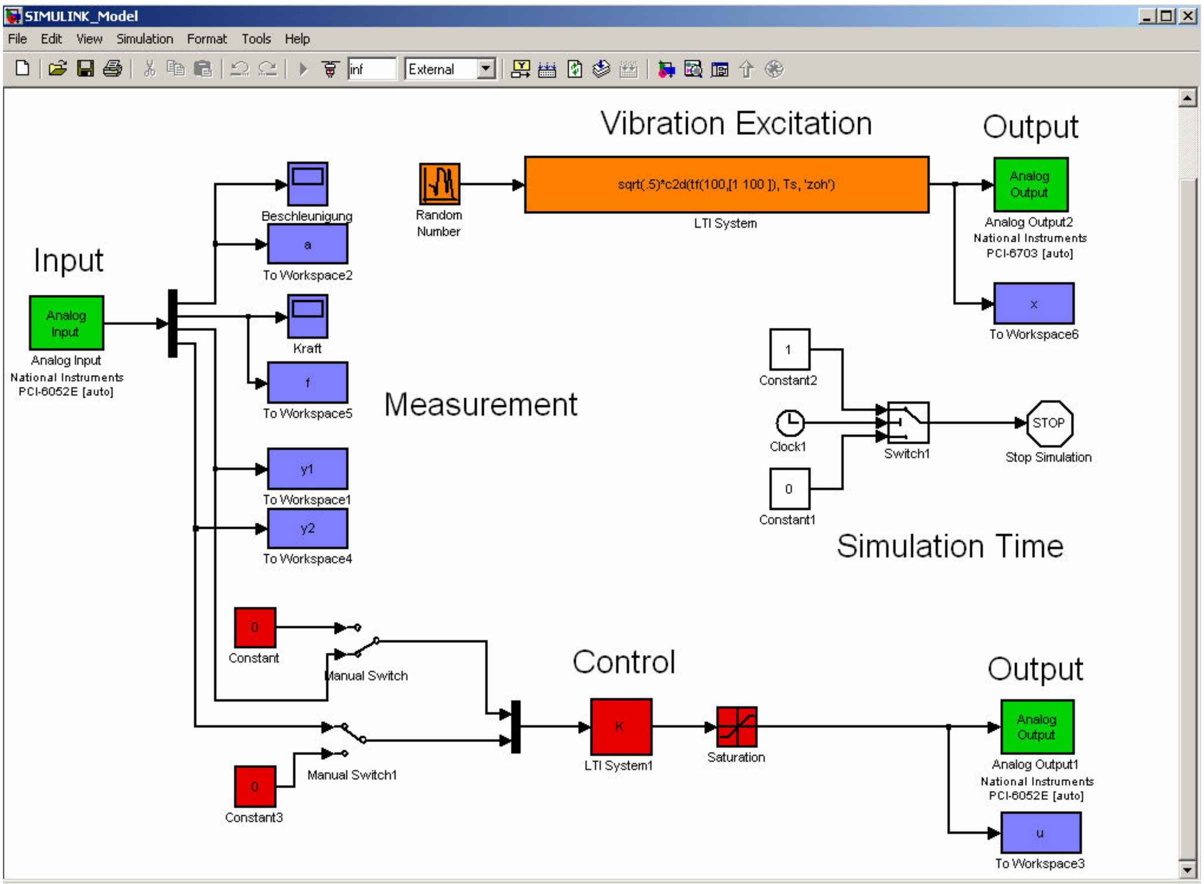


**Figure 3: Simulink® model**

### *4.1 Practical Measurement*

To execute measurements only a short initialisation time is needed. Starting from an existing SIMULINK® model equipped with the appropriate input- and output-blocks, a building procedure – which automatically performs all the necessary interface connections - has to be carried out. After a short period of only several seconds all devices are ready to operate.
During operation some basic adjustments can be accomplished in “real-time”, such as switching on (or of) a controller. Resulting effects can be seen instantly and also data recording is continuously performed during run time.
It is only necessary to rebuild the model if basic parameter changes or structure modifications need to be carried out.

### *4.2 Measurement on the car body*

As an example measurement and control tasks carried out with the test bed are shown in Figure 4. The depicted interface shows two scopes which enable one to directly monitor the current signals. In Figure 4 acceleration, as well as force measurements are shown. Additionally, the inputs can be adjusted using the block structure that represents data acquisition and controller.

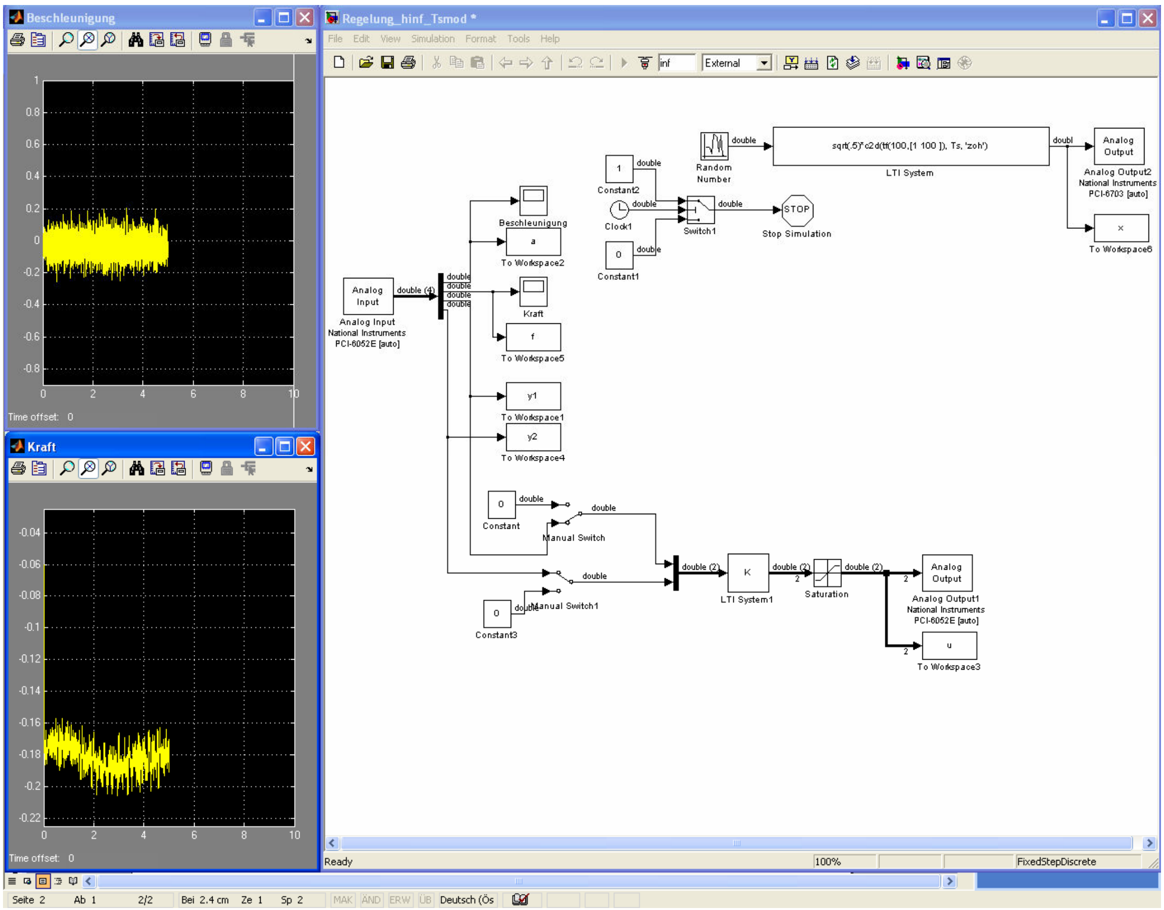


**Figure 4: Online measurement and control of the car body**

### 4.3 Signal Post Processing – Virtual Instrumentation

In Figure 5 a typical time plot of an acceleration signal is shown. This plot has been generated subsequent to the measurement run in which signal data has been stored on the PC. In such a way signal post processing like filtering, signal properties analysing and smoothing becomes easily available applying standard Matlab/SIMULINK® commands to the stored data sets. Thus, virtual instrumentation is realised which reduces the necessity for a large amount of measuring devices such as oscilloscopes, frequency analysers and voltmeters. Figure 6 additionally shows the Power Spectral Density plot of the signal in Figure 5 computed using the “psd”-command from Matlab/SIMULINK®.

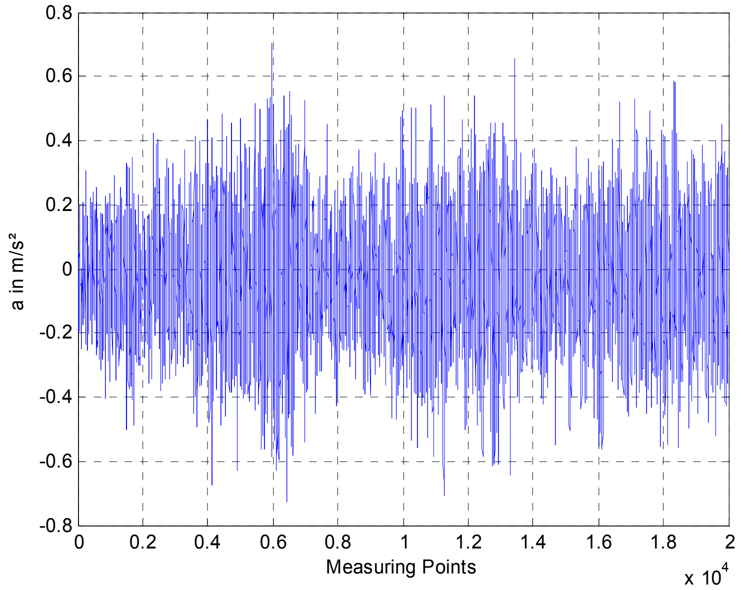


**Figure 5: Time domain, acceleration signal**

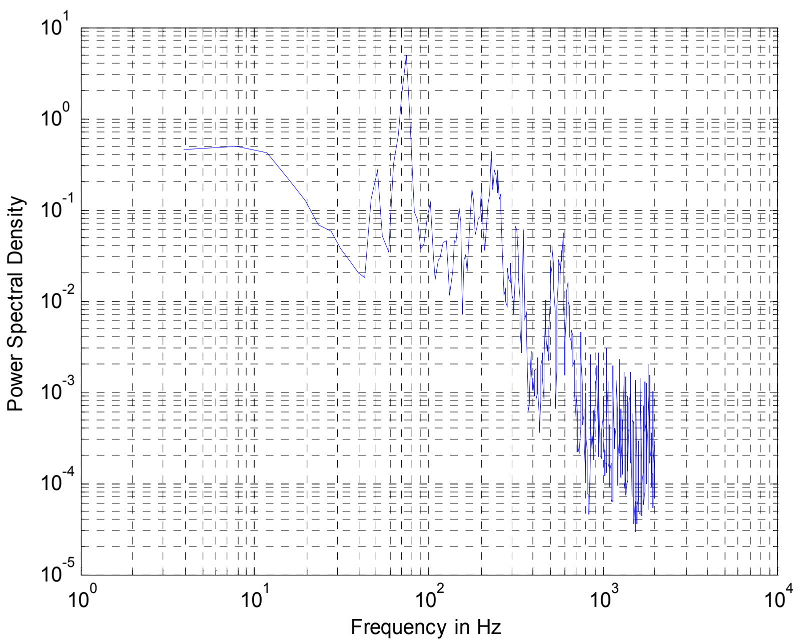


**Figure 6: Frequency domain, PSD of an acceleration signal**

Finally, it has to be remarked, that also remote engineering becomes easily possible for the described system when the PC is connected by a local network. For example, the experiment which has been built up in the laboratory can be driven by a remote PC in one of the adjoining rooms connected via TCP/IP. In such a way data can be directly transferred form the test stand to any PC connected to the network.

# 5 Conclusion

A test bed for testing different active concepts to improve the ride quality of railway vehicles has been presented. Such a system comprises a large number of different measurement and analysation-problems. All tasks from basic simulations and preliminary tests, to real measurements and signal pre-treatment can be performed with one system.
Convenient operation is possible if the user is accustomed in using Matlab/SIMULINK®. No further efforts such as programming of interfaces or long adaptation training have to be made.
The described system is robust, easy to use and low-priced compared to other available customised measurement systems which often use special hardware set ups.

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