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DATA ACQUISITION SOFTWARE APPLICATION DEDICATED TO THE DEMONSTRATIVE EXPERIMENTAL SYSTEM FOR FUNCTIONALITY TESTING OF A NEW METHOD OF REDUCING VERTICAL VIBRATION OF THE RAILWAY VEHICLE CAR BODY

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Abstract: *In the paper are presented the design stages, technical programming specifications, architecture, and project of a data acquisition software application - measurement, control, processing, representation, storage, and integration with the user interface, dedicated to the demonstrative experimental system (DES) for the functionality and effectiveness testing of a new method of reducing the vertical vibration of the railway vehicle car body. The DES comprises the experimental scale model of the car body (ESMC), supported on elastic rubber elements, and the measurement and control chain that integrates several specialized components for acquisition of experimental data and generation of control signals, controlled with the dedicated software application. The software application is to be realized in the Matlab programming environment, which includes specialized functions for connecting to different data acquisition systems.*
Key words: *software application; demonstrative experimental system (DES); scale model; railway car body vibration; measurement and control chain.*

1. INTRODUCTION

Considering the importance from the perspective of operation safety, ride quality and ride comfort, the problem of reducing railway vehicle vibrations has always represented a major concern of engineers and researchers in the field [1]. The growing requirements regarding the increase in speed have opened a new direction of research on the topic of reducing the structural vibrations of the flexible car bodies of high-speed railway vehicles.

One of the basic design criteria of high-speed railway vehicles is to reduce the weight of the vehicle, in particular the car body which is the most relevant component for the total mass of the vehicle. Reducing the weight of the car body is achieved by using lightweight materials and modifying the mechanical structures, which often leads to less structural rigidity of the car body [2]. The lighter the car body is, the more flexible it becomes, facilitating the excitation of structural car body vibrations that have a negative effect on ride comfort. The structural vibrations of the railway vehicle car body are complex, having many vibration modes [3]. Ride comfort is however affected by the first vertical bending mode of the car body. The eigenfrequency of this mode of vibration is usually between 6 Hz and 12 Hz, the range in which the vibration comfort is affected.

The problem of reducing or controlling the structural vibrations of the railway vehicle car body to improve the ride comfort at high speeds has become an active research topic. The research was developed following either approaches aimed at isolating vibrations [4 - 6], respectively limiting the possibilities of transmitting vibrations to the car body through the suspension, or approaches aimed at damping car body vibrations [7 - 9], respectively reducing the amplitude of the car body structural vibrations. In general, this research is developed on theoretical models of the vehicle, the conclusions being synthesized based on numerical simulations. Few studies have been identified in the literature in which the newly introduced concepts or the proposed methods for reducing the vibrations of the railway vehicle car body are validated in the laboratory through the results of experimental research conducted out on vehicles specially designed for testing [10]. The explanation lies in the fact that such research involves significant financial investments and time consumption for the creation of specialized systems for simulating the real conditions of railway vehicle traffic and their integration, together with dedicated measurement, control, and data acquisition systems, in an experimental stand.

A less expensive alternative is research conducted in the laboratory on experimental systems at scale. Such systems have as their main element a model of the vehicle car body reduced to a conveniently chosen scale [11 - 13]. Applications of such systems can be found in research on the possibilities of damping the flexible modes of vibration of the railway vehicle car body or increasing the structural damping of the light car body of high-speed vehicles.

In section 2 of this paper, a new DES dedicated for functionality and effectiveness testing of an original method of reducing vertical bending vibrations of the car body of the railway vehicle is described [14].

The proposed method aims both at reducing the amplitude of vertical bending vibration of the vehicle car body, and at increasing the eigenfrequency. For this, the concept of 'anti-bending bars' was introduced.

The anti-bending bars are mounted one side and the other of the car body, on the longitudinal beams of the car body chassis [15]. The couples generated by the longitudinal elastic forces with which the anti-bending bars act on the car body will limit the rotation of the transverse sections of the car body generated by the vertical bending vibration. The parameters of the anti-bending bars, respectively their length and diameter, are determined by the condition that the eigenfrequency of the first vertical bending mode of the car body increases so that it is removed from the frequency range in which ride comfort is affected.

The DES is specially designed for functionality and effectiveness testing the method described above. It comprises the ESMC, supported on elastic elements, and the measurement and control chain that integrates several specialized components for the experimental data acquisition or the generation of control signals, controlled with a dedicated software application. In sections 3, 4 and 5 of the paper they are described the design stages of the software application architecture and are presented the technical programming specifications, architecture and the data acquisition software application project - measurement, control, processing, representation, storage and integration with the user interface, dedicated to the DES for functionality and effectiveness testing of the method of reducing vertical bending vibrations of the car body of the railway vehicle based on an anti-bending bar system.

2. DESCRIPTION OF THE DES

Figure 1 shows schematically the DES for functionality and effectiveness testing of the method of reducing the vertical bending vibrations of the railway vehicles car body based on an anti-bending bar system.

The ESMC, represented by a beam to which the anti-bending bars are attached (figure 2), is the main element of the DES. The ESMC is supported on elastic rubber elements. The excitation force is generated with a Brüel & Kjær shaker type LDS V201, driven with the LDS PA25E amplifier, and measured with a Laumas SA15 load cell. The vibration measurement of the ESMC is done with three accelerometers Brüel & Kjær type 4514, mounted in the middle of it and above the elastic elements.

In the DES, several specialized components are integrated, dedicated to the acquisition, and processing of experimental data (the accelerations of the ESMC and the excitation force) or the shaker control commanded with a software application. These are represented in figure 1, where you can see the assembly formed by National Instruments (NI) equipment - the NI cDAQ-9174 chassis and the three modules, respectively NI 9234, NI 9263, and NI 9219.

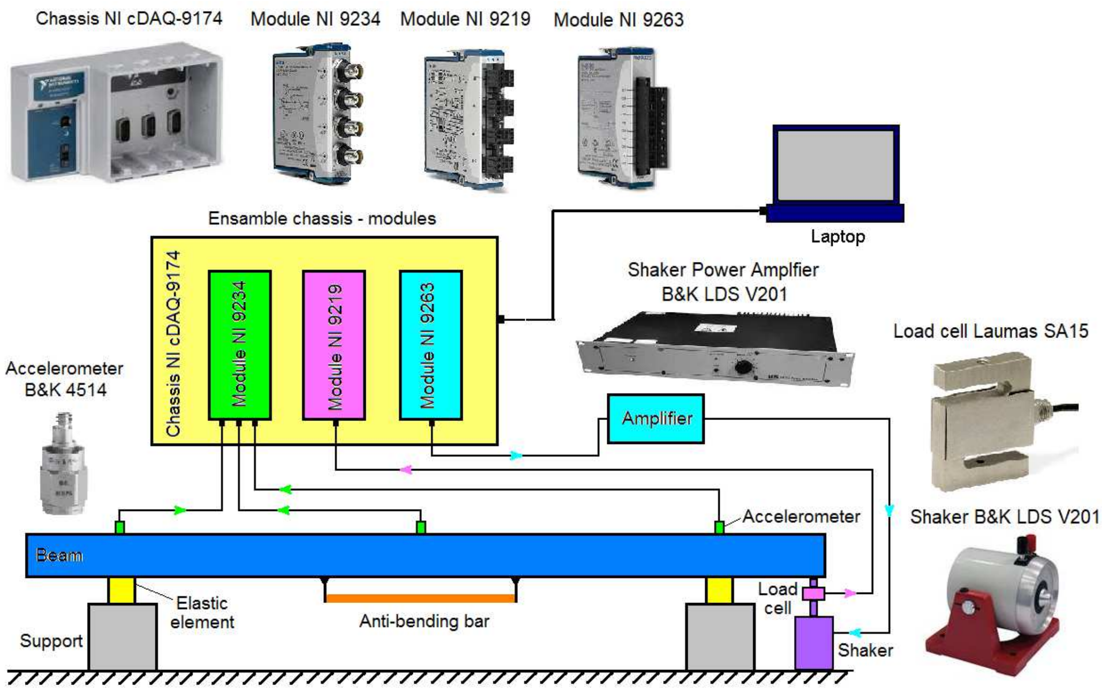

Fig.1. Scheme of the DES

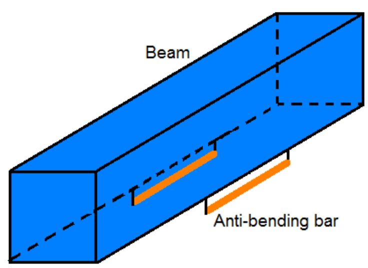

Fig.2. Schematic representation of the ESMC

The three modules have dedicated functions, as follows: the NI 9234 module has the role of retrieving and synthesizing the data flow from the accelerometers; the NI 9263 module is specialized for generating shaker control signals; the NI 9219 module is intended for voltage or current measurements. The chassis - modules assembly, the three accelerometers, the force cell, the shaker, and the amplifier form the chain of measurement and control of the DES.

3. DESIGN STAGES OF THE SOFTWARE APPLICATION ARCHITECTURE

Designing the architecture of the data acquisition software application - control, measurement, processing, representation, storage, and integration with the user interface involves going through several stages, according to the scheme shown in figure 3.

In the stage of preliminary analysis of the requirements, the software application to be designed is defined. In this case it is a software application dedicated to data acquisition – the accelerations of the ESMC measured in the middle of it and above the elastic elements and the excitation force, control, processing, representation, storage representation and integration with the interface user of this data.

Defining the initial requirements is the first step in the software application architecture design process. This phase results in a simple definition of the problem to be solved as follows:

1. Functionality. Software application designed for experimental use: the acquisition of the accelerations of the ESMC measured at the middle of the car body and above the elastic elements, the processing, storage, of these data and their integration with the user interface; excitation force measurement; generating shaker control signals.

2. The user interface. The command-control screen of the measurements and the representation of the acquired data must include the following elements:

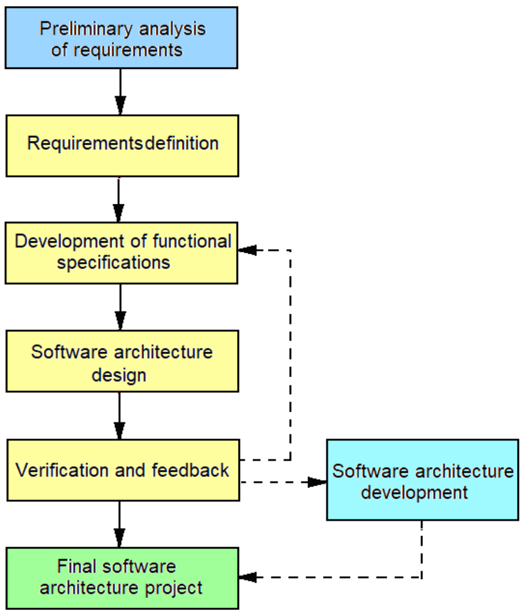

Fig.3. Stages of software application architecture design

- control windows (edit text objects) for configuring the specific parameters of the data acquisition session (the duration of the data acquisition session and the number of records/second, the excitation frequency of the shaker); they must allow the user to edit or delete and replace an initially printed value.
- control buttons for: connection with the measurement system, acquisition, and data processing; data visualization; saving data; re-initialization the application.
- windows for graphical representation of measured accelerations and excitation force.
- static text objects for labeling control windows, command buttons, and graphics windows to provide the user with information about their functions.

Functional specifications or programming specifications represent a detailed functional description, which respects the initial requirements and aims to understand and achieving them during the design of the software application.

Practically, the functional specifications are constituted in a structure in the form of a list of specifications, which describes what the software application to be designed will have to do and how to do it.

Programming specifications should be as explicit and complete, to reduce changes to the functionality or design of the software application project after its development has started.

4. FUNCTIONAL SPECIFICATIONS OF THE SOFTWARE APPLICATION

The software application for the control, acquisition, processing, storage, and representation of the measured data - the accelerations of the ESMC and the excitation force generated by the shaker must perform the following functions:

1. Connection with the measurement, acquisition and data processing system consisting of the three Brüel & Kjær type 4514 accelerometers, the LDS V201 shaker, the NI cDAQ-9174 data acquisition chassis assembly – the NI 9234 module, the NI 9263 module for generating the shaker control signals, the NI 9219 module, and the PA25E LDS amplifier.
2. Configuring the specific parameters of a data acquisition session: duration and number of records/second; excitation frequency; sensitivity of accelerometers and force cell.
3. Visualization in graphic form of the acquired data, acceleration-time and excitation force-time. After performing the measurements, based on the graphic representation of the acquired data, the decision will be made to save them for further processing, or the application will the application is reinitialized.
4. Saving the acquired data in a mat.file type file in order to further process them in the MATLAB software environment. Regarding the acquired data, these will be time, accelerations measured by the three accelerometers and excitation force.

The functions of the software application for control, acquisition, processing, storage, and representation of data, described above, can be contained in a conceptual diagram (see figure 4).

Regarding the user interface, corresponding to the initial requirements and functions mentioned above, the command and control screen of the measurements and the representation of the acquired data will include the following elements:

- 1 command button for connecting to the measurement, acquisition, and data processing system, labelled with the text 'System connection'.

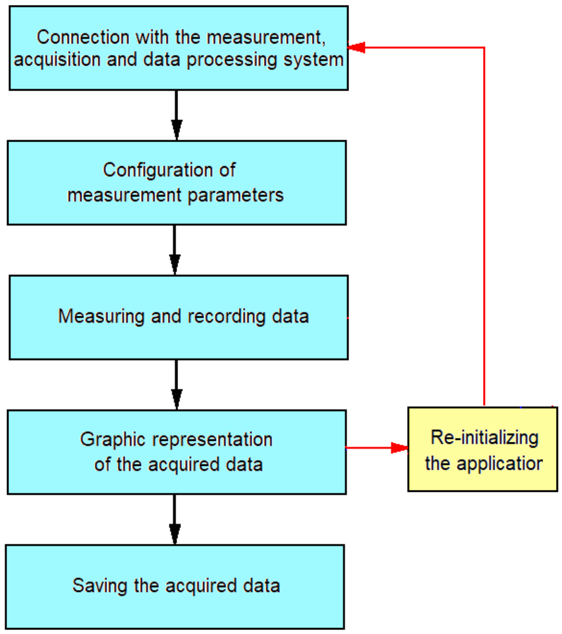

Fig.4. Conceptual diagram of software application for data control, acquisition, processing and storage

- 3 control windows (text edit type) for configuring the specific parameters of the measurement session: a window for editing the duration of the data acquisition session labelled with the text 'Duration [s]'; a window for editing the number of records/second labelled with the text 'Number of records'; a window for editing the shaker frequency labelled with the text 'Frequency [Hz]'.

- 1 button for the 'measurement and recording data' command, labelled with the text 'Data recording'.

- 1 command button for the graphical visualization of the acquired data, labelled with the text 'Data visualization'.

- 4 windows for the graphical representation of the acquired data labelled with the text 'Accelerometer 1', 'Accelerometer 2', 'Accelerometer 3', 'Excitation force'.

- 1 control window (edit text type) for editing the name of the mat.file type file in which the acquired data is saved.

- 1 object of type pop_up that allows the user to choose from a list of created folders, a folder in which the file of type mat.file will be saved.

- 1 command button for saving data, labelled with the text 'Save data'.

- 1 command button to reset the application, labelled with the text 'Re-initialization'.

5. DESIGN OF SOFTWARE APPLICATION ARCHITECTURE

The design of the software application for data acquisition, control, processing, and storage will be carried out in the MATLAB programming environment, which provides the Data Acquisition Toolbox. This toolset includes specialized functions for connecting to various data acquisition systems, including those produced by National Instruments.

The Data Acquisition Toolbox data acquisition software includes functions for controlling the analog inputs, analog outputs, counter/timer, and digital subsystems of a data acquisition device. The data can be analyzed during the acquisition process or can be saved for post-processing. In addition, tests can be automated and iterative updates of the test configuration can be performed based on the results of the acquired data analysis.

In order to communicate with the NI cDAQ – 9174 devices it is necessary to create a data acquisition session, through which the connection is made between the user, the software application, the NI cDAQ driver and the NI 9234, NI 9263 and NI 9219 modules.

According to the functional specifications presented in the previous section, the data acquisition session must include four channels, to receive the data flow from the three accelerometers and from the force cell. The session configuration must allow the measurement data to be acquired for a specified duration and with a certain number of records per second. For each acceleration measurement channel, the possibility of introducing the sensitivity of the accelerometers and the force cell must be ensured, and for the channel corresponding to the shaker, the excitation frequency must be entered.

In the elaboration of the data acquisition session, it must be considered that, before the acquired data are saved, it is desired that they be visualized in graphic form. To store the acquired data, they will be saved in mat.file type files for post-processing.

The architecture of the software application comprises several sequences, as shown in Table 1.

Table 1

The design of the software application architecture for control, acquisition, processing, and storage of data - the sequences of the data acquisition session.

1. Creating the data acquisition session A session object is created for configuring and operating the data acquisition system. For this, the function daq.createSession('.......') is used. For connection with the NI cDAQ - 9174 chassis, the syntax for defining the function for the '*s*' session is as follows: s = daq.createSession('ni').
2. Addition of analog input and output channels To add an input channel to the device represented by its ID, with the specified channel ID and the measurement type of the channel represented by measureType in session *s*, use the function: addAnalogInputChannel(s,deviceID,channelID,measurementType) To add 3 analog input channels with IDs ai1, ai2, ai3 corresponding to the NI 9234 module located in slot 1 (Mod1) of the cDAQ – 9174 chassis with ID cDAQ1: s.addAnalogInputChannel('cDAQ1Mod1', 'ai1', 'Accelerometer') s.addAnalogInputChannel('cDAQ1Mod1', 'ai2', 'Accelerometer') s.addAnalogInputChannel('cDAQ1Mod1', 'ai3', 'Accelerometer') For each 'Accelerometer' type channel, the sensitivity of the accelerometer is added. To add an analog input channel for the load cell with ID 0 corresponding to the NI 9219 module in slot 4 (Mod4) of the cDAQ chassis – 9174 with ID cDAQ1: addAnalogInputChannel(s,'cDAQ1Mod4', 0, 'Bridge') To add an analog output channel for the shaker with ID 0 corresponding to the NI 9263 module in slot 3 (Mod3) of the cDAQ – 9174 chassis with ID cDAQ1: addAnalogOutputChannel(s,'cDAQ1Mod3',0, 'Voltage')
3. Configuring the data acquisition session - Duration of the data acquisition session: s.DurationInSeconds = ….. - Number of scans per second: s.Rate = ... - The excitation frequency of the shaker: freq_ex = ... - Creating the shaker excitation signal: sig_vib=1*sin(2*pi*f*d*linspace(0, 1, s.DurationInSeconds *s.Rate))
4. Measuring and recording data For multiple scans, the startForeground function is used

5. Graphic representation of the acquired data
plot(time,data);
xlabel('Time [sec]');
ylabel('Acceleration [g]')
ylabel('Force [N]')

6. Data saving To store the acquired data for post-processing, they are saved in type files mat.file: save acquisitiondataX.mat t acc1 acc2 acc3 Fex fqex. The name of the file allows the identification of the record by its number X from a series of N records, where t, acc1, acc2, acc3, Fex, fqex are the acquired data: time, accelerations, excitation force and excitation frequency.

The user interface of the control, data acquisition, processing and storage software application will be made in MATLAB, using Graphical User Interfaces. Figure 5 shows the types of objects and buttons used to implement the programming specifications contained in section 4, and Figure 6 shows the graphic interface project.

6. CONCLUSION

The problem of reducing structural vibrations of flexible carbodies of high-speed railway vehicles has become a topic of interest in research circles in recent years. In a broad framework of research on the complex structural vibrations of light carbodies of high-speed railway vehicles, attention has been focused on the possibilities of reducing or controlling vibrations relevant to ride comfort. The first vertical bending mode of the car body was identified as having an important impact on ride comfort, its natural frequency being found in a frequency range in which the human body exhibits a high sensitivity to vibrations.

Any concept or method proposed for reducing the vertical bending vibrations of the railway vehicle car body and improving ride comfort requires the validation of theoretical results based on experimental results. In a first stage, experimental research can be carried out with experimental laboratory systems.

In the first part of the paper, a new experimental demonstrative system for testing in the laboratory the functionality and effectiveness of an original method of reducing vertical bending vibrations of the railway vehicle car body and improving ride comfort, based on a passive system consisting of two bars that oppose the car body bending is presented. The experimental demonstrative system comprises the ESMC, supported on elastic elements, and the measurement and control chain that integrates several specialized components for the acquisition of experimental data or the generation of control signals, controlled by means of a dedicated software application, which follows to be made in the MATLAB programming environment.

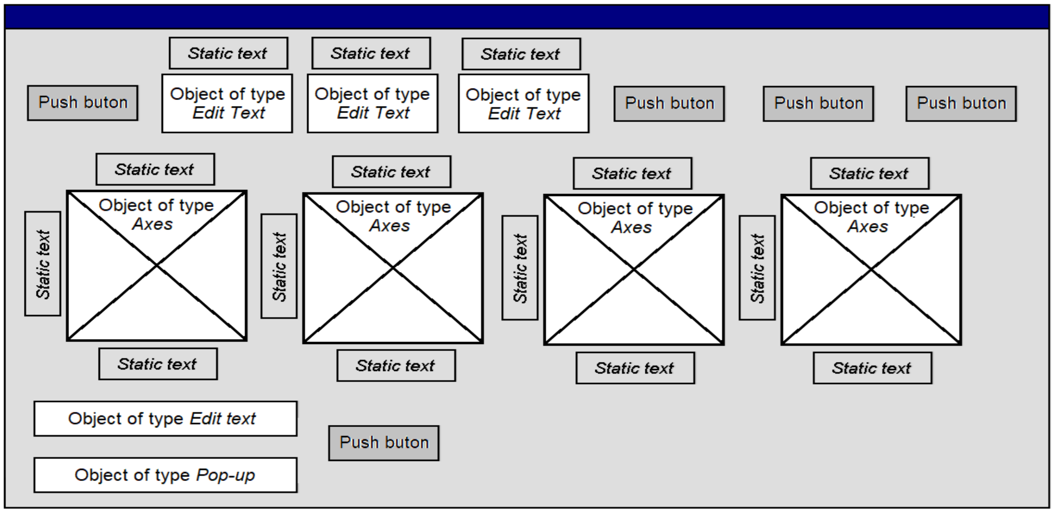

Fig.5. The instructions for executing and configuring user interaction commands with the control software application, data acquisition, representation and storage.

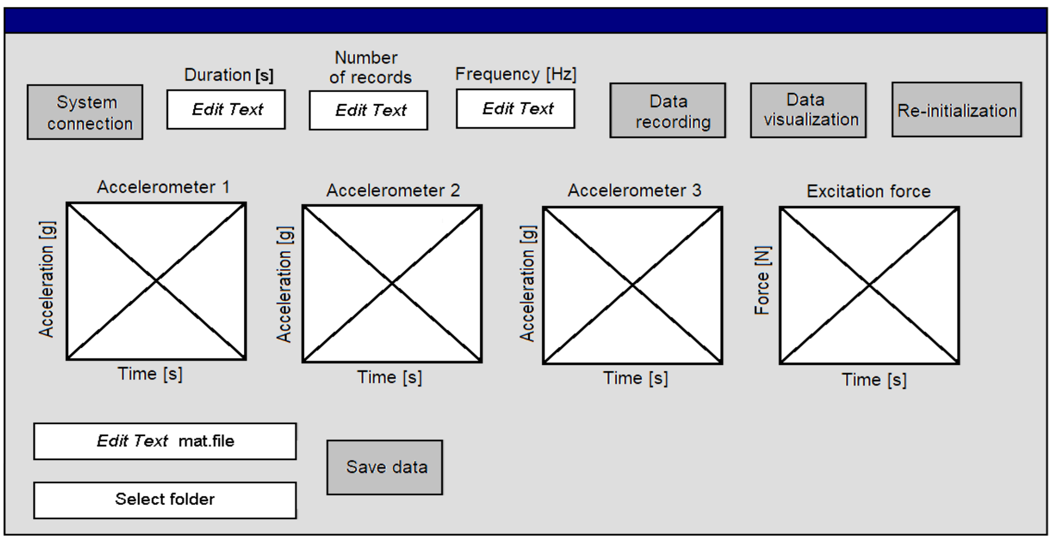

Fig.6. User interface design of the control, data acquisition, representation, and storage software application.

In the second part of the paper, the design stages, technical programming specifications, architecture, and project of the data acquisition software application – measurement, control, processing, representation, storage, and integration with the user interface, dedicated to the experimental demonstration system are described. The software application is designed for experimental use: the acquisition of the accelerations of the ESMC measured in the middle of the car body and above the support points on the elastic elements, the processing, storage, of these data and their integration with the user interface; excitation force measurement; generating shaker control signals.

7. ACKNOWLEDGEMENT

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Aplicație software de achiziție date dedicată sistemului experimental demonstrativ pentru testarea funcționalității unei noi metode de reducere a vibrațiilor verticale a cutiei vehiculului feroviar

În lucrare sunt prezentate etapele de proiectare, specificațiile tehnice de programare, arhitectura și proiectul unei aplicații software de achiziție date – măsurare, control, procesare, reprezentare, stocare și integrare cu interfața de utilizare dedicată sistemului experimental demonstrativ pentru testarea funcționalității unei noi metode de reducere a vibrațiilor verticale de încovoiere ale cutiei vehiculului feroviar. Sistemul experimental demonstrativ cuprinde modelul experimental la scară al cutiei, sprijinit pe elemente elastic de cauciuc, și lanțul de măsurare și control care integrează mai multe componente specializate pentru achiziția datelor experimentale sau generării semnalelor de comandă, controlate cu ajutorul aplicației software dedicată. Aplicația software urmează sa fie realizată în mediul de programare Matlab, care cuprinde funcții specializate pentru conectarea la diferite sisteme de achiziție de date.

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