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# Hardware and Software Implementations of Measuring System for Resonant Electromagnetic Vibratory Conveyor

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*Abstract* - **Vibratory movements are one of the most ways for conveying and transportation of granular and particulate materials. Vibratory conveyors and feeders with electromagnetic excitation belong to a group of mechatronic devices that in an efficient way provides drive force and oscillations for this conveying. They have an important role in framework of the many industrial process in which are dominant the particulate materials: food processing, cement production, certain product line in steel industry, pharmaceutical industry, agriculture, etc. Therefore, they are representing a very important element of above mentioned technologic processes and production line. Especially, the vibratory conveyors and feeders that operate in the resonant mode are used in industrial applications because of their energy efficiency increasing. The relatively small input energy of actuator drive causes intensively vibrations of load carry element (LCE) of vibratory conveyor. The intensity of the vibrations directly affects on gravimetric flow (mass flow) and therefore on the productivity of vibratory conveyors. To ensure a reliable and energy-efficient operation of vibratory conveyors, it is necessary to have a reliable and accurate measurement and testing of electrical and mechanical quantities. A hardware and software implementation of the testing and measurement system of resonant vibratory conveyor with electromagnetic drive, and their corresponding data acquisition platform are presented in this paper. The experimental results obtained on a real laboratory setup of resonant vibratory conveyor are also shown.**

***Keywords - Vibratory conveyor; mechatronics system; measurements; power converter; vibrations; LEM module; sbRIO board.***

## I. INTRODUCTION

Resonant electromagnetic vibratory conveyors (REVC) are widely used device for conveying and transportation of particulate and bulk materials in various processing industries (food, pharmaceutical, agriculture, steel, etc.). There are compact, robust, reliable in operation and easy for maintenance. This vibratory conveying systems having electromagnetic drive offers easy and simple control the gravimetric flow of conveying materials. In comparison with other traditional drives (pneumatics, inertial, centrifugal, etc...), these have a simpler construction and they are compact, robust and reliable in operation.

The absence of wearing mechanical part, such as gears, cams belts, bearings, eccentrics, inertial masses, etc., makes this conveyor drives as most economical and reliable equipment. Vibrations of through or load carry element (LCE) in which the material is placed induces the movement of material particles, so that they resemble a highly viscous liquid, and the material becomes easier to transport. The conveying material flow depends directly on the average value of particles throw movements. This average value, on the other hand, depends on the amplitude of the trough oscillation [1-4]. Optimal transport is obtained for frequency within the range $5\text{Hz}-120\text{Hz}$ and vibratory width range (double amplitude of oscillations) $0.1\text{mm}-20\text{mm}$, for the most of particulate and granular materials [5-8].

The standard power output stages of REVC using SCR devices (thyristors and triacs) [4], [9-12]. This implies using the phase angle control (PAC) and constant frequency of vibration. In this way control circuit must be synchronized to the mains frequency 50 (60) Hz. PAC can only accomplish tuning amplitude of vibration, but not the oscillatory frequency. Application of switch mode power converters (IGBT or MOSFET) enables accomplishing the amplitude and (or) frequency control of REVC [4, 12, 13-20]. Their use implies the excitation of an REVC independent of the mains frequency. In addition, the frequency control ensures operation in the region of mechanical resonance. This operation is highly energy efficient, because the relatively large output displacement is provided by small input power.

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However, their performance is highly sensitive to different kind of disturbances. For example, as the conveyor vibrations occurred at its resonance frequency, vibration amplitude is highly dependent on a damping factor. On the other hand, damping factor depends on the mass of material on the feeder through, type of material, and the vibration amplitude [13, 21]. These disturbances can reduce drastically (up to 10 times) the vibration amplitude, thus reducing the performance of REVC.

Due to the complex phenomenology of the vibratory conveying process [22-26] is very difficult to theoretically determine some parameters of REVC. This primarily refers to the damping of certain elements of the REVC, and for cases where it is empty and when filled with bulk material of different granulation. This paper presents one possible hardware and software implementation of the measurement and testing system based on sophisticated sbRIO microprocessor board and switch-mode, IGBT power converter. National Instruments [27-30] acquisition system is on possible solution to identify all the relevant parameters of the vibratory conveyor and their testing. The experimental and testing results obtained on a realized laboratory setup of REVC are shown in the next investigation.

## II. The Importance of Measuring Electromechanical Quantities of REVC

The REVC represents a very complex mechatronic system where exists a certain relationship between electrical (current and voltage of electromagnetic driving actuator) and mechanical quantities (driving force of electromagnetic actuator; displacement, velocity and acceleration of LCE and other moving parts).

To ensure a reliable and energy-efficient operation of REVC for the purpose of correct modelling and parameters identification [4, 13, 31], it is necessary to have a reliable and accurate measurements and testing.

The driving force of electromagnetic vibratory actuator is very difficult to measure directly. However, there is a relationship between the force and the current of the electromagnetic actuator [4, 12, 32-36], thus measurement of electrical current is important in these applications. A certain care should be taken into account while operating with the electromagnetic actuator regarding high voltage supplied from the power converter. This measure must be electrically isolated and must have a relatively wide bandwidth [37-40]. Displacement and acceleration measurements are possible to achieve with the appropriate sensors, where scaling levels and signals filtering need to be done.

## III. Hardware Implementation

Block diagram of power converter and acquisition-control system of REVC is depicted in Fig. 1. Control signal of REVC is provided from controllable AC/DC power converter [4, 12-17, 19], which is connected on power grid network of 230V, 50Hz.

The output of power converter provides the driving current, with adjustable frequency, amplitude and time duration. Control pulse signal with range of frequency (5-150Hz/ concretely 49.2Hz) and duty-cycle range (1-50%/ concretely 10%) is generated with NI sbRIO-9636 board and this signal control AC/DC power converter. The special module, RIO-power (AC/DC), supply the microprocessor and sensors' circuit, as shown in Fig. 1.

The sbRIO-9636 board has a powerful 32-bit microprocessor based on ARM architecture and very robust and powerful hardware-programmable and reconfigurable electronic device i.e. FPGA of company Xilinx. FPGA enables easy implementation of the most complex access points so that this device can be easily and simply adapt to various types of electrical sensors and peripherals devices to communicate with the microprocessor.

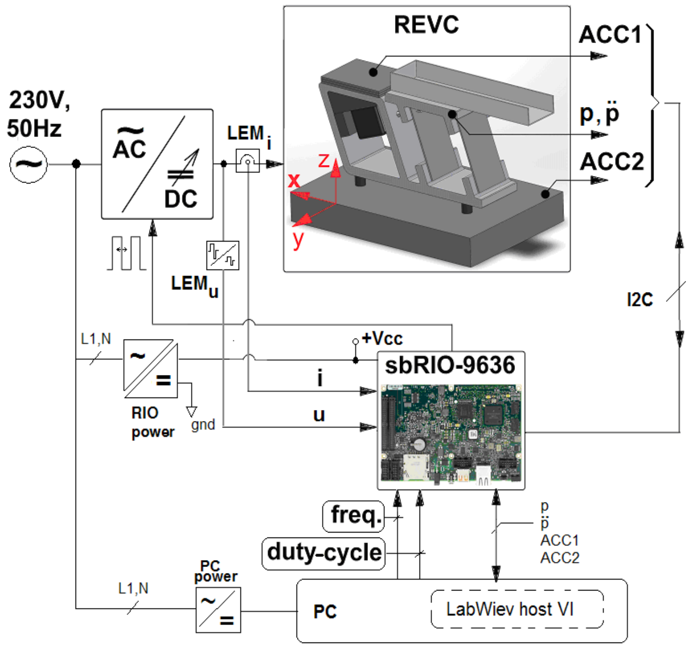


Figure 1. Block diagram of power and acquisition-control system of resonant electromagnetic vibratory conveyor (REVC) based on platform sbRIO-9636 National Instruments

In our case, there are several signals of interest that are acquired with sbRIO board: analog signals- vibratory trough displacement relative to the base (*p*), acceleration in direction of relative displacement ($\ddot{p}$) and electrical current (*i*) and voltage (*u*) of REVC vibratory actuator; digital signals- accelerations in XYZ directions of the base (ACC1) and the ground (ACC2) of REVC construction.

Vibratory trough displacement is measured with contactless inductive sensor Ni10-18-LiU-H1141 of [1,7]mm range together with an amplifier that provides output of [0,10]V range [40].

Measuring of electrical current of electromagnetic vibratory actuator coil is realized with high band-width LEM current sensor LA-25N [36-38] with measuring range of [-5,+5]A, output measuring resistor and corresponding electronic transmitter that is design to provide output of [0,10]V range, suitable for sbRIO board analog input. Voltage measuring of electromagnetic vibratory actuator coil is realized with high band-width LEM voltage sensor LV100-1000 [36-38] with measuring range of [-1500,+1500]V, output measuring resistor and corresponding electronic transmitter that is design to provide output of [0,10]V range, suitable for sbRIO board analog input.

The all accelerometers have ADXL345 [41], 3-axis modules with ultra-low power and high 13-bit resolution measuring at +/-16g. Sensors' communication with target board is realized via I2C digital interface. All data captured with sbRIO board are sequentially stored in board's internal RAM memory as small memory packages. After storing, the memory packages are sequentially transferred to the PC via TCP/IP communication protocol. Memory packages are then restored on the PC as data of interest.

## IV. SOFTWARE IMPLEMENTATION

National Instruments Single-Board RIO 9636 integrates an embedded real-time processor, a high-performance Field-Programmable Gate Array (FPGA), and onboard analog and digital I/O (Fig. 2). All I/O is connected directly to the FPGA, where customization of timing and I/O signal processing on low-level is provided to user. The FPGA is connected to the embedded real-time processor via a high-speed PCI bus.

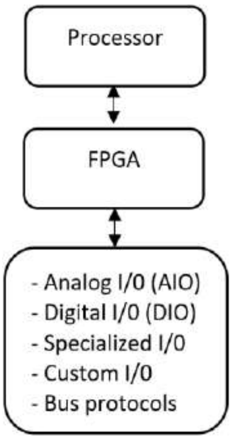


Figure 2. NI-sbRIO-9636 simplified architecture

LabVIEW contains built-in data transfer mechanisms to pass data from the I/O to the FPGA and also from the FPGA to the embedded processor for real-time analysis, post processing, data logging, or communication to a networked host computer, shown in Fig. 3.

I2C communication of the accelerometers and the sbRIO board (DIO) is realized over adapter board. This board contains two MOSFET I2C level converter circuit depicted in Fig. 4. Each accelerometer has the level converter, because of different logic levels of the accelerometer (3.3V) and sbRIO board (5V).

LabView FPGA allows us to customize I/O processing and timing. Analog and digital signals are configured so that matches sensors and actuator. Writing, reading and control of data transferred via I2C communication as well as acquiring data from remaining sensors is done in the FPGA by using FIFO registers and proper timing.

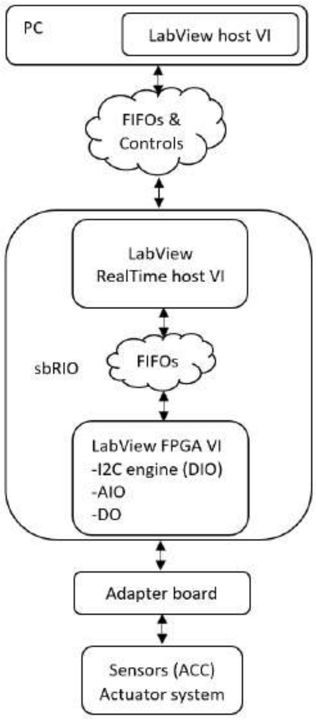


Figure 3. Software and hardware architecture of LabView and NI sbRIO-9636

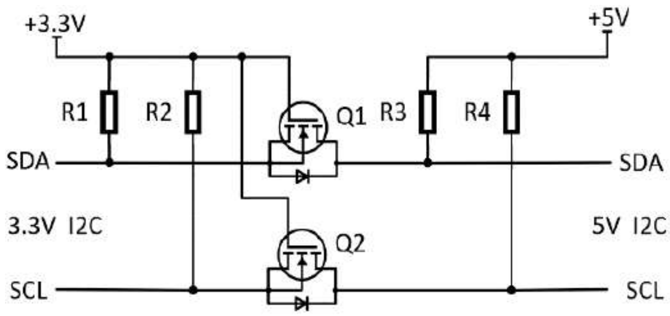


Figure 4. I2C level converter

Accelerometer configuration is performed in several stages: initialization, configuration I2C bus, accelerometer setup and scan accelerometer stage. The delay of 200ms is set in initialization to ensure non-data on I2C bus from the accelerometer. The I2C fast mode defines transfer rates up to 400 Kbit/s in configuration I2C bus. In accelerometer setup is defined the following: output data rate of 3.2 kHz, measurement mode and accelerometer resolution of ±16g. Accelerometer reading of 6 bytes and charging temporal memory with ACC data is accomplished in the last step. Addressing accelerometers and transferring data with FIFOs is done in the last three stages.

All acquired data between real-time host VI and FPGA VI are transferred over FIFO registers, where addressing, data control and adequate timing are taken into account. Plotting and saving the data into a single file have been performed in LabView Host VI by using FIFOs. Driving electromagnetic actuator with control variables (frequency and duty-cycle) is also performed in Host VI.

## V. EXPERIMENTAL RESULTS

In this section are presented and discussed obtained measurement signals on real system (Fig. 5).

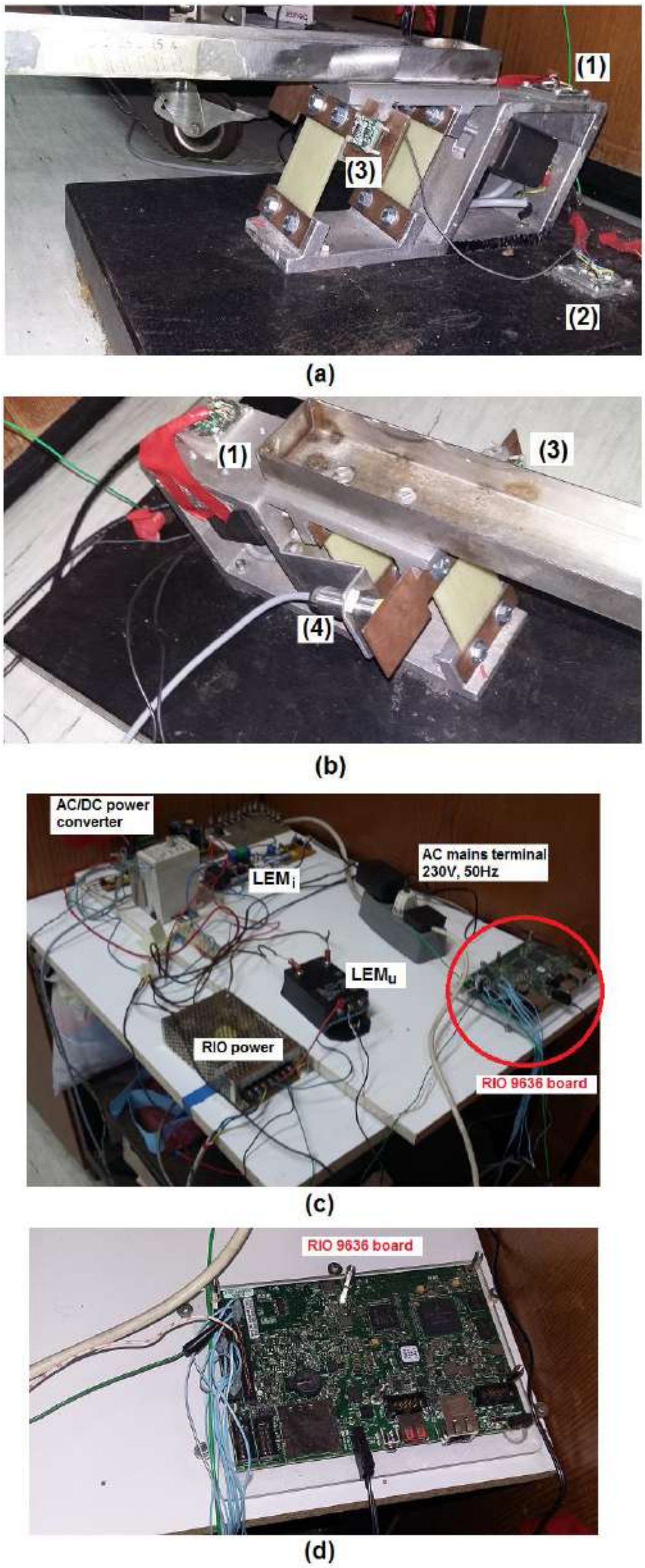


Figure 5. The realized experimental setup for measuring and testing of REVC; (a)side scope of RVCS, (b) top view of RVCS, (c) power control system of RVCS, (d) scope of NI sbRIO-9636 board

In Fig. 5(a) and (b) are shown the two characteristic views of REVC including the measuring sensors. The acceleration sensors ACC1, ACC2 and are placed on the positions (1), (2) and (3). Contactless inductive displacement sensor for measuring relative displacement p (position (4)) is mounted on the base of REVC with Al bracket. In Fig.5(c) is shown the mains AC connecting terminal, AC/DC power converter with variable DC output pulsating current, voltage and current LEM modules and power module for sbRIO-9636 board. In Fig 5(d) is shown NI sbRIO-9636 board with corresponding connection terminals (analog inputs, digital PWM output and I2C communication interface).

In the exploitation testing and measuring the two experiments are carried out: the first experiment where vibratory through is empty, and the second one where the vibratory through are filled with granulated material-sugar.

In both the cases, REVC is excited with triangular current, to satisfy steady-state of the system, and after that REVC is deactivated by setting current to very small value. All measurements were performed on a digital storage oscilloscope, with high resolution and bandwidth. Several quantities of interest are measured during experiments.

In Fig. 6 is depicted displacement of empty vibratory trough relative to the base.

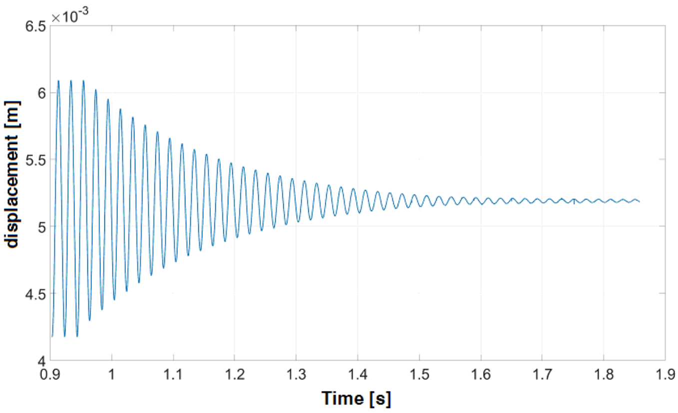


Figure 6. Displacement of empty vibratory trough relative to the base

It can be observed that the system has damped where damping time constant is about 0.3 sec. Also, from this experiment can be determined resonant frequency of REVC. In this case, the measured value of resonant frequency was 49.2Hz.

Based on the known mass of the moving part of vibratory conveyor (empty vibratory through), can be determined stiffness of supported fiberglass composite springs of REVC. For $m_0$=1kg mass of LCE and the angular frequency $\omega_0 = 2\pi\cdot 49.2=309$ rad/s, in a simple manner is obtained the total stiffness of the supporting elements of LCE i.e. fiberglass composite springs $\Sigma k= \omega^2{}_0\cdot m_0$=95481N/m=95.48N/mm.

In Fig. 7 is shown displacement of vibratory through filled with granulated material (food sugar), relative to the base.

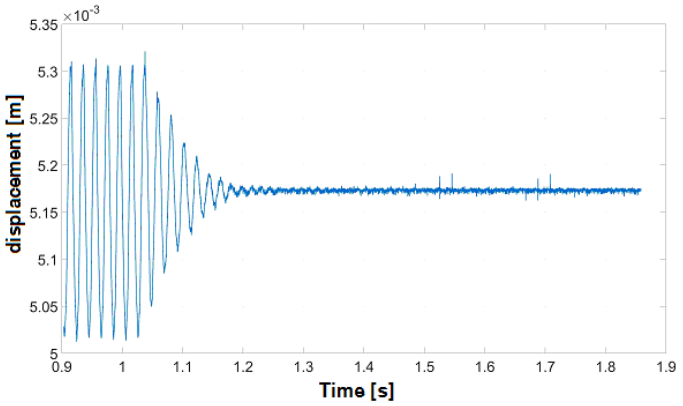


Figure 7. Displacement of full trough (with sugar) relative to the base

In this case, higher damping is caused with increased total mass of vibratory trough. This increase in the total mass is formed as a result of filling the trough with a vibratory bulk material (food sugar). It can be observed that the system has damped, where damping time constant is approximately 0.1 sec. Based on this experiment, it is concluded that the bulk material (food sugar) contributes to increased damping. This is the result of phenomenological and physical processes occurring in the material during the vibratory conveying.

In Fig. 8 are shown the oscilloscopic records of accelerations' difference between the base of REVC and its the ground (foundation), where blue, red and yellow records represent accelerations' difference in X, Y, Z directions, respectively. The smallest acceleration difference is in X direction (blue record), because of compensation resulting from the movement of the vibratory trough.

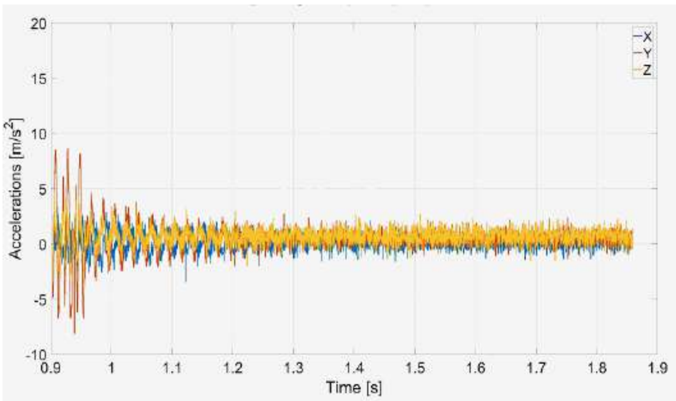


Figure 8. The acceleration's difference between the base and the ground for empty vibratory trough

Fig. 9 depicted oscilloscopic records of accelerations' difference between the base and the ground of filled vibratory trough. The Fig. 9 clearly shows the difference comparing to measurements depicted in Fig. 8.

We can see lower accelerations in all direction regarding smaller displacement of the vibratory trough relative to the base (Fig. 6. and Fig. 7).

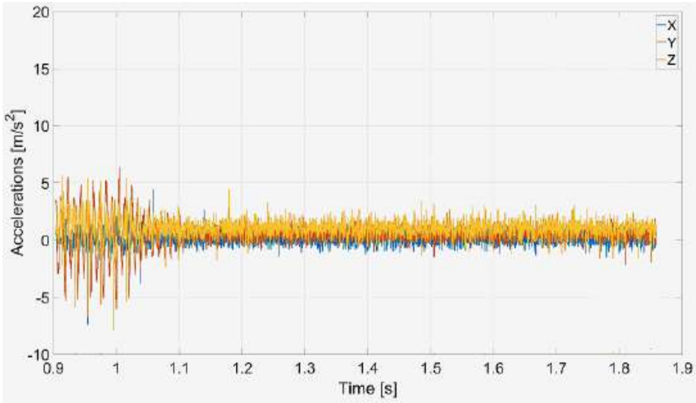


Figure 9. The accelerations' difference between the base and the ground for full vibratory trough

In Fig. 10 are shown the oscilloscopic records of waveforms: displacement of the empty vibratory trough relative to the base and actual current of electromagnetic vibratory actuator coil. The frequency of excitation current pulses is set to 49.2Hz i.e. the mechanical resonant frequency of REVC.

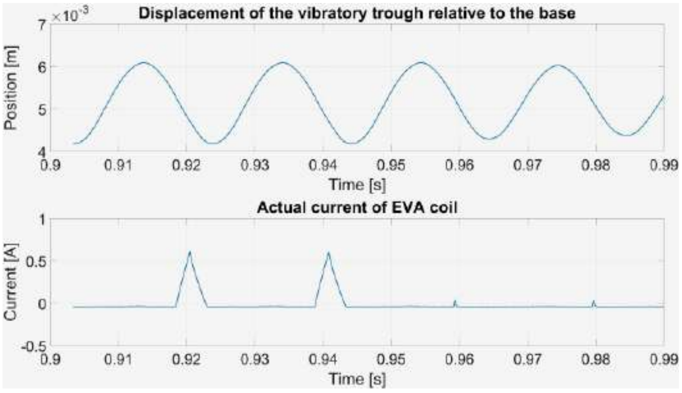


Figure 10. Displacement of empty vibratory trough relative to the base and excitation current of the REVC

In Fig. 11. are shown the oscilloscopic records of waveforms: displacement of the vibratory trough (filled with food sugar) relative to the base and actual current of electromagnetic vibratory actuator coil. The frequency of excitation current pulses is remained unchanged. Since the vibratory trough is completely filled with sugar (the total mass is increased), the mechanical resonant frequency is decreased to a value of 271 rad/s. As a consequence, there has been a signal distortion of displacement of the vibratory trough relative to the base. As can be seen from Fig. 11, displacement signal has not pure sine waveform.

Regarding to increased load of the vibratory trough with bulk material (food sugar), amplitude of the relative displacement $p$ is decreased in regard to the case when the vibratory trough was empty (the characteristic waveforms for this case are shown in Fig. 10).

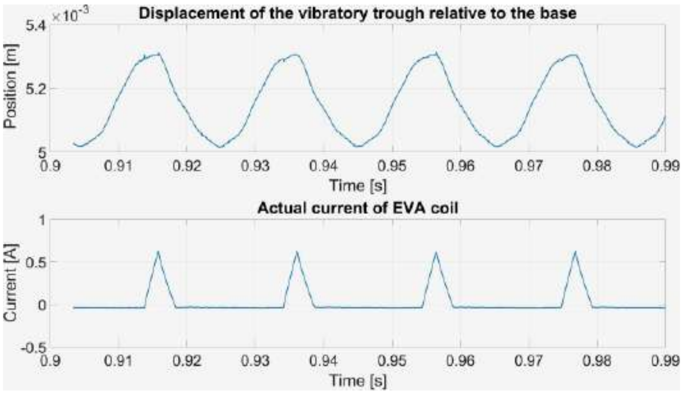


Figure 11. Displacement of filled vibratory trough (with food) sugar relative to the base and excitation current of the REVC

Given that the experiments carried out measurements of the current and voltage of the electromagnetic vibratory actuator, the idea was to present their oscilloscopic records.

In Fig. 12 are shown the oscilloscopic waveforms of electrical current and voltage obtained on the connection terminals of the coil of electromagnetic vibratory actuator. The measuring is made by two LEM sensors: measuring sensors $LEM_i$ (for electrical current) and $LEM_u$ (for voltage). The recording corresponds to REVC with filled vibratory through (i.e. Fig. 11).

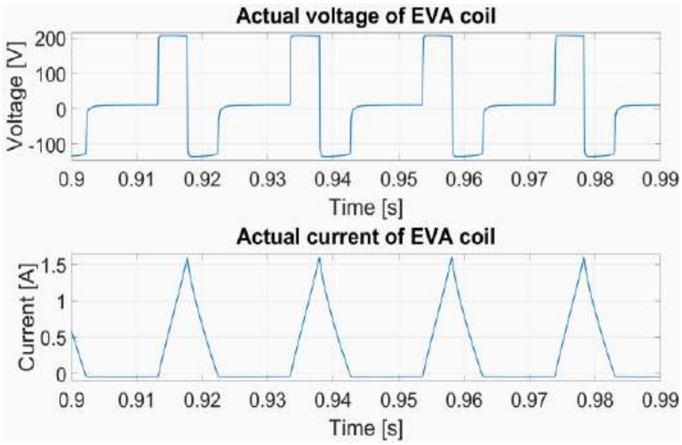


Figure 12. Oscilloscopic records of current and voltage of electromagnetic vibratory actuator for case of filled vibratory through and driving frequency of 49.2Hz.

## VI. Conclusion

This paper presents a hardware and software implementations of the testing and measurement system for resonant electromagnetic vibratory conveyor (REVC), which is aimed to parametric identification and assess the impact of bulk and particulate materials on the total damping of the vibratory conveying system. In addition, the hardware platform based on sbRIO-9636 *National Instruments* enables estimation of relevant parameters of the REVC from the standpoint of its optimal control. The software implementation is based on LabVIEW platform with implemented built-in data transfer mechanisms to pass data from the I/O to the FPGA and also from the FPGA to the embedded processor for real-time analysis, post-processing, data logging, or communication to a networked host computer.

The complete system for vibratory conveying of particulate materials was shown. Measurements and acquisition of electrical and mechanical quantities affecting on the comprehensive investigation and phenomenology of vibratory transport are presented.

The presented system allows us to experimentally verify very complex process occurring in the bulk or particulate material during vibratory conveying. This process significantly affects on the total damping of the entire vibratory conveying system. From this standpoint, the experimental setup shown in this paper provides a comprehensive study of the phenomenology of vibratory conveying. Also, the implemented hardware and software experimental setup can be used very efficiently in mechatronic educational purposes.

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