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Hardware Implementation of Measuring System of Resonant Electromagnetic Vibratory Conveyor

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Abstract — **Vibratory conveyors with electromagnetic excitation belong to a group of mechatronic devices that in an efficient way provides conveying bulk and particulate materials. They have an important role in the process industries such as: food processing, pharmaceutical industry, agriculture industry, etc., and represent a very important element of technological production line. Particularly, the vibratory conveyors that operate in the resonant mode are well used in industrial applications because of energy efficiency. The relatively small input energy causes high vibrations of load carry element (LCE). The intensity of the vibrations directly affects mass flow and therefore 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 of electrical and mechanical quantities. A hardware implementation of the measurement system and data acquisition platform is presented in the paper. The measuring experimental results obtained on a specific resonant vibratory conveyor are also shown.**

Key words - Vibratory conveyor, measurements, vibration, current, voltage, LEM module, sbRIO board

I. INTRODUCTION

Resonant electromagnetic vibratory conveyors (REVC) are widely used device for conveying and feeding of particulate and bulk materials in various processing industries (food, pharmaceutical, agriculture, etc.). There are compact, robust, reliable in operation and easy for maintenance. This electromagnetic drives offer easy and simple control the mass flow of conveying materials. In comparison with other 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, etc., makes this conveyor drives as most economical equipment. Vibrations of trough or load carry element (LCE) in which the material is placed induce the movement of material particles, so that they resemble a highly viscous liquid, and the material becomes easier to transport and to dose. 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 $5\text{Hz} \div 120\text{Hz}$ and vibratory width range $0.1\text{mm} \div 20\text{mm}$, for the most of particulate materials [5]-[8].

For standard power stages for control of REVC are used 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 vibratory frequency. Application of transistor (IGBT or MOSFET) switch mode power converters 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 large output displacement is provided by small input power.

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 trough, 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 implementation of the power converter drive, based on IGBT switch and measurement system based on sophisticated sbRIO board *National Instruments* [27]-[30], with whose would be possible to identify all the relevant parameters of the conveyor. The experimental results obtained on a realized REVC are shown in this 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 reliable and accurate measurements. The crucial parameters of vibratory conveyor are the damping and stiffness of elastic elements (composite springs) and equivalent damping of whole vibratory system (mechanical load carrying element plus particulate material).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 on Fig. 1. Control signal of REVC is provided from controllable AC/DC power converter [4], [12], [13]-[14], [15]-[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, typically 50Hz) and duty-cycle range (1%÷50%, typically 20%) is generated with NI sbRIO-9636 board and this signal control AC/DC power converter. The special power module RIO-power (AC/DC) is used for supplying of microprocessor, digital inputs, analog inputs and sensors' circuits, as shown in Fig. 1.

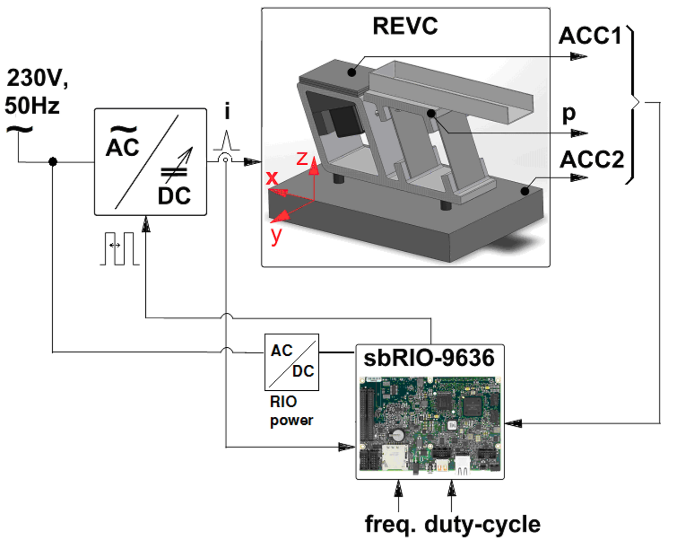

Figure 1. Block diagram of power and acquisition-control system of resonant electromagnetic vibratory conveyor (REVC) based on platform sbRIO-9636 National Instruments

The 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, made in of company *Xilinx-FPGA*, enables the 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. In our case, there are several signals of interest that are acquired with sbRIO board: analog signals-vibratory trough displacement (p) and electrical current (i) 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 [40] that provides output of 0÷10V range. Measuring of REVC current is realized with LEM current sensor LA-25N [36]-[38] with measuring range of -5A..5A, and measuring resistor and corresponding electronic transmitter that is design to provide output of 0÷10V range suitable for sbRIO board analog input. Accelerometers have ADXL345 [41], 3-axis modules with ultra-low power and high 13-bit resolution measurement 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. Experimental Results

In this section are presented and discussed obtained measurement signals on real system (Fig.1.). The two experiments are carried out: the first experiment where vibratory trough is empty and the second one where the vibratory trough is 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.

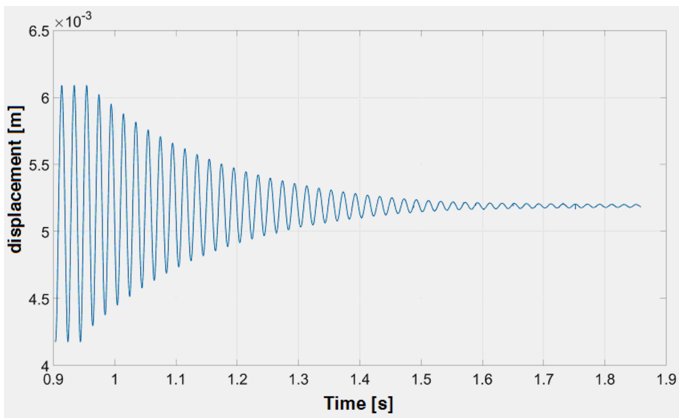

Figure 2. Displacement of empty vibratory trough relative to the base

All measurements were performed on a digital storage oscilloscope, with high resolution and bandwidth. Several quantities of interest are measured during experiments.

On Fig. 2 is depicted displacement of empty vibratory trough relative to the base.It can be observed that the system has damped where damping time constant is about T_{d1} = 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 i.e. mass of empty vibratory trough m_0, 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 way is obtained the total stiffness of the supporting elements of LCE i.e. fiberglass composite springs $k_\Sigma = \omega^2{}_0\cdot m_0$=95481N/m=95.48N/mm.

On Fig. 3 is shown displacement of vibratory trough filled with granulated material (food sugar), relative to the base.

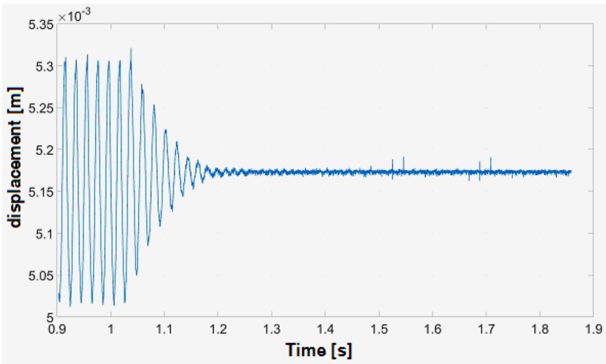

Figure 3. Displacement of full trough (with sugar) relative to the base

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 T_{d2} = 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.

The estimated values of damping coefficient $\gamma=1/T_d$ for the previous two cases are: (1) for empty vibratory trough $\gamma_1=1/0.3=3.33s^{-1}$, (2) for full filled vibratory trough $\gamma_2=1/0.1=10\ s^{-1}$.

On Fig. 4 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.

Fig. 5 depicted oscilloscopic records of accelerations' difference between the base and the ground of filled vibratory trough. The Fig. 5 clearly shows the difference comparing to measurements depicted on Fig. 4.

We can see lower accelerations in all direction regarding smaller displacement of the vibratory trough relative to the base (see Fig. 2. and Fig. 3).

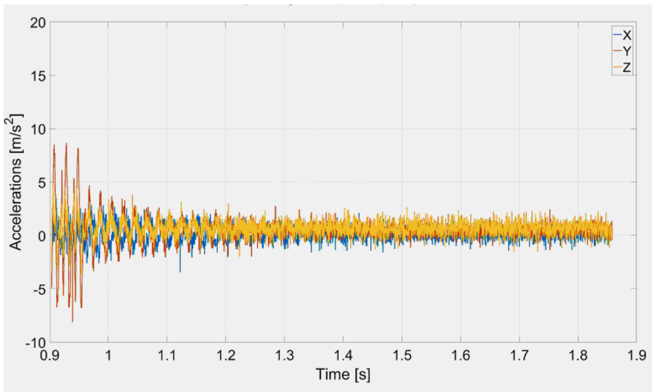

Figure 4. The acceleration's difference between the base and the ground for empty vibratory trough

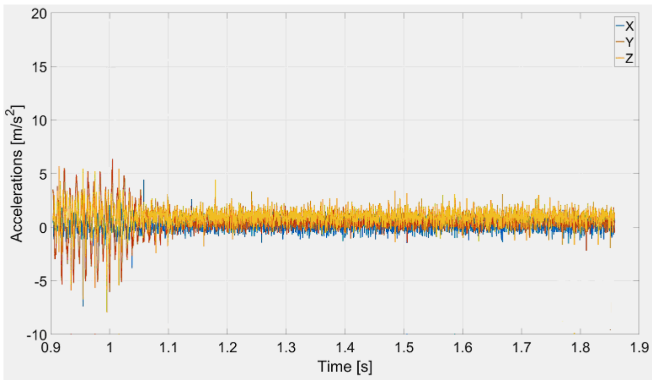

Figure 5. The accelerations' difference between the base and the ground for full vibratory trough

On Fig. 6 is shown the oscilloscopic records of waveforms: displacement of the empty vibratory trough relative to the base and actual current of electromagnetic vibratory actuator's (EVA) coil. The frequency of excitation current pulses is set to 49.2Hz, i.e. the mechanical resonant frequency of REVC.

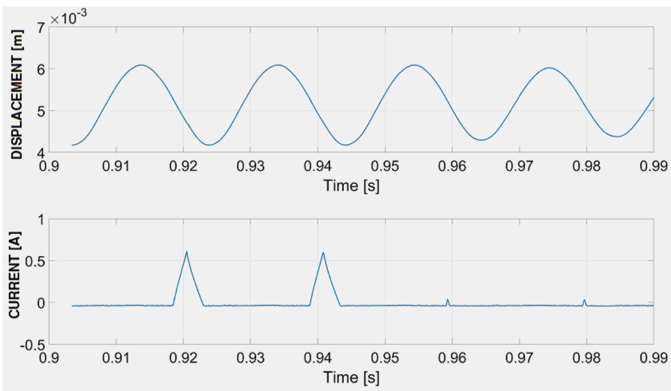

Figure 6. Displacement of empty vibratory trough relative to the base and excitation current of the REVC

On Fig. 7 is 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's (EVA) 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. 7, displacement signal has not pure sine waveform.

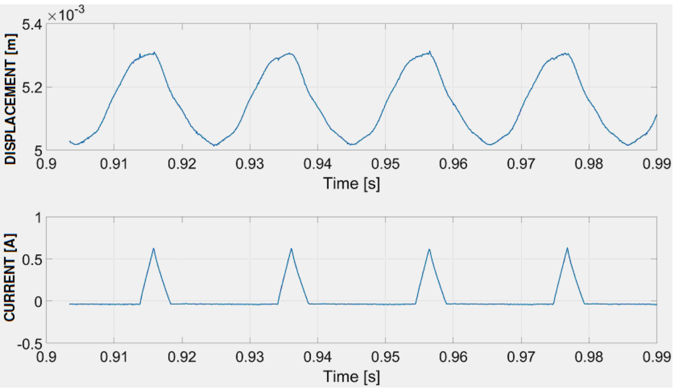

Figure 7. Displacement of filled vibratory trough (with food sugar) relative to the base and excitation current of the REVC

Regarding to increased load of the vibratory trough with bulk material (food sugar), amplitude of the displacement is decreased relative to the case when the vibratory trough was empty (Fig. 6).

CONCLUSION

In this paper are presented a hardware implementation of the control and measurement system of the vibratory conveyor, which is aimed to identify the parameters and assess the impact of bulk 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 complete system for conveying materials was shown. Measurements and acquisition of electrical and mechanical quantities affecting on the phenomenology of vibratory transport are presented.

The presented system allows experimental verification of very complex processes which occurring in the bulk or particulate material during conveying which affects on the total damping of the entire mechanical system, in the relatively simple way.

The presented hardware implementation of measuring and control system of resonant vibratory conveyor having electromagnetic drive is practically realized in Robotics Laboratory, Mihajlo Pupin Institute.

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