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TOPIC n° 2.1

Vibration effects of bumper suspension system on pipeline sensor-based platform for soil water monitoring

Ioannis Gravalos[1], Spyros Loutridis[2], Dimitrios Moshou[3], Theodoros Gialamas[1], Dimitrios Kateris[3], Zisis Tsiropoulos[1], Panagiotis Xyradakis[1]

[1]Department of Biosystems Engineering, School of Agricultural Technology, Technological Educational Institute of Larissa, 41110 Larissa, Greece (gravalos@teilar.gr)

[3]Department of Electrical Engineering, School of Technological Applications, Technological Educational Institute of Larissa, 41110 Larissa, Greece. (loutridi@teilar.gr)

[2]Department of Hydraulics, Soil Science and Agricultural Engineering, School of Agriculture, Aristotle University, 54124 Thessaloniki, Greece (dmoshou@agro.auth.gr)

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Abstract: This work examines the dynamic vibrational behavior of a bumper suspension system which is part of a sensor-based platform. The sensor-based platform travels through an underground pipeline system and monitors the soil water content in real time. The mechanical vibrations were measured with a triaxial piezoelectric accelerometer, and data acquisition system from Brüel & Kjaer. Based on the results obtained from the analysis of results, one may conclude that the modes in the y and z axes are interlinked. It is evident that the mode expected to cause most problems is that centered at 140 Hz. The r.m.s vibration value at high speed operation is almost double to that produced when the sensor operates at low speed.

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1. Introduction

Currently, mobile robotic systems are used for automated inspection of the inner surface of piping systems using advanced techniques such as visual inspection, magnetic leakage detection, etc. (Qi et al., 2009). The pipeline robotic systems can be classified into the following categories, based on their driving mechanism: wheel type robot, caterpillar type robot, walking type robot, pig type robot, wall-press type robot, screw type robot, and inchworm type robot (Choi and Roh, 2007).

Wall-press type is one of the most popular in-pipe robotic systems. The advantage of wall-press type robot is the realization of adaptive (flexible) mechanism for pressing the wall. It solves several technical problems associated with the change in pipe diameters, presence of vertical pipes, and various elbows. Zhang and Yan (2007) proposed an in-pipe robot with active pipe-diameter adaptability and automatic tractive force adjusting for gas pipelines with different diameter. It consisted of three sets of parallelogram wheeled legs. Each leg had a front and rear driving wheel. The adaptive mechanism was driven by a step motor. This motor drives rotation of a ballscrew that can push the sets of parallelograms legs with driving wheels to contact surface wall of pipeline. Also, Choi and Ryew (2002) proposed an alternative type of wheeled leg mechanism. The proposed mechanism had three wheeled legs spaced 120° around the body of the robot. The folding and unfolding of the leg is succeeded on a pantograph mechanism with sliding base. The wall-press type robots interacted with the pipe wall with pressing forces in order to ensure adequate and stable traction. Due to this ineraction mechanical vibrations were produced. The analysis of the vibrations can be subsequently used for the optimization of the robot operating parameters. In addition, the characteristics of vibrations should be used as a criterion of efficient operation of the wall-pressing mechanism of robots.

Gravalos et al. (2010) presented a sensor-based platform that travels through an underground pipeline system and monitors the soil water content in real time. This sensor-based platform can be classified as a wall-press vehicle. It consists of a modified commercial soil water sensor Diviner 2000, which is placed on two circular articulated wheeled bases, each of them driven by a small wheeled electric motor. The driving wheels are supported via bumper suspensions. This suspension system allows motion only in vertical direction and relies on flexible members (compression springs) to hold the bumper loosely in place. The deflection of the bumper suspensions allows foldable characteristics for the driving wheels, which in turn are in contact with pipeline walls. The aim of this paper is to study the vibrational behavior of the bumper suspension system which is a part of a sensor-based platform used for soil water monitoring.

2. Materials and methods

Experiments were carried out in laboratory conditions, on an artificial soil tank 1.44 m long by 1.10 m wide, and with a depth of 0.25 m (Fig. 1). Three PVC pipeline was placed horizontally along soil tank at depths of 0.2 m under the soil surface. Apparatuses used in the study were the sensor-based platform and a vibration analyser. The mechanical vibrations of sensor-based platform were measured by a compact triaxial piezoelectric accelerometer type 4524-B. The accelerometer was attached on the body of mobile platform via mounting clip (UA-1407). The voltage signals of the accelerometer were sampled with the data acquisition unit PULSE type 3560-C from Brüel & Kjaer. Vibration levels were measured under two different operating speeds.

3. Results and conclusions

A number of three runs were tried both for low and high speed operation. The sampling frequency was 65536 samples per second. Each record typically contained a little more than 500000 points resulting in time series with duration of approximately 8 seconds. First, the root mean square (r.m.s) acceleration was numerically calculated directly from the time series. Next, the power spectral density (PSD) was computed using the Welch's statistical method. A Blackman window was used with 50% overlap between successive segments resulting in a true frequency resolution of 16 Hz.

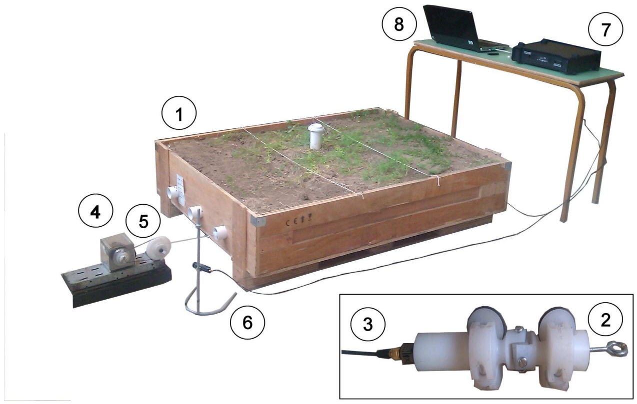

Fig.1. The experimental setup
1. soil tank, 2. sensor-based platform, 3. triaxial accelerometer, 4. electric motor, 5. reducing gear, 6. photoelectric sensor, 7. data acquisition unit PULSE type 3560-C, 8. laptop computer

For low speed operation, the mean value of r.m.s acceleration on x-axis is 2.75±0.31 m/s^2, while on y and z axes we have 4.81±0.5 m/s^2 and 5.44±0.36 m/s^2 respectively. Vibration magnitude is always higher along the z-axis direction. The general form of the power spectral density is computed from the x- axis vibration time series, it is that of a low pass filter passing frequencies up to about 200 Hz. This is to be expected as the mechanism is forwarded using rubber wheels that filter out high frequency vibration. A number of peaks are evident at approximately 40, 400 and 4000 Hz. These peaks may be associated with structure’s modes excited by the contact between the wheels and tube walls. In case of the power spectral density of the y-axis acceleration, a number of modes are apparent at 140 Hz, as well as, at 5 and 6 kHz. Finally in fig. 2, the spectrum of the vibration along the direction of the z axis is presented. The general shape is similar to those of x-axis and y-axis, only the magnitude is a little higher. Two vibration modes are apparent at 140 Hz and 5900 Hz.

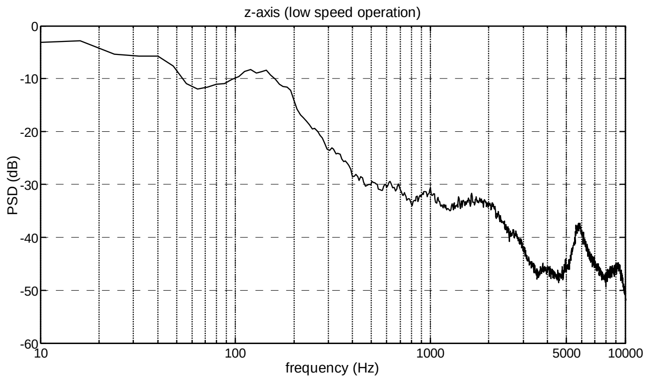

Fig.2. Power spectral density of vibration recorded on the direction of z-axis, low speed operation

For high speed operation, the mean value on x-axis is 5.4±1.3 m/s^2, on y-axis 9.05±2.5 and on z-axis 9.74±2.3 m/s^2. Vibration magnitude is almost doubled when compared to the case of low speed operation. The standard deviation is also significantly higher. As before, the highest values are observed along the z-axis direction. The PSD of the x- axis vibration when using high speed operation shows the same 40, 400 and 4000 Hz peaks as in the case of low speed operation. However, the 400 Hz peak is greatly suppressed. The spectral content of the y-axis vibration shows prominent peaks at 140, 1900, 5000 and 6100 Hz. Finally, the spectral content of the z-axis vibration contains two relatively undamped peaks at 140 and 5800 Hz, figure 3.

From the above one may conclude that the modes in the y and z axes are interlinked. The modes noticed along the direction of the x-axis are not linked to the modes in the other directions. Take out the magnitude of the vibration, the picture in the case of high speed operation is exactly the same as with low speed operation. This is to be expected because the modal behaviour of the structure depends only on the constructional details and is irrelevant to speed and type of excitation provided that the last one is broadband. It is well known, that the vibration amplitude is highest at resonance frequencies. A capacitive probe is quite insensitive to vibration effects. Nevertheless, when designing equipment it is always a good practice to take care of undamped modes in order to increase both the measurement accuracy, as well as the reliability of the device. From figures 2 and 3, it is evident that the mode to cause most problems is that centered at 140 Hz. Higher modes may have much lower damping, but their excitation level is more than 20 dB lower and therefore are not expected to cause much trouble.

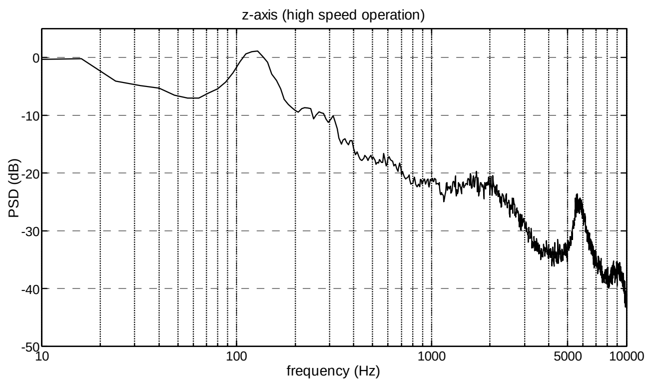

Fig.3. Power spectral density of vibration recorded on the direction of z-axis, high speed operation.

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