430. The Research System for Vibration Analysis in Domestic Installation Pipes

R. Ramanauskas, D. Gailius, V. Augutis
Kaunas University of Technology, Studentu str. 50, LT-51424, Kaunas, Lithuania
e-mail: *ramunas.ramanauskas@ktu.lt; darius.gailius@ktu.lt; vygantas.augutis@ktu.lt*

(Received 10 January 2009; accepted 10 March 2009)

Abstract. A measurement and data processing system was developed for investigation of processes that influence sound propagation in pipes, which are commonly used in residence building industry. An impact-type excitation was mainly used for a controlled wide-band frequency mechanical vibrations excitation. Pipe surface vibrations were measured by means of accelerometers and microphones. Scanning device was used for positioning transducers over a tested pipe. The wave propagation and vibration analysis in pipeline segments of several types of pipes (plastic and metallic) was carried out. Because of various pipes working conditions, empty and filled pipes were tested as well. The experimental data indicates that both in metal and plastic pipes vibrations up to several kilohertz may propagate with low attenuation factor.

Keywords: pipe vibrations, vibration measurement, transducers.

Introduction

In private apartments, the question of sound pollution is important. One of sound pollution sources is the noise generated by building installation systems (heating system, pumps, taps, etc.). In order to reduce noise produced in such systems it is necessary to deepen knowledge about properties of propagating vibrations, their dependence on used materials, fixing structures, etc. A measuring system was built for this task that is capable of testing various pipe segments up to 2 m length with 2 or 3 fixing elements.

Pipe vibrations measurement system

The schematic view of the pipe vibrations measuring system is illustrated in Fig. 1. For movement of transducers over tested structures FESTO one-axis electromechanical scanning device DGE-25-2000 with additional pneumatic cylinder was used [1].

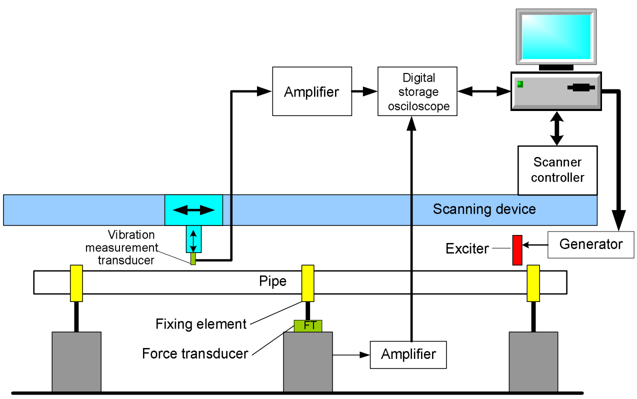

Fig. 1. Pipe vibrations measurement setup

Vibration measurement transducers. For vibration parameters (such as displacement, vibrating velocity, acceleration, sound pressure) measurement proper measuring transducers are needed.

Microphones. For sound pressure field measurement we have used capacitive microphones with frequency ranges from 30 Hz to 20 kHz (±3 dB). As a reference microphone for calibration purposes we have used B&K microphone type 4135 with frequency range 10Hz…50 kHz (±0,5 dB). The sound pressure level is proportional to the vibrating surface velocity amplitude, so using microphones it is possible to evaluate vibrating surface velocity.

Accelerometers. For acceleration measurements we have used B&K accelerometer (frequency range 10 Hz ... 15 kHz) type 4333 and custom-made accelerometers built on the basis of Analog Devices ADXL202 chip (frequency range approximately from 0 Hz to 5 kHz) [2]. Acceleration measurement is attractive, because it does not need a non-vibrating reference point for sensor (as in the cases of displacement or velocity measurements). Using integration it is possible to calculate velocity or even displacement amplitudes out of the acceleration measurement results.

Main parameters of developed MEMS based accelerometers:

Acceleration measurement range	±10 or ±2 g
Frequency range	0… 6 kHz (-3dB)
Dimensions	25x25x22 mm

For reference and calibration purposes the Polytec OVF -522 laser Doppler vibrometer-interferometer with OFV-5000 Modular Vibrometer Controller [3, 4] was planned for use.

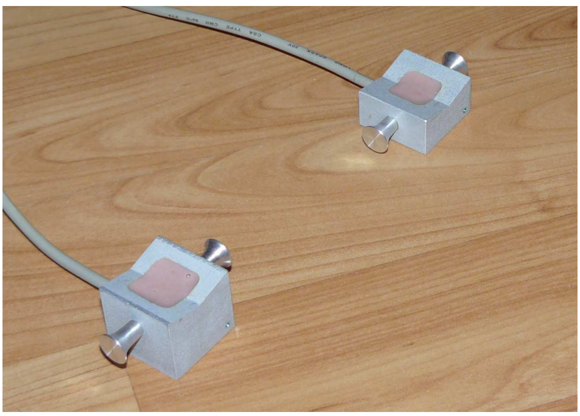

Fig. 2. 3-axial and 2-axial MEMS based accelerometers for vibration measurements developed in KTU

Data acquisition and control unit. For vibration signals digitization we have used the USB data acquisition module Data Translation DT9816 [5]. Key features of this unit are:

- Six, independent, successive-approximation A/D converters with track-and-hold circuitry. Each converter uses a common clock and trigger for *simultaneous sampling* of all six analog input signals at up to 50 kHz per channel.
- A/D resolution of 16 bits and analog input ranges of +/-10 V and +/-5 V.

Vibrations excitation. Controlled vibrations excitation in the pipe may be accomplished in two ways:

1. Harmonic excitation using various shakers.

Using this approach vibrations are excited and measured only in one frequency point, further the excitation frequency is changed to make measurement in other planned frequency points, and so on.

Advantage of this approach is that no wide amplitude dynamic range is needed for vibrations measurement at the same time.

Disadvantages:

- Constant shaker parts interaction with the object, thus changing its own dynamic properties
- High level vibrations is problematic to introduce over wide frequency range (heat problems, noise, vibrations)
- Measurements are prolonged in time

Possible magnetoelectric excitation transducer setups are presented in the Fig. 3.

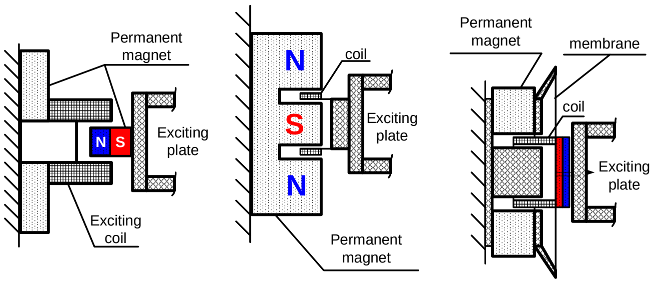

Fig. 3. Varieties of tested harmonic excitation setups

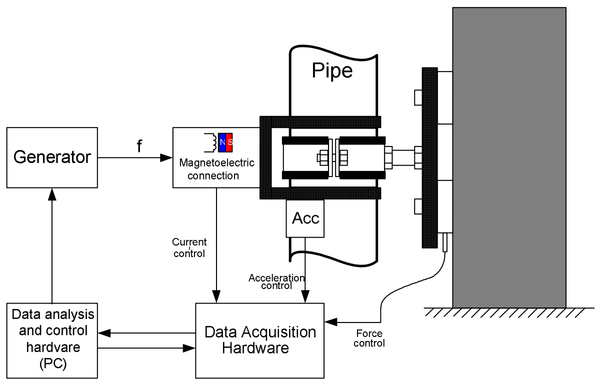

Fig. 4. Harmonic excitation system

2. <u>Pulse excitation using impact type exciters (hammers, electromagnetic strikers, etc.)</u>

Using this approach vibration is excited, when short force pulses acts on a pipe. Frequency range of excited vibrations depends on force impact duration (Figs. 5-6). Impact duration may be varied by choosing different striking zone materials and striker masses (Fig. 7.).

Advantages of this approach are:

- Simple implementation
- Short measurement duration
- Short hammer interaction time with the object
- High impact energies possible
- Wide frequency range

Disadvantages:

- measured vibration (acceleration) signals are usually complicated, thus amplitudes dynamic range is large

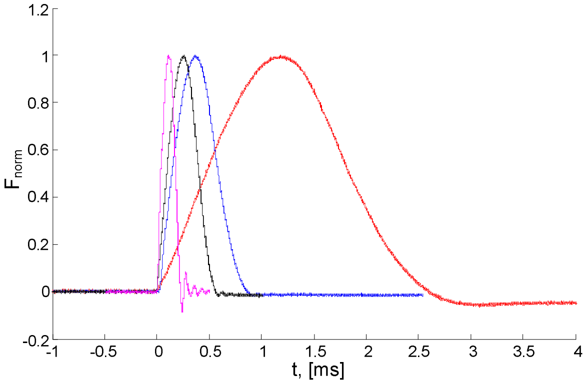

Fig. 5. Measured excitation force signal pulses (different hammers materials)

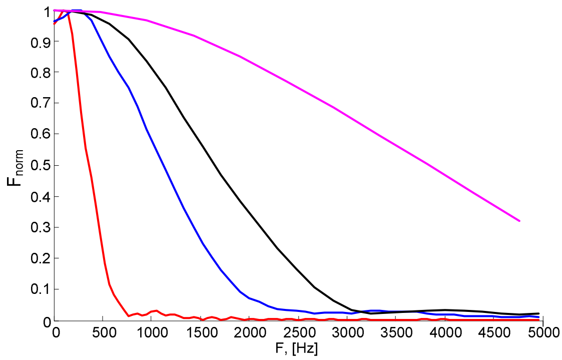

Fig. 6. Spectrum of the force pulses

Fig. 7. Varieties of used impact type exciters

The experimental results revealed that both excitation techniques are nearly equivalent. Results are presented below:

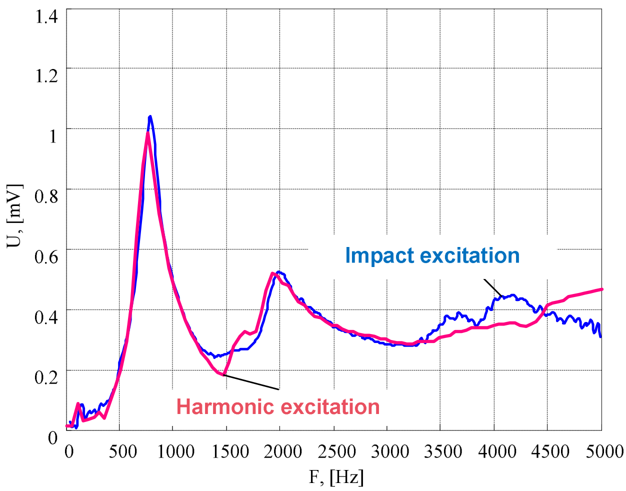

Fig. 8. Harmonic excitation comparison with impact excitation

After testing harmonic and impact type excitation techniques, we have concluded that both approaches provide comparable results however harmonic excitation is complicated in implementation (energy, heat, noise, evaluation durations are large). Therefore impact-type excitation is more promising because of larger excited vibrations and smaller influence on the tested pipe as research object. Impact duration depends on the striker and object stiffness and in our case may be varied from 50 μs to several ms, choosing proper impact zone properties. Variation of impact duration enables generation of desired excitation spectrum frequency range from tens Hz to tens kHz.

For control and data processing of measurement devices a suitable software code for MATLAB data analysis environment was developed. The software allows flexible control of all connected units as well as measurement and processing of all required signals. The MATLAB programming and data processing environment provide the possibility to flexibly change and test required data processing software techniques.

Experiments

Using the above-presented system we have made numerous experiments with pipes fixed at 2 or 3 points (2 at the endings and one approximately in the middle of the pipe).

Propagation of vibrations in the empty 32 mm diameter copper pipe.

As the typical example of the experimental vibrations in the fixed pipeline segment tests we present the data from the 32 mm diameter 1.5 m length copper pipe research.

In Fig. 9 several wave types with different propagation speeds, reflections from the pipe ends are visible. The strip in the middle of the picture is the middle fixing point, where vibration measuring was not made correctly, due the complex configuration near fixing element. The color bar indicates relation of the image color to the amplitude of vibration. Red arrows refer to falling waves, green arrows - to waves reflected from the pipe end or other disturbances such as fixing elements.

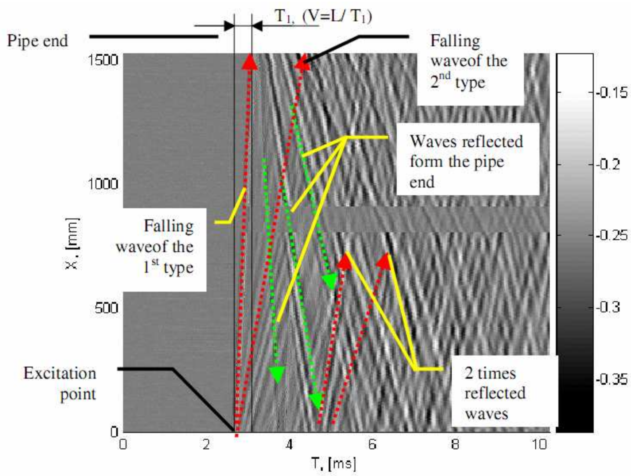

Fig. 9. Example of measured waves traveling along the copper pipe

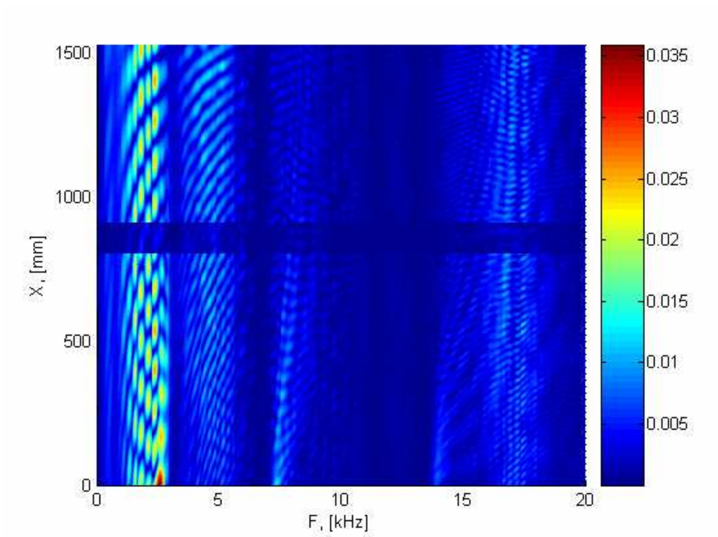

Fig. 10. Example of spectrum of vibrations shown in Fig. 9

Propagation of vibrations in the empty 110 mm diameter PVC pipe. The 110 mm diameter and 2 m long PVC wastewater pipe was used in this preliminary research. Purpose of this research was to check how acoustic waves propagate in the empty PVC wastewater pipe when the sound source is inside the pipe. The high voltage discharges were used as sources of short acoustic pulses [6]. Vibrations were measured using B&K accelerometer (frequency range 200 Hz to 20 kHz) along the outer pipe wall.

In Fig. 12 red spot refers to excitation place. Red arrow indicates waves propagating in the pipe wall (higher speed waves), green arrow - waves propagating inside pipe through air and leaking outside through walls. As we can observe the main part of acoustic energy propagates without significant attenuation inside pipe through the air and only small part of energy goes in plastic wall.

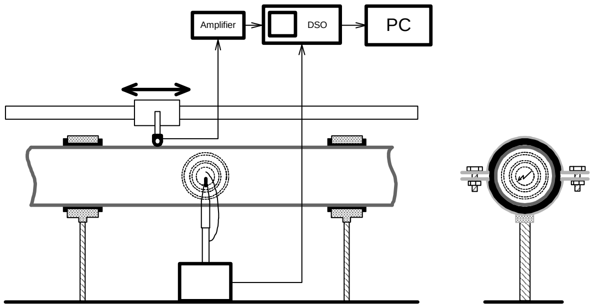

Fig. 11. Empty plastic pipe research setup

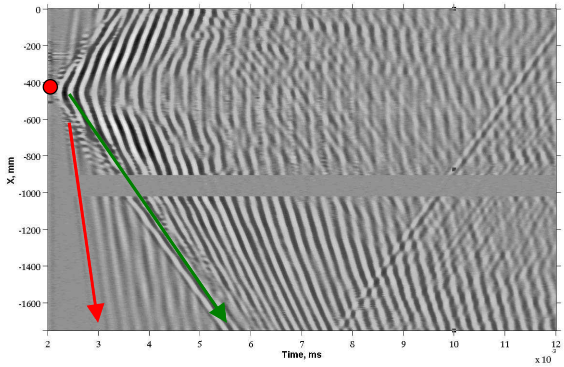

Fig. 12. Length- time projection waves propagation in empty pipe view

Conclusions

- The developed measurement system enables experimental study in the fixed pipe segment setups simulating the installations in real buildings. Pipes of different diameters and materials together with different fixing elements can be tested in order to acquire more information about different vibration energy transfer mechanisms in various residential pipeline installations.
- Harmonic and impact-type excitation are nearly identical however harmonic excitation needs powerful shaker to introduce measurable imitator vibrations.
- In some cases the harmonic exciter approach is complicated because of hard contact between object of research and sometimes quite massive shaker elements
- Impact-type excitation usually needs more than one hammer to introduce sufficiently high vibrations in specific frequency ranges (e.g. rubber hammer for low frequencies, steel hammer for higher frequencies).

Literature

[1] DGE Electromechanical Linear Actuators. http://www.festo.com//INetDomino/us/en/b6f5ea87d39f9fefc1257059006d91d6.htm

[2] ADXL202 Low-Cost ±2 g Dual-Axis Accelerometer with Duty Cycle Output. http://www.analog.com//UploadedFiles/Data_Sheets/ADXL202E.pdf (retrieved 20.02.2008)

[3] Polytec OFV-551/552 Data sheet. http://www.polytec.com/eur/_files/LM_DS_OFV-551_2005_04_E(1).pdf

[4] OFV-5000 Modular Vibrometer Controller. http://www.polytec.com/eur/_files/LM_DS_OFV-551_2005_04_E(1).pdf

[5] DT9816 Datasheet. http://www.datx.com/docs/datasheets/ECONseries.pdf

[6] **Augutis V., Gailius D.** Ultragarsinių ėmiklių charakteristikų matavimo metodas.// Matavimai Nr.3. Kaunas "Technologija", 1996. 74 – 77 p.