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Universal acceleration measurement unit for energy harvesting sources

Abstract. *This article describes a universal acceleration measurement unit designed for measuring parameters of vibrations of different objects and with the use of the results allows modelling of energy harvesters for them. The paper presents the design of the measurement unit, the prototype and example measurements.*

Streszczenie. *Niniejszy artykuł przedstawia uniwersalny układ do pomiaru przyspieszeń zaprojektowany w celu pomiaru parametrów wibracji różnych obiektów. Znajomość tych parametrów pozwala na modelowanie dedykowanych źródeł energii opartych o przetworniki piezoelektryczne dla badanych źródeł. (**Uniwersalny układ do pomiaru przyspieszeń**).*

Keywords: energy harvester, acceleration measurement, vibration measurement.
Słowa kluczowe: przetwornik piezoelektryczny, pomiar przyspieszenia, pomiar wibracji.

Introduction

This article describes a universal acceleration measurement unit designed for measuring parameters of vibrations of different objects and using the results especially to allow modelling energy harvesters for them. The paper presents the design of the unit, the prototype and example measurements taken with the use of the prototype. Energy harvesters allow to regain energy from heat, light or vibrations and convert it to electrical energy. Systems which use energy harvesters as their only power supply can work as long as mechanical or other form of energy is generated by the main system. Energy harvesters can be used, for example in wireless sensor networks installed in hazardous environment on vibrating elements like pumps, generators. The knowledge of the character of vibrations produced by these elements is crucial in the phase of modelling and prototyping energy harvesters. Knowledge of the vibrations' frequencies allows to tune the resonance frequency of the piezoelectric energy converter to maximize its output power. Knowledge of acceleration amplitude in each axis allows to estimate the value of maximum output power and the optimal direction in which the circuit should be installed [1-3].

To determine the basic parameters of vibrations generated by different objects measurement of acceleration is needed. Real time measurement of acceleration in three orthogonal axis and their analysis in the frequency domain allows to discover dominant frequency of vibrations its harmonics and orientation in which the amplitude of displacement is maximum. Additionally real time measurements and analysis allows to check how different factors like rotations per minute or additional mass influence the frequencies and its amplitudes. Presented measurement unit consist of modules which allow to measure the acceleration in three directions and analyze the results on a real time basis.

Measurement system overview

The proposed measurement system block diagram is shown in Fig. 1. The system consists of three main blocks: acceleration sensor, microcontroller and analyzing software. First two blocks are the designed measurement module which main role is to measure acceleration and transfer it to the analyzing software.

The acceleration sensor consists of an integrated MEMS three axial acceleration sensor. It measures the magnitude of acceleration and direction in each axis.

The microcontroller takes care of many important tasks in the measurement system. It converts the output signals from the accelerometer with the use of an embedded A/D converter. The second task is to process the converted data and prepare the data frame for transmission. Measuring sampling time is also one of the important tasks of the microcontroller. Precise measurement of sampling period is needed for precise frequency determination.

Analyzing software is a PC-based application which receives the data frames from the microcontroller, calculates Fast Fourier Transform and displays the results in a graphical form.

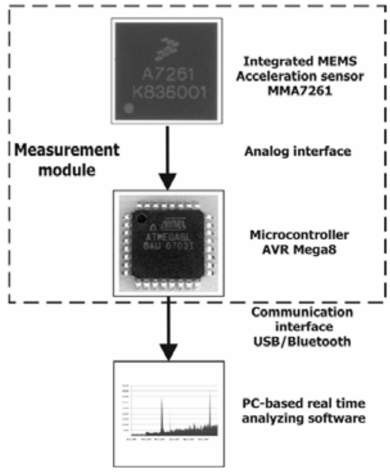

Fig.1. Block diagram of the designed system

Acceleration sensor

The acceleration sensor used in this project is a MEMS miniature three axis sensor enclosed in a small surface mount leadless package. The size and weight of the sensor is very important when measuring vibrations of light objects because every additional mass changes the vibration component frequencies. Used sensor is the MMA7261 Freescale three axis acceleration sensor. The acceleration sensor elements are commonly used capacitive type sensor cells. Used sensor includes common capacitive sensor elements, C to V converter and simple combined amplification and filter stage. The output signal is analog with shifted zero acceleration level. Sensor's configuration uses 2,5g full scale range at which the sensitivity is 480 mV/g. One of the most important parameters of the sensor in this application is its bandwidth which for MMA7261 is from DC to 350 Hz for X and Y axis and from DC to 150 Hz for Z axis [4]. It doesn't mean that the sensor isn't able to detect vibrations which frequency is greater than 350 Hz or 150 Hz, higher frequencies will be still detectable but the detected amplitude will be smaller than the real one. It is known that this sensor is able to detect vibrations up to 1 kHz [5].

Because sensors can have different scale factors and zero-g offset voltages each of them has to be calibrated before using it to measure acceleration. The calibration procedure consists of two steps for each axis and utilizes the Earth's gravity vector to determine scale factors and offset voltages. First step is to measure positive V_p and negative V_n voltages at the output of axis for positive and negative 1g=9,81 m/s^2 acceleration. Next the offset O and sensitivity S can be calculated from equations (1) and (2) [6].

$$O = \frac{V_p + V_n}{2} \quad (1)$$

$$S = \frac{V_p - V_n}{2} \quad (2)$$

After the offset and sensitivity factor is known the acceleration in g can be obtained using the equation (3).

$$A = \frac{V - O}{S} \quad (3)$$

where: A – acceleration in g=9,81m/s^2, V – output voltage from sensor, O – offset, S – sensitivity.
The calibration procedure has to be conducted for each axis. The procedure is implemented in the PC analyzing application.

Microcontroller and interface

The microcontroller main task is to control the A/D converter and take samples from X,Y and Z axis of the sensor. The algorithm also constantly measures sample period which is used during the frequency domain analysis. The sampling frequency determines maximum frequency for the time domain analysis. Because the sensor is able to detect vibrations up to 1 kHz the sampling frequency is set to 2 kHz. When the samples are ready to be sent the algorithm forms a data frame and sends it through USART module which is connected to a FT232 USART to USB converter. The converter allows to connect the system to a PC using USB which also allows to power the circuit from the computer. In further works the USB interface will be replaced with a Bluetooth module which will allow convenient vibration measurements of moving objects such as bicycles and other.

Analyzer application

The analyzing application is responsible for receiving the data frames from the serial port, it has to allow full calibration of each axis of the acceleration sensor, calculate the FFT (Fast Fourier Transform) for acquired data and plot time domain data and frequency domain analysis results. The main window of developed application is shown in the Fig 2. In the upper part of the window received data frames are drawn in time domain for three axis in the same plot.. In the lower part three separate plots allow to show the results of frequency domain analysis for each axis separately. Additionally the application has a built in calibration procedure and many other options like auto ranging, manual, different frequency domain resolution settings etc.

The application works as follows. Firstly depending on the chosen resolution which may vary from 0,49 Hz to 31,25 Hz, the program acquires required amount of data from the measurement module. Next the application calculates FFT and plots its results in the lower part of the main window. The user can also choose the maximum visible frequency or turn on precise frequency markers.

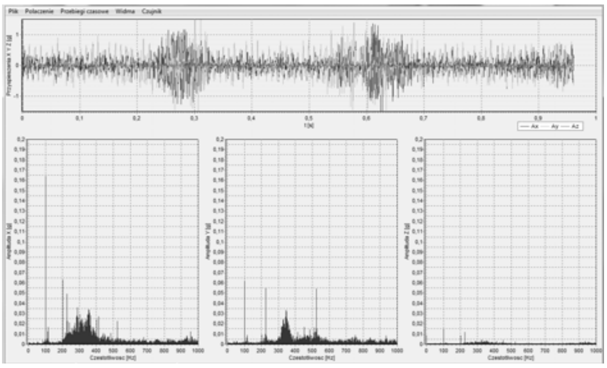

Fig.2. Main window of the analyzer application

Evaluation and tests

To determine that the system is working correctly two things should be checked. Firstly the correctness of acceleration magnitude measurement and secondly the correctness of frequency determination by the analyzer application.

After a full calibration procedure was performed obtained scale factors and offsets were compared with the datasheet of the acceleration sensor. A comparison of calibrated (CAL) and datasheet (DAT) offsets and scale factors for each axis is shown in the table 1 [4].

Table 1. Comparison of calibrated and datasheet values

Axis	Offset		Sensitivity	
	CAL [V]	DAT [V]	CAL [mV/g]	DAT [mV/g]
X	1,59	1,485	486	444
Y	1,63	to	480	To
Z	1,6	1,815	502	516

As it can be seen the obtained values of calibration parameters are consistent with the datasheet of the sensor and it can be assumed that the measurement module properly measures acceleration magnitude.
The second test of the frequency determination was performed in a test set. The measurement module was placed on a loudspeaker (Fig 3) which was connected to a sine wave generator and additionally a frequency meter was connected to the generator.

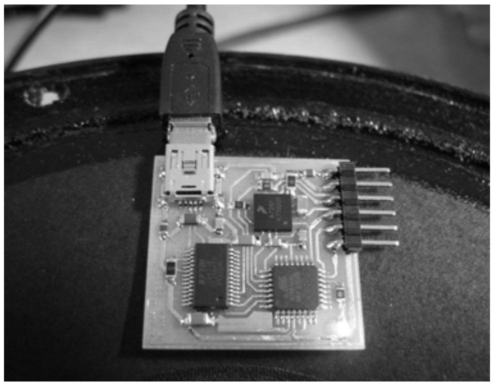

Fig.3. Measurement module on a loudspeaker membrane

The module measured vibrations of the loudspeaker's membrane. The test was performed for different frequencies, the results are shown in the Table 2 and sample picture of frequency meter and analyzer window is shown in Fig. 4.

Table 2. Frequency measurement comparison

No.	Generator frequency [Hz]	Frequency measured by the analyzer [Hz]
1	70,1	70,3
2	100,1	100,5
3	200,1	201,1
4	300,2	302,2

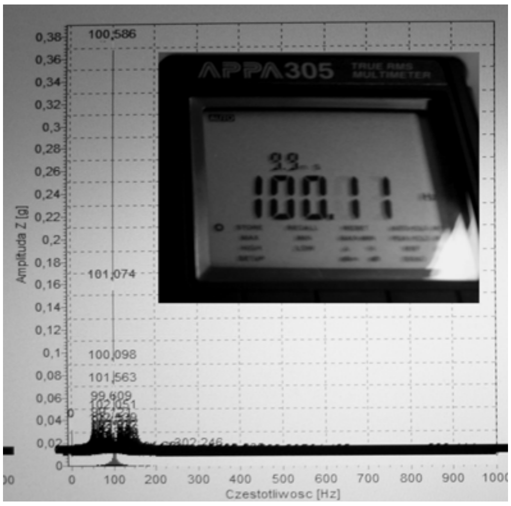

Fig.4. Measurement of 100 Hz vibration of a speaker membrane

As it can be seen the frequencies measured by the analyzer application are consistent with the frequencies of the signal which powered the loudspeaker. Small differences that can be observed are the result of different factors like additional mass on the loudspeaker membrane, finite 0,49Hz resolution of the analyzer programme and accuracy of the frequency meter.

After performing the above tests it can be assumed that the measurement module and analyzer application properly measures vibration amplitude and its component frequencies.

Table 3. Frequency measurement comparison

Object	Dominant frequency [Hz]	Vibration amplitude [x g]
Electric mincer	100	0,17
Microwave oven	100	0,015
Mixer low speed	100,5	0,015
Mixer high speed	225,5	0,37
Lawn mower (petrol engine)	44,8	1,3
Grinding machine	48,8	0,37
Boring machine	100,5	0,195
Vacuum cleaner low speed	201	0,13
Vacuum cleaner high speed	100	0,115
Ventilator low speed	21,5	0,43
Ventilator high speed	23,4	0,37

Sample measurements

After calibration and evaluation tests sample measurements of potential vibration sources for energy harvesters were taken. The orientation of the measurement module was always such that the Z axis was oriented vertically and X,Y axes horizontally. Sample measurements are shown in Table 3.

As it can be seen the dominant frequencies and amplitudes differ for each object. Moreover frequencies depend on speed of moving parts inside the object but not always higher rotation speed means that vibrations on that frequency will have higher magnitudes. With higher rotation speeds there are more harmonic and other vibration frequencies and vibration amplitude is distributed between the dominant frequency and other frequencies. Other sources of vibrations can be found in [1, 2]. In Fig. 5 sample frequency domain plot for X axis taken during ventilator vibration measurement from the analyzer application is shown.

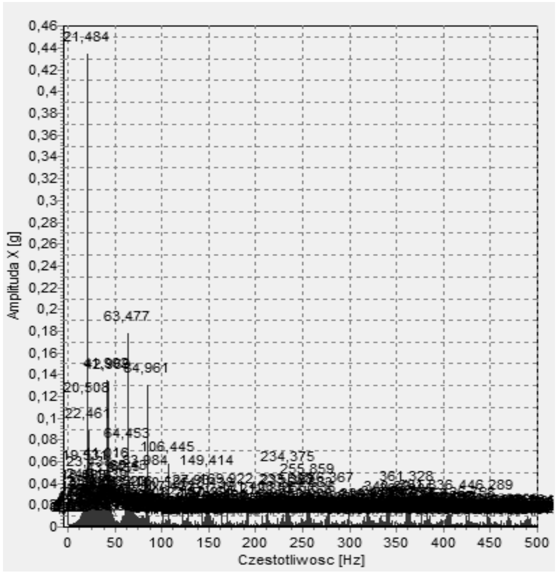

Fig.5. Measurement of ventilator vibration component frequencies

Conclusions

Designed universal acceleration measurement system is very useful in determining the component frequencies of vibrations and their magnitudes of different objects which can be a potential place for installing an energy harvester. The designed system will be used in future works for determining the dominant frequency of vibration for different objects of interest.

REFERENCES

[1] Erturk A., Electromechanical Modeling of Piezoelectric Energy Harvesters, Wirginia Polytechnic Institute and State University, 2009

[2] Roundy S., Wright K.P., Rabaey J., A study of low level vibrations as a power source for wireless sensor nodes, *Computer Communications*, 26, 1131-1144

[3] Jarzyna W., Bocheński M., Augustyniak M., Warmiński J., Characteristics and implementation of the piezoelectric structures in active composite systems, *Przeglad Elektrotechniczny (Electrical Review)*, 86 (2010), n.7, 320-322

[4] Freescale Semiconductor., ±2.5g – 10g Three Axis Low-g Micromachined Accelerometer, Technical Data, AN3916, rev 3, 2007

[5] Kimberly T., Frequency Analysis in the Industrial Market Using Accelerometer Sensors, Freescale Semiconductor AN3751, rev 0, 2008

[6] Kimberly T., Offset Calibration of the MMA8450Q, Freescale Semiconductor AN3916, rev 0, 2010

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