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New approach to measuring vibration parameters of the remote objects with the ZigBee technique

Borowik Bohdan

Technical University of Bielsko-Biala, ul. Willowa 2, 43-309 Bielsko Biala, Poland, bborowik@ath.bielsko.pl

Abstract-The paper presents the monitoring and measurement process for the remote object vibration in the plain space. Wireless, RF communication in Tx/Rx duplex mode provides transfer of data with ZigBee transceivers. Presented ZigBee technology operates in many various modes on frequency 2,4 GHz allowing the coordinator node to select certain path and data. Zig Bee technology can be alternative for other vibration research techniques. The vibration displacement is processed further by DSP Digital Signal Processing made with the microcontroller.

Keywords – Microcontroller, Acceleration, Duty Cycle, Accelerometer

I. Introduction

Contemporary industrial world often creates requirements for microcontroller applications with the measurements of vibrations. Accelerometer applications due to embedded control and I/O digital signal processor DSP play the crucial role in determining vibration and machines fatigue strength testing. It registers, among other, the temporary industrial parameters and monitors plant system parameters such as vibration and/or pressure. Our research, controlled by ZigBee technology can be alternative for other techniques of vibration research.
The paper presents diagnostic procedure and measurements process of the vibration in the plain space. Role of the node play ZigBee transceivers. The vibration monitoring system is gathering information from space through transceivers. The vibration displacement is processed further by DSP Digital Signal Processing made with the microcontroller.
The ZigBee technology are global standard under the IEEE 802.15 working group. IEEE 802.15.4 this is the standard applicable to low-rate wireless Personal Area Networks. ZigBee is the wireless networking standard targeted at low power sensor applications.

II. The acceleration sensor

We use for measurement the dual-axis acceleration measurement system ADXL202E, manufactured by Analog Devices. It has build in the polysilicon surface-micromachined sensor. The polysilicon springs suspend the structure over the surface of the wafer and provide the resistance against acceleration force. Deflection of the structure is measured using the differential capacitor. The acceleration will deflect the beam and unbalance the differential capacitor, resulting in an output square wave, whose amplitude is proportional to acceleration. For determining the direction of the acceleration the Phase demodulation techniques are used.
The system can measure both dynamic acceleration like vibration and static acceleration e.g., gravity. The output is digital signal whose pulse is a Duty Cycle modulator. This pulse equals:

$$P = \frac{T1}{T2} \tag{1}$$

where: T1 - denotes pulse width, T2 - is a period.
The acceleration is directly proportional to the ratio of P. Subsequently the duty cycle can be directly measured with a counter on board of the microcontroller dsPIC33FJ256GP710.
The architecture of the integrated circuit also includes the signal conditioning circuitry to implement an open loop acceleration. For each axis an output circuit converts the analog signal to a duty cycle modulated digital signal DCM. Finally, the signal DCM can be decoded by the stand alone microprocessor. In our case we applied the 16 bit microcontroller manufactured by Microchip, dsPIC33FJ256GP710, operating as the digital signal processor DSP. It is preprogrammed with the firmware to fulfill its function as the digital signal processor for the

incoming DCM signal from the sensor. The functional block diagram of the accelerometer is presented on the figure1.

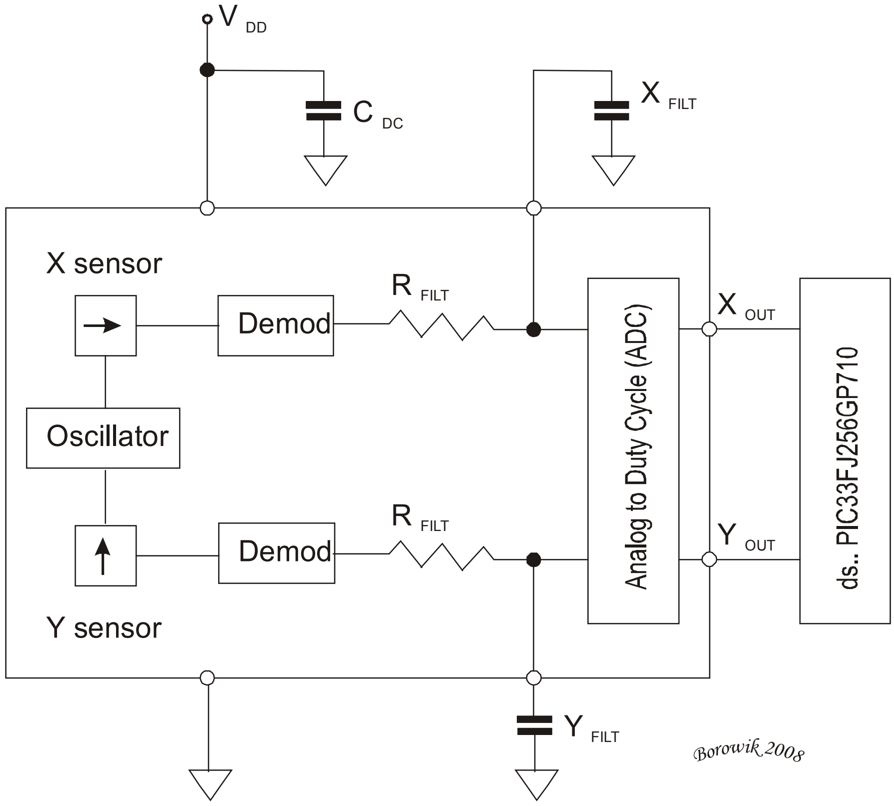

Fig.1. Functional block diagram of the accelerometer

III. Interfacing the Accelerometer with the microcontroller dsPIC

Acceleration is proportional to the ratio T_1/T_2. The nominal output of the circuit is: 0 *g* = 50% Duty Cycle. Scale factor = 12,5% Duty Cycle Change per g.

The time period T_2 does not have to be measured for every measurement cycle. It need only to be updated to account for changes due to ambient temperature. Since the T_2 time period is shared by the X and Y channels, it is necessary only to measure it on one channel. The decoding algorithm for the microcontroller dsPIC33F256GP710 was burnt on firmware. Acceleration circuit is designed especially to work with microcontroller. For the appropriate design of the parameters measured in the object which is endless bandsaw, some preconditions should be observed in the system in term of:

- resolution
- bandwidth
- acquisition time on axis x and y.

These requirements will help to determine the accelerometer bandwidth, the speed of the microcontroller clock and the appropriate Duty Cycle. While the accelerometer is very accurate, it has a wide tolerance for initial offset. The simplest way to clear this offset is with a calibration factor saved on the microcontroller, or by a user calibration for zero g. When the offset is calibrated during manufacturing process, the *one time programmable* microcontroller can be used.

IV. Setting the Bandwidth while adjusting the values of C_x and C_y capacitors

Accelerometer has provisions for band limiting the $\mathbf{X}_{FILT}$ and $\mathbf{Y}_{FILT}$ outputs. Capacitors must be added to the output pins to implement Low-Pass filtering for antialiasing and noise reduction. The equation for the 3 dB bandwidth is

$$F_{-3dB} = \frac{1}{\left(2\pi\left(32k\Omega\right)\cdot C\left(x,\,y\right)\right)} \tag{2}$$

simplifying:

$$F_{-3dB} = \frac{5\mu F}{C_{(X,Y)}} \tag{3}$$

A minimum capacitance equals 1000 pF for $C_{(X, Y)}$. The Filter capacitor selection C_x and C_y are shown below

Table 1 Selection Filter Capacitor

Bandwidth [Hz]	C_x, C_Y [μF]	rms noise [mg]	Peak-to-Peak Noise [mg]
10	0,47	0,8	0,47
50	0,10	1,8	0,10
100	0,05	2,5	0,05
200	0,027	3,6	0,027
500	0,01	5,7	0,01

V. Seting the DCM Period with R_{set}

The analog signal is converted for duty cycle modulated DCM output which is shown on fig.2. Further more impulses of DCM can be decoded by counter/timer included on microcontroller dsPIC33FJ256GP710.

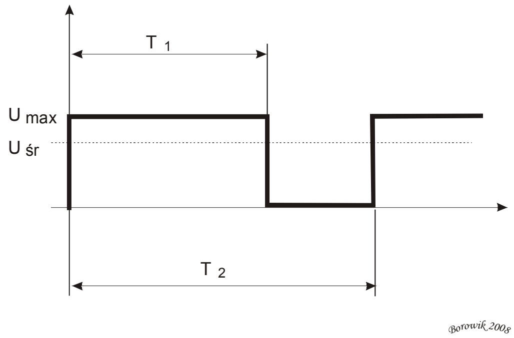

Fig.2. Output of the Duty Cycle

The period of the DCM output is set for both channels by a single resistors from R_{SET} to ground. The equation for the period is:

$$T_2 = \frac{R_{SET}(\Omega)}{125\ M\Omega} \tag{4}$$

$$A_{(g)} = \frac{\left(\frac{T_1}{T_2} - 0{,}5\right)}{12{,}5\%} \tag{5}$$

where: 0 g = 50 % Duty Cycle
A 125 kΩ resistor will set the duty cycle repetition rate to approximately 1 kHz, or 1 ms. The device is designed to operate at duty cycle periods between 0,5 ms – 10 ms.

VI. Selection the accelerometer NOISE/BW

In the accelerometer the filtering can be used to lower the noise floor and improve the accelerometer resolution. Resolution is dependent on both the analog filter bandwidth at X_{FILT} and Y_{FILT} and the speed on the microcontroller counter, that can be attained. The analog output of the ADXL202E has a typical bandwidth of 5 kHz while the Duty Cycle modulator has bandwidth of 500 Hz. In such case the aliasing error appear. Then the signal must be filtered. To minimize DCM errors the analog bandwidth should be less than 1/10 of the DCM frequency. Analog bandwidth may be increased to up to 1/2 the DCM frequency in most applications. In such cases this will result in greater dynamic error generated at the DCM.

The analog bandwidth may be further decreased to reduce noise and improve resolution. It is recommended to limit bandwidth to the lowest frequency needed by the application to maximize the resolution and dynamic range of the accelerometer. With the single pole roll-off characteristic the typical noise of the mentioned accelerometer is determined by the following equation:

$$Noise_{(rms)} = \left(\frac{200\,\mu g}{\sqrt{Hz}} \right) \cdot \left(\sqrt{BW \cdot 1{,}6} \right) \tag{6}$$

then at 100 Hz the noise will be:

$$Noise_{(rms)} = \left(\frac{200\,\mu g}{\sqrt{Hz}} \right) \cdot \left(\sqrt{100 \cdot (1{,}6)} \right) = 2{,}53\,mg \tag{7}$$

Very often the peak value of the noise is desired. Peak-to-peak noise can only be estimated by statistical methods. Table 2 shows estimating the probabilities of exceeding various peak-to-peak values for various rms values.

Table 2. Estimation of Peak-to-Peak noise

Nominal Peak-to-Peak Value	% of Time that Noise will Exceed Nominal Peak-to-Peak Value
2.0 x rms	32%
4.0 x rms	4.6%
6.0 x rms	0.27%
8.0 x rms	0.006%

VII. Mounting the acceleration sensor on the bandsaw.

During the normal operation of the bandsaw there are arousing accompanying vibrations of the chassis, of its sub-assembly and of the bandsaw itself. Because of the teeth geometry those vibrations have the pulse waveform.
In the surveillance as a x, y sensor, the ADXL 202 E accelerometer was used The accelerometer sensor was placed on the passive wheel of the bandsaw (se figure 3).
During the process of cutting metals, the blades of the teeth receive the impulse burden. It applies as well to the endless band saw. The severity of this burden depends on several factors, such as the clamp between the saw and the stock, thickness of the material, to be cut, or the number of saw's teeth being in contact with the work piece. Especially the clamp of the work piece to the saw has the crucial meaning. It is difficult to protect the teeth of the saw against overloading, when cutting the profiled material, tubes, pipes or contours.

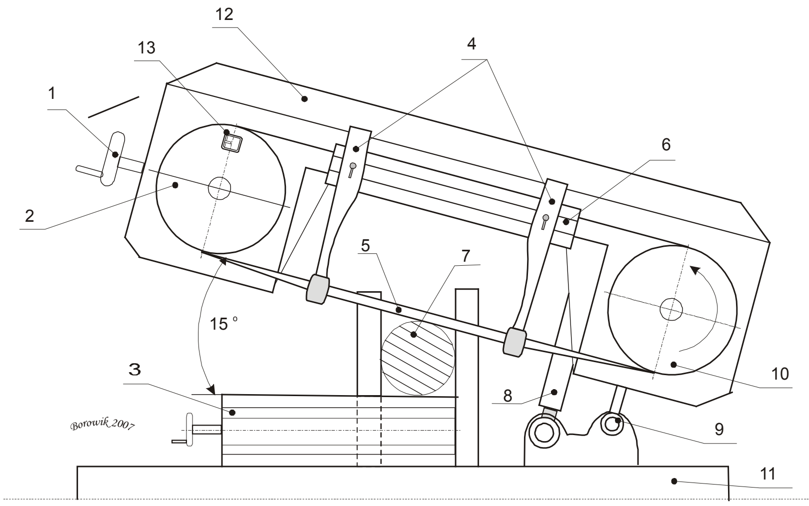

Fig 3. Identification of Basic Cutting Bandsaw Parts during operations

1. Blade tightening screw
2. Stretching wheel
3. Assembling clamping block

4. Stationery blade guard
5. Blade
6. Support of blade guard
7. Material to be cut
8. Hydraulic linear motor
9. Head frame pulley
10. Active wheel
11. Frame of cutting bandsaw
12. Head of cutting bandsaw
13. Accelerometer sensor gathering the impulse burden

In the assumed bandsaw vibration model the oscillations caused by the movement of the mass m_s. are described. The upper constrain of the exploitation speed equals:

$$\beta_0 = v\frac{v_0}{v_{kr,l}} = \frac{v_{eo}}{\sqrt{1+v_{eo}}} \tag{8}$$

The critical speed for the parametric resonance equals:

$$v^*_{0,1} = \frac{v_{kr,1}}{\sqrt{1+\chi_1^{*2}}}\ , \mathit{while}:\ \chi_1^* = \frac{v_l}{2\pi\sqrt{\chi}} \tag{9}$$

The equation of the vibration of mass m_s of the stretching wheel is equal:

$$\ddot{x} + 2h_s\cdot\dot{x} + \omega_s^2 x_s - \gamma_{ks}\left(1-\beta_{ks}\ q_k^2\right)\dot{x}_s = 0 \tag{10}$$

where:

$$\varpi_s = \sqrt{\frac{k_s}{m_s}},\quad 2h = \frac{c_s}{m_s},\quad k_s = \left(\frac{k\pi}{l}\right)^2\cdot\frac{T_0}{m_s v_0} \tag{11}$$

After applying the no-dimensional time: $\tau = \omega_0 t$, $\varpi = \frac{v_0}{m_s v_0}$, we obtain from (10) as follows:

$$q_k'' + \left(a_k^2 + \chi_k\cos\tau\right)q_k + \gamma_{k0}\left(1-\beta_{ks}q_k^2\right)\ddot{x}_s = 0 \tag{12}$$

$$\ddot{x}_s + 2h_{s0}\dot{x} + \gamma_{ks0}\left(1-\beta_{ks}q_k^2\right)\ddot{x}_s = 0 \tag{13}$$

where: $\gamma_{k0} = \frac{\gamma_k}{\varpi_0}$, $\gamma_{ks0} = \frac{\gamma_{ks}}{\varpi_0}$, $h_{s0} = \frac{h_s}{\varpi_{s0}}$, $k_s = \left(\frac{k\pi}{l}\right)^2\cdot\frac{T_0}{m_s v_0}$

The border cycle plot for the bandsaw speed of: v_0 = 0,5 m/s and the tension of the band ***S*** equal 400 N is shown on the figure 4.

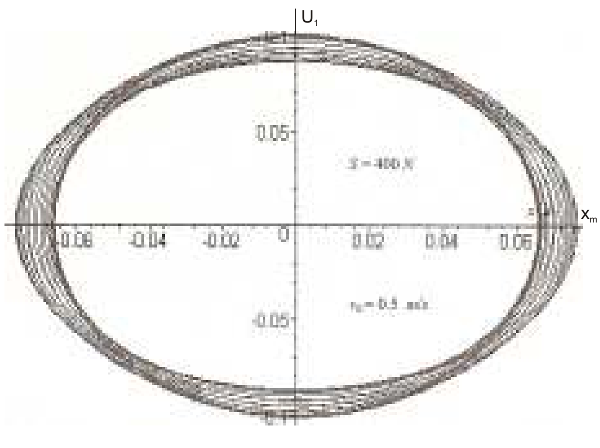

Fig. 4. The border cycle plot (0,5 m/s, 400 N)

The unstable phase portrait for the band saw speed of 4.7 m/s is presented on figure 5.

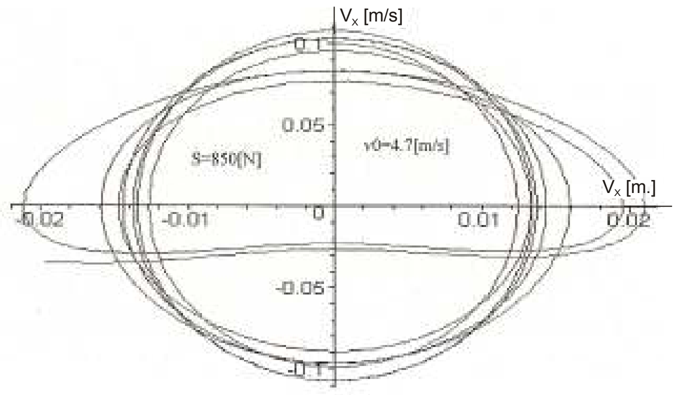

Fig. 5. The unstable phase portrait for the band saw speed $v_0 = 4.7$ m/s

VIII. Data acquisition and data transfer by means of the ZigBee solution

Zigbee with inherent firmware provides a wireless personal area networking PAN of data from the sensor to microcontroller PIC18F4455. The base of Zigbee hybrid module is IC ZDMAI128-B0. It provides point-to-point communication. A serial port is used to communicate with a host device through an AT command interface, as shown bellow on schematic fig. 6.

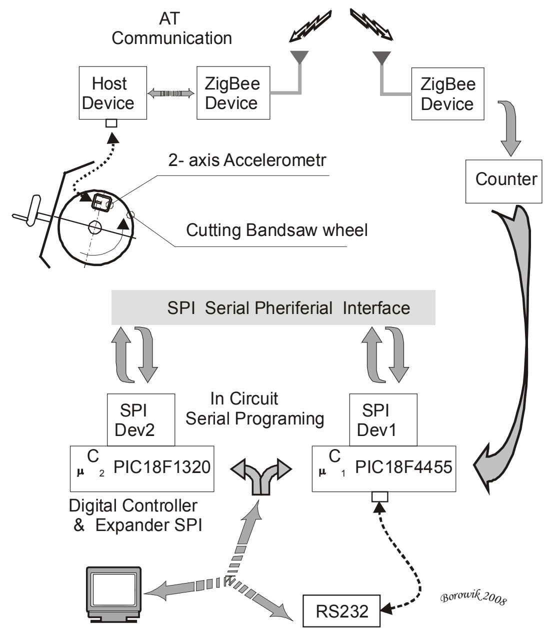

Fig.6. The Zigbee module used for data transfer from the accelerometer sensor

IX. Conclusion

The aim of present investigation was to considerer the possibilities of measure the detachable parts oscillation. The ADXL 202 E accelerometer sensor has been chosen because of its possibility of the dual axis operation. This way the data was acquired during the normal work of the cutting bandsaw. The Aim was achieved by employing the powerful microcontroller PIC18F4455.

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