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ACQUIRING VIBRATION DATA FROM A REMOTE ACCELEROMETER WITH ZIGBEE-BASED TECHNIQUES

Summary. In this research we convey experiments that take into consideration wireless data acquisition using ZigBee-based techniques. During the process of cutting metal with the endless band saw excitations are determined by applying 2-axis acceleration sensor. This sensor is interfaced with the PIC microcontroller. All measurements are made with a high sensitivity Analog to Duty Cycle (ADC) converter.

ZASTOSOWANIE SIECI SENSORYCZNYCH W TECHNOLOGII ZigBee PRZY POMIARACH WIBRACJI REJESTROWANYCH AKCELEROMETREM

Streszczenie. W pracy został zaprezentowany sensoryczny interfejs bezprzewodowy oparty na ZigBee, specyfikacja IEEE802.15.4 dla akwizycji danych z piły taśmowej. Dla pomiarów wibracji głowicy piły taśmowej użyty został akcelerometr umieszczony na ruchomej części piły. Procesowanie danych oparte jest na mikrokontrolerze DSP.

1. Mechatronic model of the endless band saw

Mechatronics integrates a control theory, electronics, software engineering and mechanics, and enables monitoring and analyzing processes. For the purpose of data acquisition we use a PIC microcontroller together with a wireless ZigBee-based network. As the accelerometer is chosen the Analog Device 2 –Axis sensor with Tilt sensing capabilities and a fast response. It allows for a detailed analysis of the vibration caused by a band saw during its work. Using ZigBee-based techniques is especially important for identifying, from where come particular sources of vibration. It helps to detect which parts: pulleys, motors, wheels, or the endless band saw do generate respective excitation. To simplify the picture we limit our model of the endless band saw to the chain of rigid blocks ($m_1 - m_{12}$) connected together by means of resilient-dumping elements ($c_1 - c_{12}$), as shown in figure 1.

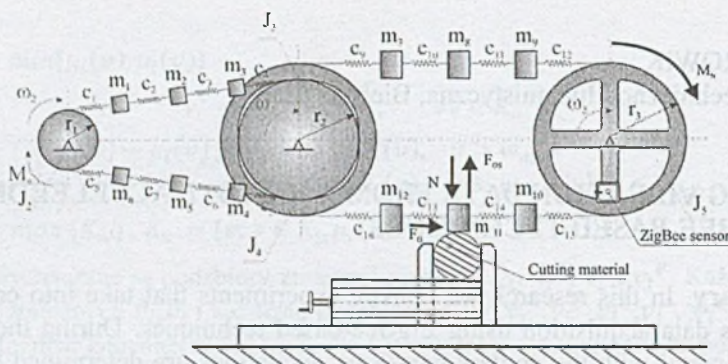


Fig. 1. Mechatronical model of the endless band saw

A metal cutting process accompanies a complex physical phenomena that has an immediate effect on the resulting quality of cutting materials and on the smoothness of their surface. The entire cutting band saw system proves to be susceptible to vibrations from the 105 to 130 Hz range.

2. The acceleration sensor

In our investigation the dual-axis ADXL202E acceleration measurement system (manufactured by the Analog Devices, Inc.) has been used. It has build-in polysilicon surface-micromachined sensor. Polysilicon springs suspend the structure over the surface of the wafer. They provide a resistance against acceleration forces. 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 vibration displacement is processed further by the DSP Digital Signal Processing made by a PIC microcontroller. The system can measure both dynamic accelerations, like vibration and static acceleration (e.g. gravity). The output is a digital signal whose pulse (P) is a duty cycle modulator. So a Duty Cycle is the following ratio:

$$P = \frac{T_1}{T_2}, \quad (1)$$

where: T_1 denotes the length of the "on" portion of the cycle (i.e. a pulse width) and T_2 is the length of the total cycle (i.e. a period).

The duty cycle T_1/T_2 is directly proportional to acceleration. Subsequently, a duty cycle can be directly measured by a counter on the board of the DS PIC33F256 microcontroller.

The architecture of an integrated circuit includes also a signal conditioning circuitry to implement an open loop acceleration. For each axis the output circuit converts an analog signal to a duty cycle modulated digital DCM signal. Finally, the DCM signal can be decoded by a stand alone microprocessor. In our case we applied the dsPIC33FJ256GP710, a 16 bit microcontroller manufactured by the Microchip Corporation, operating as a Digital Signal Processor (DSP). It is preprogrammed with

the firmware to fulfill its function of a DSP for the incoming DCM signal from the sensor. The functional block diagram of the accelerometer is presented on figure 2.

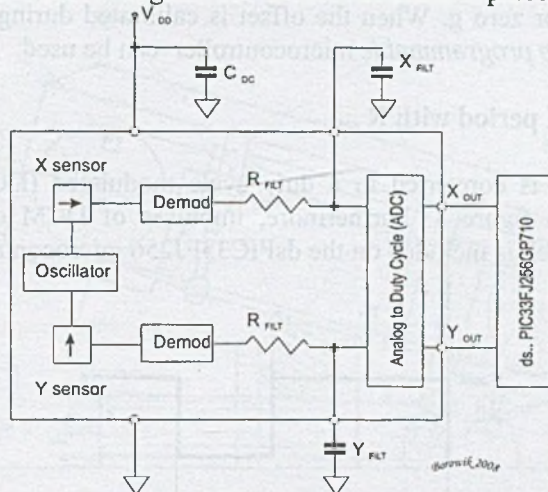


Fig. 2. A functional block diagram of the accelerometer

3. Duty Cycle decoding

Acceleration is proportional to the ratio T_1/T_2 , i.e.:

$$A_{(g)} = \left(\frac{T_1}{T_2} - 0,5 \right) / 12,5\% \quad (2)$$

The nominal output of the circuit is:

$$0 g = 50\% \text{ Duty Cycle.}$$

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 needs only to be updated to account for changes due to the 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 dsPIC33F256 microcontroller has been burnt on its firmware.

4. Interfacing the accelerometer with the dsPIC microcontroller

An acceleration circuit is designed especially to work with a microcontroller. For the appropriate design of the parameters measured in the object, such as an endless band saw, 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 remove this offset is use a calibration factor saved on the microcontroller, or by a user calibration for zero g. When the offset is calibrated during the manufacturing process, the *one time programmable* microcontroller can be used.

5. Setting the DCM period with R_{set}

Analog signal is converted to a duty cycle modulated (DCM) digital output, which is shown on figure 3. Furthermore, impulses of DCM can be decoded by a counter/timer, which is included on the dsPIC33FJ256 microcontroller.

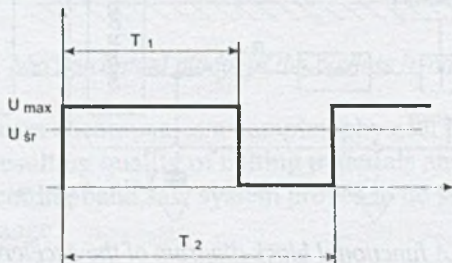


Fig. 3. Duty Cycle output

The period of the DCM output signal is set for both channels by a single resistor from R_{SET} to ground. The equation for the length of the total cycle is as follows:

$$T_2 = \frac{R_{SET} (\Omega)}{125 \text{ M}\Omega} \quad (3)$$

A 125 k Ω 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.

6. Mounting the acceleration sensor on the band saw

During the normal operation of the band saw there are arousing accompanying vibrations of the chassis, of its sub-assembly and of the band saw itself. Because of the teeth geometry those vibrations have a pulse waveform.

In the investigation the ADXL 202 E accelerometer has been used as the x, y sensor. The accelerometer sensor has been placed on the passive wheel of the band saw (see figure 4).

During the process of cutting metals, the blades of teeth receive the impulse burden. It applies to the endless band saw also. 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 on the number of saw's teeth being in contact with the work piece. Especially the clamp of the work piece to the saw is of a crucial meaning. It is

difficult to protect the teeth of the saw against overloading, when cutting the profiled material, tubes, pipes or contours.

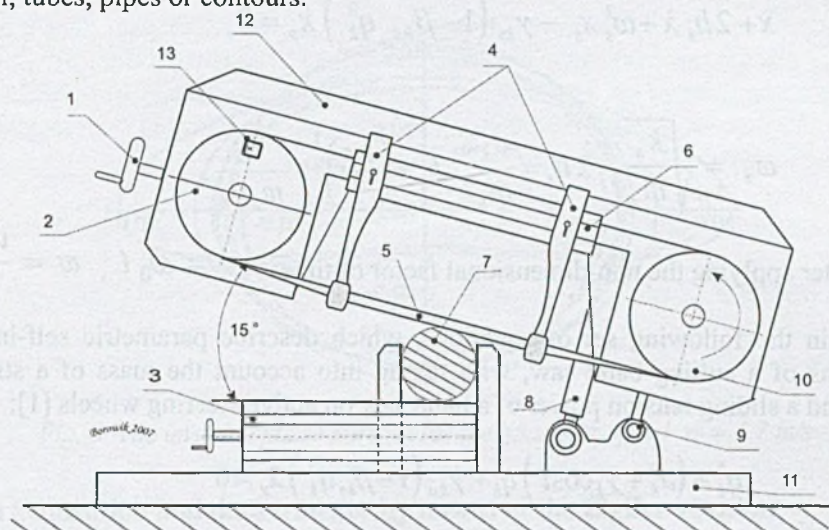


Fig. 4. Identification of a basic cutting band saw parts during operations

1. Blade tightening screw
2. Stretching wheel
3. Assembling clamping block
4. Stationary blade guard
5. Blade
6. Support of a blade guard
7. Material to be cut
8. Hydraulic linear motor
9. Head frame pulley
10. Active wheel
11. Frame of cutting band saw
12. Head of cutting band saw
13. Accelerometer sensor gathering the impulse burden

In the assumed band saw vibration model the oscillations caused by the movement of the mass m_s have been described. The upper constrain of the exploitation speed equals to the following [1]:

$$\beta_0 = \frac{v_0}{v_{kr,1}} = \frac{v_{eo}}{\sqrt{1 + v_{eo}^2}} \quad (4)$$

The critical speed for the parametric resonance equals [1]:

$$v_{0,1} = \frac{v_{kr,1}}{\sqrt{1 + \chi_1^2}}, \text{ where: } \chi_1^* = \frac{l}{2\pi\sqrt{\chi}}, \quad a_1^* = \frac{1}{2}. \quad (5)$$

The equation of the m_s mass vibration of the stretching wheel is as follows [1]:

$$\ddot{x}_s + 2h_s \dot{x}_s + \omega_s^2 x_s - \gamma_{ks} (1 - \beta_{ks} q_k^2) \dot{x}_s = 0, \quad (6)$$

where:

$$\omega_s = \sqrt{\frac{k_s}{m_s}}, \quad 2h_s = \frac{c_s}{m_s}, \quad k_s = \left(\frac{k\pi}{l} \right)^2 \cdot \frac{T_0}{m_s v_0}. \quad (7)$$

After applying the non-dimensional factor of time: $\tau = \omega_0 t$, $\varpi = \frac{v_0}{l}$,

we obtain the following set of equations, which describe parametric self-inductive vibrations of a cutting band saw, with taking into account the mass of a stretching wheel and a sliding tension power of a band saw on active steering wheels [1]:

$$q_k^* + (a_k^2 + \gamma_k \cos \tau) q_k + \gamma_{ks} (1 - \beta_{ks} q_k^2) \ddot{x}_s = 0 \quad (8)$$

$$\ddot{x}_s + 2h_{so} \dot{x}_s + \gamma_{kso} (1 - \beta_{ks} q_k^2) \dot{x}_s = 0, \quad (9)$$

where:

$$\gamma_{ks} = \frac{\gamma_k}{\varpi_0}, \quad \gamma_{kso} = \frac{\gamma_{ks}}{\varpi_0}, \quad h_{so} = \frac{h_s}{\varpi_0}, \quad \varpi_{so} = \frac{\varpi_s}{\varpi_0}. \quad (10)$$

The border cycle plot for the band saw speed (v_0) equal to 0,5 m/s and the tension of the band saw (S) equal to 400 N - is shown on figure 5.

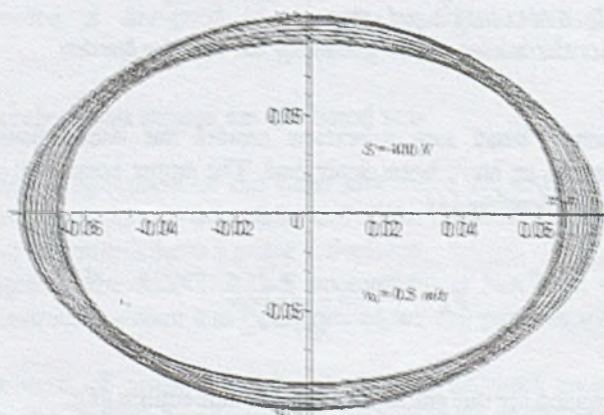


Fig. 5. The border cycle plot ($v_0 = 0.5$ m/s, $S = 400$ N)

The unstable phase portrait for the band saw speed of 4.7 m/s is presented on figure 6.

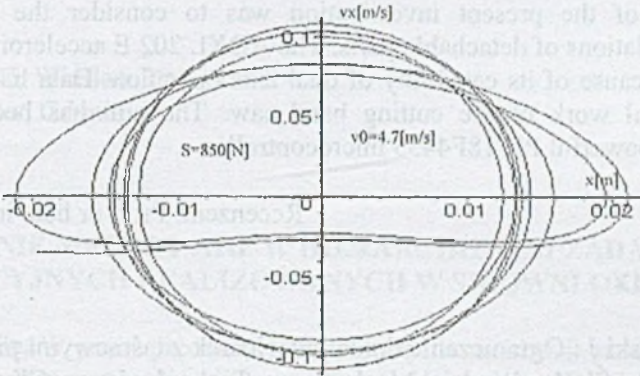


Fig. 6. The unstable phase portrait for the band saw speed $v_0 = 4.7$ m/s

7. 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 the dsPIC33F256 microcontroller. The base of the Zigbee hybrid module is the 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 on the schematic figure 7.

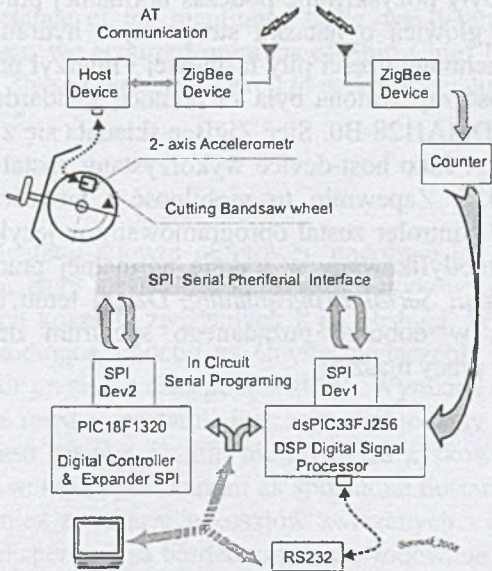


Fig. 7. The Zigbee module used for data transfer from the accelerometer sensor

8. Conclusion

The aim of the present investigation was to consider the possibilities of measuring oscillations of detachable parts. The ADXL 202 E accelerometer sensor has been chosen because of its capability of dual axis operation. Data has been acquired during a normal work of the cutting band saw. The aim has been achieved by employing the powerful PIC18F4455 microcontroller.

Recenzent: Prof. dr hab. inż. Jerzy Świder

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Omówienie

W pracy przedstawiono aplikację sieci sensorycznej zbudowanej dla pomiaru wibracji. Jako sensor użyty został akcelerometr f-my Analog Device typu ADXL202E. Ten typ akcelerometru posiada zdolność pomiaru przyspieszeń w dwóch płaszczyznach. Dane były pozyskiwane podczas normalnej pracy urządzenia, którym była piła taśmowa z głowicą o nacisku sterowanym hydraulicznie. Akcelerometr umieszczony był na ruchomej części piły taśmowej i mierzył przyspieszenie w czasie rzeczywistym. Łączność zapewniona była za pomocą standardowego układu ZigBee opartego na module ZDMA1128-B0. Sieć ZigBee składała się z koordynatora, routera i urządzenia *end-device*. Jako host-device wykorzystany został mikrokontroler firmy Microchip: PIC18F4455. Zapewniło to mobilność i łatwość całego układu. Ten 5-portowy (*enhanced*) kontroler został oprogramowany w języku maszynowym. Kod programu mógł być modyfikowany w trakcie normalnej pracy urządzenia według protokołu ISP *In Circuit Serial Programming*. Dzięki temu rozwiązaniu udało się uzyskać elastyczność w doborze pożądanego spektrum danych i znajdowaniu krytycznych obszarów pracy maszyny.