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MATHEMATICAL MODELLING APPLIED FOR THE RESONANCE FREQUENCY SENSOR IN THE LIGHT OF THE REVERSE LOGISTICS SYSTEM

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Abstract

Prior to the process, when the shredded waste paper in factory is pressed into pellets, as a part of the chain in the context of the reverse logistics, the pieces of paper pass through the chamber. As paper pieces flow through the chamber with the pressing apparatus, the overfilling can cost the damage and stop the process. The sensor can detect overfilling in the pressing apparatus giving timely signal to the service staff. The designed sensor is constructed as a vibration rod that is based on the measuring and evaluating the resonance frequency using the sensor circuit board (PCB) with microprocessor. Evaluation of the vibrations, as an expression of the sensor vibrating rod, is realized through ASSEMBLER. The crystal frequency is 24 MHz, while the rod frequency is 55.5Hz. The damped vibrations of the sensor were modeled. The amplitudes were expressed using the least squares method for the curve fitting. The differential equation was used to determine the damping ratio of the system.

Keywords: Reverse logistics, sensor, mathematical modelling, programming

1.0 INTRODUCTION

The stress on the necessity of the recycling processes [10] to keep the clean environment requires building the reverse logistics channels as well as the development of new technologies leading to compact reverse logistic system that is able to cope with the products and materials intended to remanufacturing. Different parts of industry require specific approach to reverse material flows. Sasitharan Nagapan *et al*. [8] deal with the necessity to build the reverse logistics channels in construction industry. There are many ways also regarding organizational issues. Bart A G Bossink [1] stresses the idea of demonstration project as an effective organizational form to build the prototype of the clean technology application. Denni Kurniawan *et al*. [6, 7] stress the work with eco-friendly materials analysing the optimum mechanical properties.

Our work is devoted especially to the paper recycling. Paper is usually not recycled directly in the small and medium sized enterprises. Paper material is usually pressed into the pellets (Figure 1) and then transported to the factory for the recycling process itself. Pelleting process is carried out in the special machine. The paper is first crushed into small pieces. So pieces of paper are transported in quantities through the chamber (Figure 2) for pelleting in the pressing machine. The pieces of the paper during transfer often overfill the chamber to the extent that they prevent further processing. Our research work Intended to designing and implementation of sensor that is able to detect overfilling in a pressing apparatus. The designed sensor is based on resonance frequency.

The example of sensor using nonlinear resonance magnetoelectric effect [3] is presented for instance also with Y. K. Fetisov and a group of the researchers from Moscow. A self-resonant frequency-modulated micromachined passive pressure sensor, of American scientist [2] Antonio Baldi with his colleagues, uses the self-resonant frequency modulation to detect the pressure variations. A. Hassani with Skorobogatiy M [4] introduced a fully polymeric fibre sensor. V

Todorova and D Kolev [8] try to decrease the efficiency of the sensor system whose sensitivity is based on the piezoelectric resonance array. A group of Chinese scientists propose a piezoelectric vibration energy harvester [5] that meets the needs of many microelectronic devices.

However, the sensor that was designed in our research, to detect overfilling in a pressing apparatus, is specific in its construction as well as its use. It is based on the resonance frequency.

2.0 METHODOLOGY

The paper is not recycled directly in the small and medium sized enterprises; therefore it is important how it is packed to be suitable for the transportation as material for the further processing. The waste paper, which appears during the manufacturing, is collected and shredded in the paper mill into the small pieces. The pieces of the waste paper are falling down in a great amount in the inner part of the machine (Figure 2). During the falling they touch the sensor. If the overfilling does not occur in the chamber the resonance frequency of the sensor is not influenced. The pieces of paper are finally transported through the chamber (Figure 2) to the machine for the pelleting process. The pieces of waste paper are pressed during the palletization and molded into the blocks in the shape of the prism as shown in Figure 1.

Figure 1 Pellets of the pieces of paper intended to the transport for further processing

As a great amount of paper pieces passes through the chamber (Figure 2), it often happens that overfilling blocks the continuous process. Therefore monitoring the process can prevent the further manufacturing problems. Construction the sensor for detecting the overfilling in a chamber with the pressing apparatus is one of the possible ways to keep the transportation of the paper pieces continuous. The sensor is based on the resonance frequency of the rod (Figure 3) and is mounted on the wall of the pressing machine.

Figure 2 Chamber with the sensor that is mounted on its wall. The pieces of paper are transported through the chamber to the pressing machine for the pelleting process

The sensing principle is based on the attenuation the vibration of measuring rod (Figure 3) under the influence the contact of waste pieces. The microprocessor AT89C2051 (Figure 6) sends to one (internal) end of the rod short pulse that causes the entire rod damped vibrations of oscillator with decreasing amplitude. The size of these amplitudes is sensed by the same coil, which caused the vibration (Figure 5) of the rod (Figure 4).

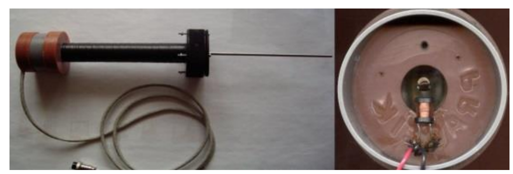

Figure 3 Resonance frequency sensor and its detail of drive coil on the right

The signal is then amplified and evaluated by a microprocessor. Every scrap piece of paper causes attenuation when touched the rod and it is immediately detected by a microprocessor. There will be an optical indication of this condition. If this action continuously takes less than 30 seconds it will also switch the output circuit for the alarm in order to alert the operator the need to address the situation.

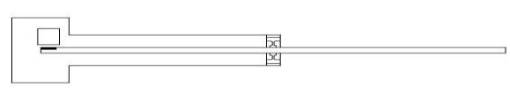

Figure 4 Resonance frequency sensor with its details

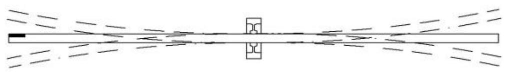

Figure 5 Schematic representation of the rod of the resonance frequency sensor

Figure 3 shows in the detail the drive coil with two functions. The first function of the drive coil is impulse excitation of the rod vibration. The next function is evaluating a subsequent number of damped mechanical oscillations of the rod. The damped oscillations are expressed in Figure 8.

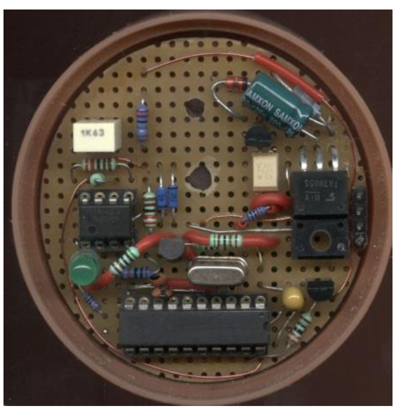

Figure 6 View of the sensor circuit board (PCB) with microprocessor AT89C2051

Signaling for functioning of the operating mode is represented by the means of LEDs. Green LED indicates power supply and the proper mode. Red blinking of the LED indicates that the interfering signal is captured and vibration rod is abnormally subdued. The red LED will light when the interfering signal lasts continuously for at least 30 seconds. Interfering signal arises in contacting rod with the waste paper pieces. Interfering signal, which lasts continuously for more than 30 seconds occurs for overfilling of the pressing apparatus and is indicated as alarm.

Figure 7 expresses schematic representation of the sensor circuit principle through the following components:

T … transistor for excitation the pulses on the coil L,

D … Schottky promotion diode which blocks the overvoltage on the coil L,

M … the oscillating magnet,

R … resistance due to the perception of the rod vibration,

D2, D3 … Schottky diodes for limiting signal to approximately 250mV,

C … a condenser for blocking the DC signal,

< … signal amplifier with dual operational amplifier,

IN ... input to microprocessor for the oscillating signal processing,

OUT … the microprocessor output for controlling the excitation signal.

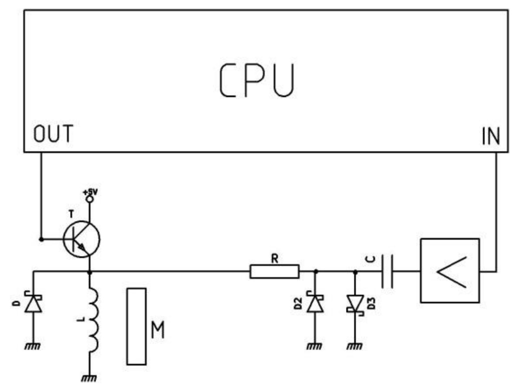

Figure 7 Schematic representation of the sensor circuit principle

3.0 RESULTS AND DISCUSSION

Constructed sensor that is based on the resonance frequency is typical with its damped vibrations. The vibrations, which were measured using the digital oscilloscope DS1102E, are expressed in Figure 8.

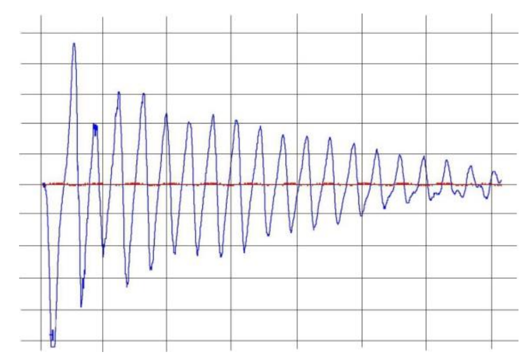

Figure 8 Damped vibrations of the sensor for case if the signal is not disturbed. The scale interval on x-axis represents the value of 50ms. The scale interval on y-axis represents the value of 10mV

3.1 Mathematical Modelling

The amplitudes of the damped vibrations from the graph in Figure 8 are expressed in Figure 9. The trend line is constructed as a curve fitting using the Least Squares as statistical method.

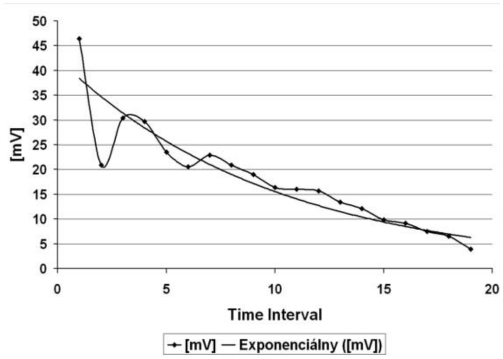

Figure 9 Trend line as a curve fitting for the amplitudes of the sensor damped vibrations

The shape of the trend line in Figure 9 is expressed using the exponential function through the formula:

$$y = 42.473e^{-0.0056t} \tag{1}$$

with the index of determination
$R^2 = 0.893$
The differential equation for the damped vibrations:

$$\frac{d^2y}{dt^2} + 2\zeta\frac{dy}{dt} + \omega_0^2 y = 0 \tag{2}$$

where
ω_0 … the natural frequency of the system,
ζ … the damping ratio of the system.
General solution of the differential equation (2):

$$y = e^{-\zeta t}\left(A_1 e^{\omega t} + A_2 e^{\omega t}\right) \tag{3}$$

Using the comparison of the equations (1) and (3), we can determine the approximate value for the damping ratio of the system:
$\zeta = 0.0056$

3.2 Programming

Evaluation of the rod vibrations is realized through ASSEMBLER. The crystal frequency is 24 MHz, while the rod frequency is 55.5Hz.

The program in ASSEMBLER for the microprocessor AT89C2051:

```
;------------------------------------------------------------------
;coil        P1.7 ... P1.2     ;log 0, pulse to the coil
zled         equ P3.7          ;green led,log 0
vstup        equ P3.2          ;pulse from the coil
vystup       equ P3.0          ;output,log 0, for the
             optocoupler
rled         equ P3.1          ;red led,log 0, after 30s.
;------------------------------------------------------------------
Bseg                           ;bit segment directive
kmity        BIT 0             ;bit for measurement
;------------------------------------------------------------------
Dseg                           ;data segment directive
             ORG   30          ;bytes
tmem:        ds 1              ;the memory for times
impul:       ds 1              ;counter for the pulse
             ORG   40h
stack:
;------------------------------------------------------------------
Cseg                           ;code segment directive
             ORG        0h     ;start of the program
Begin:       ajmp START        ;jumping
             ORG        03h    ;interrupt INT0
             ajmp detek
             ORG        0Bh    ;interrupt T0
             reti
             ORG        13h    ;interrupt INT1
             reti
             ORG        1Bh    ;interrupt T1
             reti
             ORG        23h    ;interrupt serial link
             reti
             ORG        2Bh
;--------------------------------------------------------------
START:                         ;hardware-reset
mov SP,#stack
;..................................................................
mov TMOD,#00010001b            ;internal,mod1,mod1
             setb IT0          ;edge pulse
             setb EA
             setb EX0          ;interrupt from sync
             clr kmity
             mov tmem,#0
             mov impul,#0
             setb vystup
;------------------------------------------------------------------
zaciat:
             call impulz
                               ;pause 40ms for the coil
             mov r7,#200
za4:
             mov r6,#200
za5:
             djnz r6,za5
             djnz r7,za4
             mov impul,#0
             setb EX0          ;pulse detection
                               ;waiting 800ms to response
             mov r4,#13
za2:
             mov r3,#250
za1:
             mov r2,#250
za0:
             djnz r2,za0
             djnz r3,za1
             djnz r4,za2
             clr EX0           ;pulse detection disabled
                               ;memory testing
             mov a,impul       ;pulse counting
             anl a,#11110000b
             jnz za6
                               ;pulse < 16
             setb zled         ;green led off
             cpl rled          ;red led blinking
```

```
            inc tmem
            ajmp za7
za6:
            mov tmem,#0
            setb rled
            clr zled
            setb vystup
          ;optocoupler off
            ajmp za3
za7:
                                ;pulse > 15
            mov a,tmem
            anl a,#11100000b
            jz za3
                            ;memory for pulse times > 31
            clr rled        ;red led on
            setb zled       ;green led off
            clr vystup
            ;optocoupler on
za3:
            ajmp zaciat
;-------------------------------------------------------------------
                                ;excitation pulse 10ms
impulz:
            mov P1,#0
            mov r7,#50
im2:
            mov r6,#200
im1:
            djnz r6,im1
            djnz r7,im2
            mov P1,#255
            ret
;-------------------------------------------------------------------
;                       I N T E R R U P T
;-------------------------------------------------------------------
                                ;INT0 pulse detection
detek:
            clr EX0             ;blocking other
            push psw
            push acc
            mov a,impul
            inc a
            jz de1
                                ;addition allowed
            inc impul
de1:
            pop acc
            pop psw
            setb EX0
            reti
;-------------------------------------------------------------------
            ORG    07FDh
            ljmp START         ;if the program looping
;.......................................................................
END
```

The reverse logistics system in a factory involves pelleting the pieces of waste paper for transfer to further processing. As paper passes through the chamber with the pressing apparatus, the overfilling may cost the problems and stop the process. The system with sensor was developed and constructed for detection the overfilling in the pressing apparatus. The laboratory experiments proved that the evaluation of the vibration intensity corresponds to the amount of paper that impinges on a vibrating rod as a part of the sensor.

The sensor is based on detection the vibrations the rod and evaluation the attenuation the resonance frequency using the sensor circuit board (PCB) with microprocessor. ASSEMBLER was used as a program for the process evaluation.

The graphic characteristics the amplitudes of the sensor damped vibrations were constructed. The trend in amplitudes was modelled using the least squares method for the curve fitting. The coefficient of determination in the value of R^2 = 0.893 proved sufficient accuracy for the exponential dependency (1). The differential equation for the damped vibrations (2) was used to determine the damping ratio of the system in the value of 0.0056.

So the value of damping ratio of the system was determined for the phase when the pieces of paper hit the rod without causing the clogging.

4.0 CONCLUSION

Our research that is devoted especially to environmental use in developing the methods for the reverse logistics system shows the sensor using the resonance frequency for detecting overfilling with waste paper in a pressing apparatus. The overall process is used to optimize the processing of waste paper in the pressing apparatus to blocks (Figure 1), which are suitable for handling during the transportation for recycling. The developed sensor was tested and implemented as it is shown also in Figure 2. It was stated as suitable to detect the overfilling in a pressing apparatus. The sensor is suitable also for its resistance against the difficult environmental conditions such as high dustiness.

The analysis using the mathematical modelling and some statistical methods such as Least Squares was used to express the formula for the damped vibrations. Finally also the approximate value for the damping ratio of the system was determined as ζ = 0.0056.

The sensor is suitable not only for the detection the overfilling in a pressing apparatus for the waste paper. The sensor based on the resonance frequency can be used also in other places with flowing pieces in a tube or closed chamber. However there are still some problems in the processes of the reverse logistics system which are important questions for the researchers.

Acknowledgement

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