ORIGINAL RESEARCH PAPER

Information Technology

MATHEMATICAL MODELLING WITH OPTIMIZATION THE RESULTS OF THE CONTINUOUS MEASURING THE DISTANCE WITH INDUCTIVE SENSOR THAT IS MOUNTED IN ADHESIVE MACHINE

KEY WORDS: Analysis, Mathematical Modelling, Optimization, Proximity, Inductive Sensor

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ABSTRACT

The quality of the process to manufacture the corrugated paper is directly influenced with the accuracy of setting the distance and parallelism of the rolls for the precise adhesive application the glue to stick the pieces of paper. Inductive proximity sensor might be used to set up the distance. To keep the parallelism, the sensor is mounted on the both ends of the rollers at the extreme conditions with a high humidity where the operating temperature is about 80°C. Therefore precise experimental laboratory testing was conducting to test the equipment reliability. Analytical processing of evaluation the inductive method of accurately measuring the position of the stable ferritore in the oscillator coil with thermal stability confirmed the suitability of the designed device. The resolution 0.01mm is considered to be precise for the technology.

INTRODUCTION

Production of the corrugated paper requires, because of the technology, the precise gluing of individual paper components at a high temperature. The adhesive is applied by means of rollers, where it is necessary to set the distance up properly and keep it symmetrically to observe their distance.

To set the distance of the rollers for applying the adhesive, which is not functioning at high temperature, was fabricated such sensor that uses the electronic circuit module with the rotary encoder [1]. However, the optimum control of the rollers at operating temperature (near the sensor) around 140°C increased demands on the sensor construction. A wireless inductive-capacitive sensor to monitor the temperature of the rotating components [8] shows one of the possible solutions. J. Long and Wang [5] also proposed the method combining inductive-capacitive sensing for detecting and distinguishing metallic and non-metallic objects, measuring both of their inductive and capacitive responses, based on the fact that they respond differently to inductive and capacitive sensing.

There are a few next examples of construction the sensors for the specific purposes. For instance the Italian researchers Berrettoni, Trono and a group of coauthors [2] used an optical fiber sensing system for simultaneous measurement of temperature and refractive index solutions. American scientists [3] developed passive ceramic pressure sensor that uses a wireless telemetry scheme. Ron Mancini specifies individual criteria for oscillation [6]. Sensors based on metal nanoparticle-decorated carbon nanotubes were constructed when titanium adhesion layers and gold films were sputtered onto Si/SiO2 substrates for obtaining the electrical contacts [9].

Implementation of a re-configurable wireless sensor networks (WSNs) might play a key role in ensuring the safety of people working in the conditions of underground mine and tunnels [4]. An open-source radiofrequency, identification standard for WSN, named as DASH7, is used for practical implementation. Scientist Sara Pellegrini with the colleagues performs computer simulation of the obtained results of the laser-based distance measurement [7].

In our research we decided for the inductive proximity sensor. The results acquired at the experimental laboratory testing are analyzed using both the statistical as well as the mathematical methods to model the dependency based on the digital output from the oscillator.

METHODOLOGY

There are used two sensors constructed and these are located at either end of for adhesive application cylinder. Both ends of the cylinder can be independently set according to the measurement of gaps, so that symmetric application the adhesive for the same paper board for the whole width of the material. Symmetrical adhesive application for individual parts of paperboard is set as the accurate joint position of the rollers (parallelism) by measuring the gaps between rollers.

The evaluation section is thus on the left and right of the machine, in an area where the ambient temperature is considerably more acceptable and there can be seen the set values of roll gaps, on the green display.

Figure 1: device with inductive sensor mounted on the left part of the adjusting mechanics of the machine

Coil with a capacitor form a parallel resonant circuit oscillating at a frequency of 750kHz to 400kHz. Since moving the ferrite core into the coil, it changes the inductance of the coil and thus the resulting resonant frequency of the circuit (coil plus capacitor) is changed too. When the rollers are shifted towards each other, it also causes changes by inserting a ferrite core into the coil.

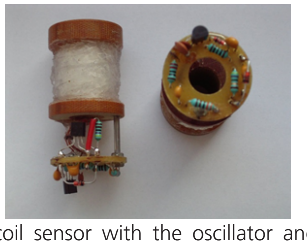

Figure 2: the coil sensor with the oscillator and temperature sensor

We drifted stabilized ferrite core to the coil on a global scale 16 mm (Figure 5: the graphical representation). It was measured in 0.1 mm (in steps of tenth of a millimeter).

Figure 3: ferrite core with an outer piston as well as the glasstextite rod and a compression spring

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It has been found by the measurement and then also programmed as a recalculation of values such that the display shows the resulting values directly with the accuracy (resolution) on a hundredth of a millimeter. So the processor measures the frequency and directly converts it to the value of the distance with the accuracy of the hundredth of a millimeter. The temperature of the device is also measured with a resolution more precise than 1°C, with an error of less than 0.5°C. The processor takes into consideration, when evaluating, also the temperature of the device and based on the result, a correction is made. Since the frequency is measured by a microprocessor, the value (frequency) was chosen below 1Mhz.

EXPERIMENTAL MEASUREMENT DEVICE DESCRIPTION

The oscillator (Frequency section) is stable but under changing temperatures, which in this case, in practice, can rise to about 60°C (in the limit case from 70°C to 80°C), there is a large change on properties of the oscillator components. Therefore, the integrated circuit DS18B20 measured temperature in the very part of the sensor and thus the microprocessor gets in digital form both signals, frequency and temperature. reclaimed.

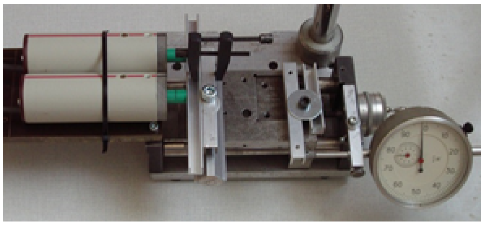

Figure 4: the device for experimental laboratory measurement with a display that shows the actual distance after the previous conversion of constants to the real evaluation with the microprocessor

So the microprocessor processes the signal from the oscillator and converts it into the value for the displacement of the stabilized ferrite core into the coil in millimeters. The microprocessor then corrects the temperature variations so as the resulting value of the shift is minimally dependent upon the effect of the temperature, or the resulting value is not dependent on the temperature at all.

ANALYSIS USING THE MODELLING METHODS

To start with the modelling methods to analyze the relationship of the correlation between the values on the digital output from oscillator and the values of the distance [mm] as the position of the ferrite core in the coil oscillator we used the Least Squares as the statistical method for linearization.

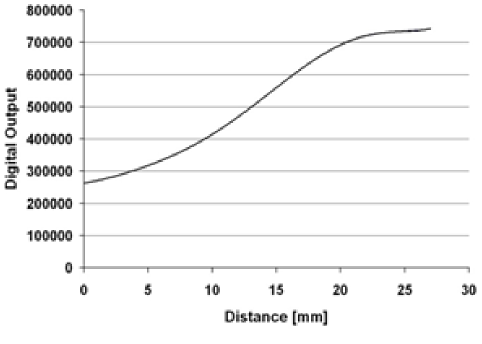

Figure 5: the Digital Output from oscillator (y axis) that shows also the input values which are evaluated by a microprocessor

Correlation was checked using the value of the Pearson's correlation coefficient according to the formula:

$$r_{xy} = \frac{\sum_{i=1}^{n} x_i y_i - n.\bar{x}.\bar{y}}{\sqrt{\left(\sum_{i=1}^{n} x_i^2 - n.\bar{x}^2\right)\left(\sum_{i=1}^{n} y_i^2 - n.\bar{y}^2\right)}} \qquad (1)$$

where

x_i … the values of distance of the distance [mm] as the position of the ferrite core in the coil oscillator,

y_i… the digital output from oscillator.
Hence the value of the Pearson's correlation coefficient is:
r_{xy} = 0.99

Using the formula (2) on the level for α= 0.05 the correlation was proved.

$$\frac{r_{xy}\sqrt{n-2}}{\sqrt{1-r_{xy}^2}} > t_{1-\frac{\alpha}{2}}(n-2) \qquad (2)$$

Using the Least Squares as statistical method we set the relationship as polynomial using the program system EXCEL.

$y = 0.0171x^6 - 1.153x^5 + 25.372x^4 - 225.71x^3 + 1629x^2 + 5858.6x + 263253$ (3)

Index of determination shows a very high value of accuracy for the performed curve fitting:

$R^2 = 1$

The relationship is expressed as a result of a curve fitting in the Figure 5.

The inflection point was determined, using the method of mathematic analysis, on the interval (10;20) through the differentiation:

$f''(x) = 0.513x^4 - 23.06x^3 + 304.464x^2 - 1354.26x + 3258$ (4)

$f''(x) = 0$ (5)

$0.513x^4 - 23.06x^3 + 304.464x^2 - 1354.26x + 3258 = 0$ (6)

There several numeric methods that are appropriate to find the proper value of x, especially, when we know the interval for x to satisfy the constraint (6). However we decided for the iterative method (Table 1).

Table – 1 The Values Set As A Part Of The Iterative Method

x	*f''(x)*
14.5	10.69
14.6	-71.23
14.51	2.54
14.52	-5.61
14.513	0.1
14.514	-0.72
14.5131	0.02
14.5132	-0.06

Using the iterative method we determined the coordinates for the inflection point where the shape for the graph of a function passes from the convex to concave. To determine y coordinate, formula (3) was used.

Hence the coordinates for the inflexion point:
[14.5131; 544459.46789104]

CONCLUSIONS

The device to measure the distance between the rollers using the inductive sensor was designed. The design of mechanical particles is based on the requirement for a minimum impact on the electronic properties of the high-frequency coils, good temperature resistance and stability. The design of the coils has been chosen to be the minimum ratio of changes the inductance between the individual coils according to the degree of insertion of

the ferrite core into the hole of the coil.
The measurement had to be done with the fine resolution in order to be accurate in the range 0-4mm. The deviations are in the range 0-3mm within ±0.01mm, the deviation for 4 mm is 0.04 mm, where also the non-linearity is greater. In practice, a range of 0-2 mm is used the most often and in this range the precision is 0.01mm, which is the sufficient value due to the 3-digit LED display.

The correlation of the values of distance of the distance [mm] as the position of the ferrite core in the coil oscillator and the digital output was proved. The dependency was determined as a trend line using the Least Squares as statistics method. The linearization was performed using the methods of statistics, mathematic analysis and numeric mathematics.

In our future research we will continue with the analysis of laboratory experimental testing the capacitive proximity sensor.

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