METHOD OF WIRELESS PASSIVE TEMPERATURE MEASUREMENT FOR DIAGNOSTIC PURPOSES

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Summary

This paper presents the method of wireless passive temperature measurement by using the battery-free sensing platform based on RFID technology. Described platform serves as an interface between any sensor and standard RFID reader connected to the host computer. Utilizing the RFID technology working in high frequency band results in the possibility of providing energy from the reader to the sensing platform via magnetic coupling between their antennas and wireless data transmission of the measured data, even in the proximity of metal objects. Investigation related to the wireless temperature measurements of bearing supporting a rotating shaft are presented in this paper. Comparison with the measurements performed by using of an infrared camera shows high compliance of data obtained by using those two methods. The result demonstrates that presented wireless temperature measurement method could be attractive in many diagnostic purposes.

Keywords: wireless, passive, temperature measurement, RFID

METODA BEZPRZEWODOWEGO PASYWNEGO POMIARU TEMPERATURY DLA ZASTOSOWAŃ DIAGNOSTYCZNYCH

Streszczenie

Artykuł opisuje metodę bezprzewodowego pasywnego pomiaru temperatury przy wykorzystaniu platformy sensorycznej opartej na technologii RFID, nie posiadającej własnego źródła zasilania. Opisywana platforma służy jako interfejs pomiędzy dowolnym czujnikiem, a typowym czytnikiem RFID przesyłającym dane do podłączonego komputera. Wykorzystanie technologii RFID pracującej w paśmie wysokich częstotliwości (HF) pozwala na dostarczanie energii z czytnika do platformy poprzez sprzężenie magnetyczne pomiędzy ich antenami oraz na bezprzewodową transmisję danych pomiarowych, nawet w przypadku obecności obiektów metalowych w pobliżu. Zaprezentowane zostały badania dotyczące bezprzewodowego pomiaru temperatury łożyska podtrzymującego obracający się wał. Porównanie wyników z pomiarami wykonanymi za pomocą kamery termowizyjnej pokazuje wysoką zgodność danych pozyskanych z wykorzystaniem tych dwóch metod. Wynik ten udowadnia, że zaprezentowana metoda bezprzewodowego pomiaru temperatury może być atrakcyjna dla różnych zastosowań diagnostyki maszyn.

Słowa kluczowe: bezprzewodowy, pasywny, pomiar temperatury, RFID

1. INTRODUCTION

Changes of temperature are one of the most common technical diagnostic symptom that could indicate a malfunction in the working machine. The temperature measurement is used in monitoring gear state [1], correct operation of rotating devices [2], often as an additional method used together with the vibration measurements [3]. Typically the process of temperature measurement could be performed by using simple and cheap equipment, although then it needs placing connection wires for the sensor powering and communication purposes. In the case of need for wireless measurements of temperature of machine elements, caused by many factors (moving elements, hard accessible places), there is still a lack of popular solution. The NDT methods based on the infrared camera are widely used [4], however they are still expensive and hard to integrate with typical control systems. Utilizing the ambient temperature for the powering purposes of sensor nodes is also possible, by the help of energy harvesting solutions [5], however, these methods need specific heat conditions and the sensor powering is not always guaranteed.

The need of wireless temperature sensing method that could be additionally completely passive and thus maintenance-free, results in the development of sensing systems based on Radio Frequency Identification (RFID) technology. This trend becomes popular together with the rapid evolution of the technology itself, from the start of XXI century. Typical RFID system can be defined as passive or active, depending on the used power delivery method and it comprises of the reader and many transponders that could posses sensing capabilities. Reader could receive small amount of data in the form of Unique Identification Number (UID) from transponders using an antenna, via electromagnetic waves. In the case of passive system, it also delivers the energy for the transponder activity. Usually RFID technology is used for the identification purposes, flow and access control in the logistic, industry and business application. There are many reports related to using RFID based sensors for measurements of different physical phenomenon. From the point of view of this paper, the most important are systems that allow wireless temperature measurement. They could be based on the measurement of differences in the backscattered signal caused by the small thermistor placed in the circuit of transponder antenna [6] or send the measured value directly to the reader using dedicated chip or circuit responsible for wireless communication with the reader [7,8]. Although all of the depicted systems give wide opportunities for different application, the use of Ultra High Frequency (UHF) band is connected with the communication problem in the proximity of the metal objects. For this reason, the development of system presented in this paper was based on High Frequency (HF) band, which is more reliable for the impact of metal elements.

2. DESCRIPTION OF THE SENSING PLATFORM

2.1. Idea of the sensing platform

The main intention behind the development of wireless, passive sensing platform based on HF RFID technology was the design of universal sensing interface that could send measured data from any low-power sensor connected to it, to the host computer without any physical connection. Moreover, the system should be passive, what allows for reduction of needed maintenance activity to minimum, in the ideal case only to the installation of sensor in the intended place.

On the basis of such requirements the main idea of the sensing platform was developed. It should be based on the common accessible RFID chip that could send some additional data beside typical UID number. The data management should be supervised by low-power microcontroller, with the buffering in the external memory. The sensor should be connected to the microcontroller directly or through the analog-digital converter (ADC) unit. Entire system should be powered remotely from the energy provided by the typical RFID reader via the magnetic coupling. Specifically designed energy harvesting part is thus necessary. Moreover the system requires development of data management software for handling the reader on the level of host computer connected. Depicted assumptions resulted in the development of few prototypes of the wireless sensing platform, however, in this paper only the last one will be presented, as it was utilized in the experimental studies.

2.2. Prototype description

The prototype design was based on two main devices. First is the M24LR64E RFID chip that allows communication with the standard reader according to the ISO15693 protocol rules. This IC features an additional ability related to integral energy harvesting module, enabling conversion of magnetic field energy provided by the reader and harvested by the connected planar coil antenna to the usable stabilized energy that could power another devices - in our case peripheral elements as microcontroller and sensor. Last significant feature of this chip is an internal 64 KBits EEPROM unit that allows to resign of additional memory buffers. The second part of the platform is the MSP430F2132 microcontroller supervising data management process, connected with the EEPROM via I2C interface. It is equipped in the internal ADC allowing for the directly connection of any sensor. Using these two main parts allowed for the significant simplification of entire design resulting in small dimension of prototype sensing system. The last significant part of the platform is utilized low-power temperature sensor LM94021 with the wide measurement range from -50^{o}C to the 150^{o}C. It is well fitted for the assumed application.

Performed sensing platform is characterized by different abilities. Thanks to the simple design, the dimensions of the platform itself are 20 x 40 mm, although one should also consider the dimensions of the platform planar coil antenna, most commonly in the form of rectangle with the side in the range of few tens of millimeters. Its dimension has a strong impact on the maximal read range of this system. In the case of described experiment, the square antenna with the side length of 60 mm was used, what resulted in the read range of 40 cm and the energy harvesting possibility on the distance of 10 cm. The platform could be connected and wirelessly power any sensor with the operational power of 15 mW, by the regulated low voltage on the level of 1,8 V. Another important feature of any sensing device is its data rate possibility and in the case of described sensing platform, the achieved value amounts 200 Hz, which is reasonable for the purposes of temperature measurement. Entire design of the platform prototype is presented on the Fig. 1.

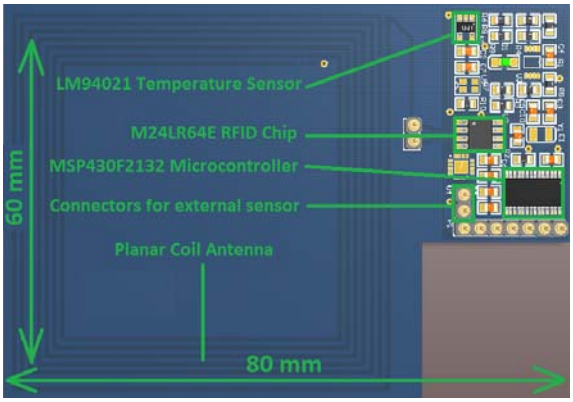

Fig. 1. Prototype board of the platform with main elements and external dimensions marked

3. PERFORMED INVESTIGATION

3.1. Test-stand description

The test-stand was prepared this way to allow the experimental verification of temperature measurement possibility in the conditions similar to these existing in the industry. The main issue was related to the proximity of the metal elements as shaft or bearing and its negative impact for the mutual coupling between the reader and the sensing platform antennas. Additional potential source of interference was the electric motor generating a strong alternating electromagnetic field. These factors could have negative impact for the communication possibilities of the wireless platform, but were not reduced by researches in any way, in order to achieve the hardest conditions that were possible to create in the laboratory.

The sensor was placed on one bearing housing, which temperature was measured during the experiment. For the purpose of faster heating of the bearing, the rotating shaft having a diameter of 25 mm was impacted by the force of 800 N, introduced on discussed support. The dimensions and view of the test-stand with the sensing platform mounted and the reader antenna visible, are presented on the Fig. 2.

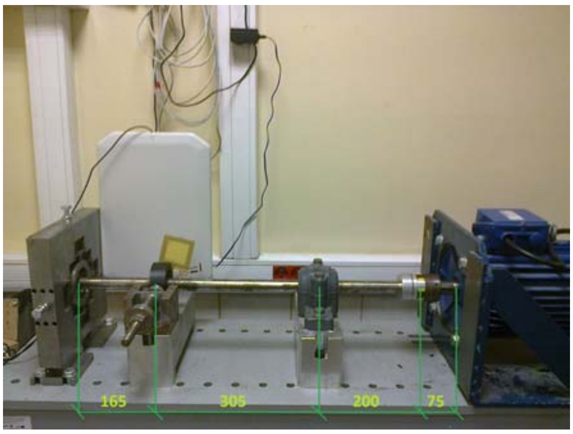

Fig. 2. Laboratory test-stand with the sensing system installed

The shaft was connected to an electric AC motor with the power of 3,0 kW, that was controlled by inverter. During the experiment the shaft was rotated with the speed of 1200 rpm. Measured data was collected on the host computer and compared with the data taken by the using of FLIR i7 infrared camera.

3.2. Experimental results

The temperature data was collected for 15 minutes of shaft rotation. Collected measurements show that wireless data transmission is possible even in hard environmental conditions. As it was shown on the Fig. 3. the temperature of the bearing housing was increasing linearly and the curve showing temperature growth is comparable with the data collected by the using of the infrared camera. On the Fig. 4. four camera images are presented. They were taken at regular time intervals of 180 s, from the start of the experiment.. The data was collected with the sampling frequency of 12 Hz, which in the connection with high sensitivity of sensor on the level of 0,25^{o}C, makes the graph noisy. For the purpose of data filtering, moving average method with the period of last 20 samples was used and this trend line was presented on the graph.

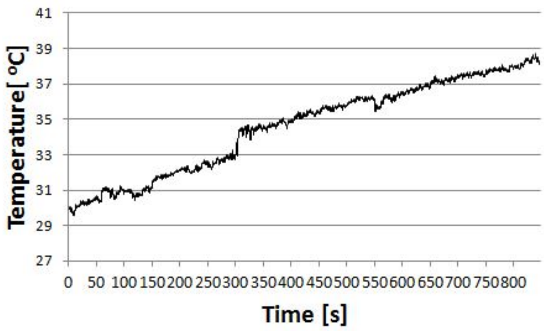

Fig. 3. Temperature data collected by the using of wireless sensing platform

4. CONCLUSION AND FUTURE WORKS

Performed investigation shows that in particular applications connected with the necessity of temperature monitoring, using wireless passive sensing method described in this paper is reasonable. It allows for wireless temperature measurement, even in the proximity of metal objects and could be used by maintenance services for the data collection from different measuring nodes by the using of handheld RFID readers. This method is simultaneously cheaper and easier to connect with existing monitoring systems than evaluation methods based on infrared cameras. Future works related to the further development of the presented wireless sensing system cover execution of testing in industrial environment, transfer of the existing reader system for the remote version, what needs development of embedded software version of the program and trial of connection of the entire measurement system with the existing monitoring environments in particular plant (SCADA systems, PLC based control systems).

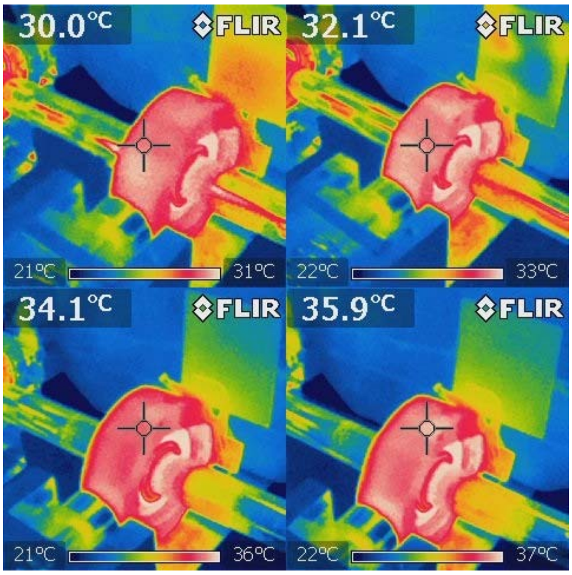

Fig. 4. Temperature data collected by the using of FLIR i7 infrared camera

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