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Correction of changing emissivity of induction heated rotating steel cylinder

***Abstract**. In the paper the method of elimination the temperature variations caused by locally changing emissivity of the cylinder surface. This method uses the classical optimization algorithm supported by approximation by artificial neural network. The method was verified for temperature measurements for infra-red camera.*

***Streszczenie.** W artykule przedstawiono metodę eliminacji wahań temperatury powodowanych miejscowymi skokowymi zmianami emisyjności powierzchni obracającego się walca stalowego. Metoda ta wykorzystuje klasyczną metodę optymalizacyjną wspomaganą przez aproksymację wykonywaną przez sztuczną sieć neuronową. Metoda została sprawdzona przy pomiarach temperatury wykonywanych kamerą termowizyjną. **(Korekcja zmiennej emisyjności powierzchni nagrzewanego indukcyjnie wirującego walca dla potrzeb pomiarów kamerą termowizyjną)**.*

Słowa kluczowe: Bezstykowy pomiar temperatury, zmieniająca się miejscowo emisyjność.
Keywords: Non-contact temperature measurement, locally changing emissivity.

Introduction

Measuring the surface temperature of the rotating steel cylinder is usually accomplished by contactless methods. The researches carried out in the Institute of Applied Computer Science deal with the system of temperature control of the rotating steel cylinder equipped with moving along cylinder axis inductors (fig. 1).

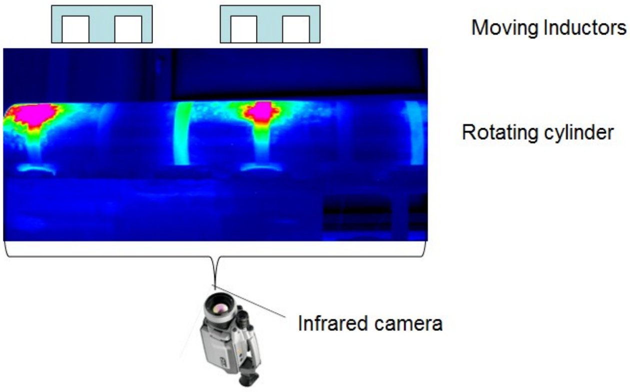

Fig. 1. The laboratory test stand of the induction heated by moving inductors rotating steel cylinder.

The purpose of the investigated system is to provide a uniform or other required by the process, temperature distribution along cylinder axis. Precise temperature control based on the changing the heating power supplied to the cylinder surface and the position of the inductor required multidrop accurate temperature measurements. For that purpose two closed loop control systems are used – feedbacks of: supplied power - temperature and position of inductors [1,2]. Temperature measurement is accomplished by FLIR A615 infrared camera, with 640x480 density. Such a camera can work in mode of data frame (640x480 points) or in form of vector 1x640 of temperature points along cylinder axis.

The level of temperature along cylinder axis recorded by infrared camera depends not only on the active power induced on the cylinder surface but on its percent of sheen, too. Due to the fact, that emissivity of calenders surface is usually less than 0.3, the IR camera indicates lower from the actual temperature level. Moreover, in many cases the surface could be smudged by, for instance, calendared paper web. This causes the effect of local increase in emissivity and thus local temperature fluctuations recorded by IR camera.

In the paper the method of elimination the temperature variations caused by locally changing emissivity of the cylinder surface is proposed. This method uses the classical optimization algorithm supported by approximation by artificial neural network.

Non-contact temperature measurements of the industrial rotating cylinders

In case of induction heating rotating steel cylinder one of the major problem during the contactless measurements method is to compensate the temperature offset caused by the low emissivity of the surface. This can be done experimentally by compare the temperature of high-glossy cylinder surface with temperature of the painted in black part of its surface. However, when the cylinder will locally dirt (for example from adhering to the surface calendared paper web) and the emissivity will suddenly increases several times, the classic signal filters should be supplemented by numerical emissivity correction. Figure 2 shows the example of temperature variations along cylinder surface recorded by IR camera for thermal quasi-steady state.

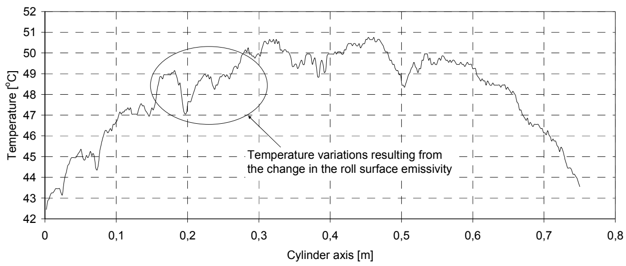

Fig.2. Temperature distribution along cylinder axis in thermal quasi steady-state

The purpose of the proposed correction method is to eliminate the temperature noise coming from the changes of emissivity while maintaining nature of temperature distribution. There are two leading examples for testing the correction method: heating the rotating calender by moving inductor supplying by constant and linearly changing active power along its axis.

Algorithm of eliminating the effects of variable emissivity distribution of the temperature fluctuations measured by the infrared camera

Shown in figure 3 flowchart of proposed method is composed of 5 blocks.

The block number 1 describes the process of measuring and transmitting a vector of signal to the next block (2) which converts temperature from degree of C to most likely temperature in Kelvins by formula 1 [3].

$$T_{R,i} = \frac{\vartheta_{p,i}}{\varepsilon^{0,25}} \Rightarrow T_{R,i} = \left[T_{R,1} \ . \ . \ . T_{R,N}\right] \quad (1)$$

where: $T_{R,i}$ – real temperature of i-th sample, $\vartheta_{p,i}$ – measured temperature of i-th sample, ε - initial mean value of cylinder surface.

Initially, the value of ε can be estimated at most likely value, (e.g. 0.3), which corresponds to average value of calenders surface emissivity.

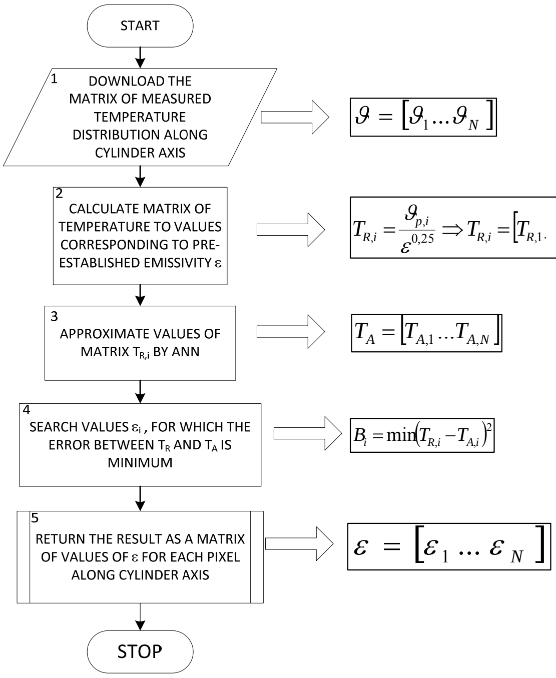

Fig. 3. The flowchart of the method for temperature correction variations.

In the block number 3 the approximation of calculated temperature distribution is done. Taking into account, that depending on technological needs the desired temperature distribution on the cylinder surface can have different form, it is important to develop an efficient method of approximation. The time of approximation determines quickness of discussed correct method. In the paper two methods of approximation have been discussed: the polynomial approximation and signal generalization by artificial neural network (ANN) algorithm. First method is effective only for relatively simple forms of temperature distribution and smooth changes of surface emissivity. In case of sharp changes of emissivity or sophisticated temperature distribution along cylinder axis the signal generalization by ANN is faster and more convenient. Figures 4 shows comparison between approximation by 5th degree polynomial and signal generalization by ANN.

Performed calculations show a slight advantage approximation using ANN, because generalization curve better maps active power distribution along cylinder axis.

In order to well-generalize signal the network with 1 input, 3, 6, 9, 10 neurons in hidden layer and 1 output was examined. The overview illustration of ANN is shown in figure 5.

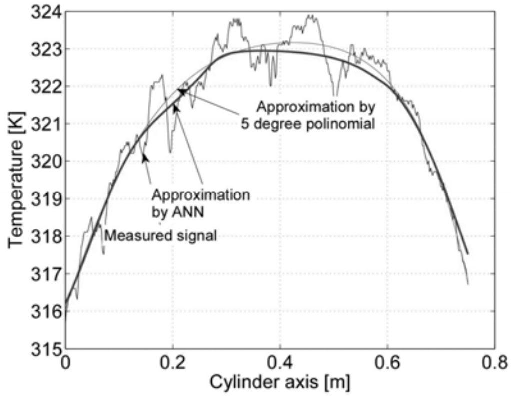

Fig. 4. Results of approximation of measured temperature distribution

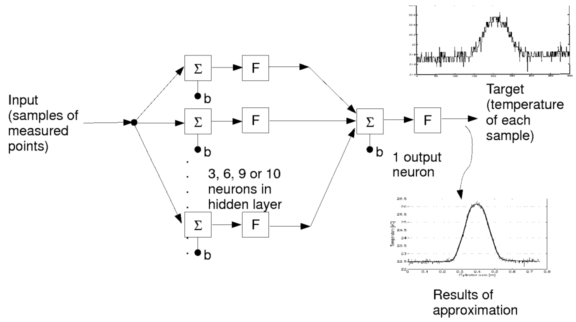

Fig. 5. The diagram of ANN with backpropagation learning algorithm.

For this purpose the fast function of SNN with 9 neurons in hidden layer and learned by backpropagation algorithm was developed and used.

The next block of the diagram contained the optimization method which searches the local surface emissivity for which value between temperature approximation curve and measured points is minimal.

$$B_i = \min\left(T_{R,i} - T_{A,i}\right)^2 \quad (2)$$

where: Bi – vector of emissivity, $T_{R,i}$ – value of real temperature in measured point, $T_{A,i}$ – value of approximated temperature.

Thus the vector of emissivity values for each measured points is determined. As a optimization algorithm the golden section search and parabolic interpolation algorithm was used [5].

As a results of optimization the vector of local emissivity values in measured each point is returned.

Results

Discussed method of emissivity correction has been tested semi-industry laboratory model of induction heated rotating steel cylinder. Two examples of temperature distribution were forced: the natural temperature distribution coming from heating the cylinder by one moving inductor powered by constant input power and constrained linear temperature distribution along cylinder axis. Results are shown in figure 6 and 7.

In both examples the ANN approximation were used for instantaneous temperature distribution along cylinder axis. Using this method it is possible to determine changes the emissivity and make a temperature variation corrections for each of measuring time step. This can be done because time of temperature correction is less than sampling time(0.1 second). Figure 8 shows a sample map of emissivity variations along cylinder axis during the heating up process from ϑ=24°C to ϑ=55°C.

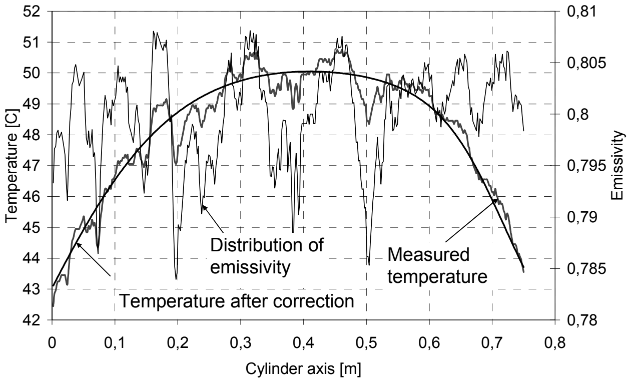

Fig. 6. Results of correction local emissivity changes in natural temperature distribution along cylinder axis.

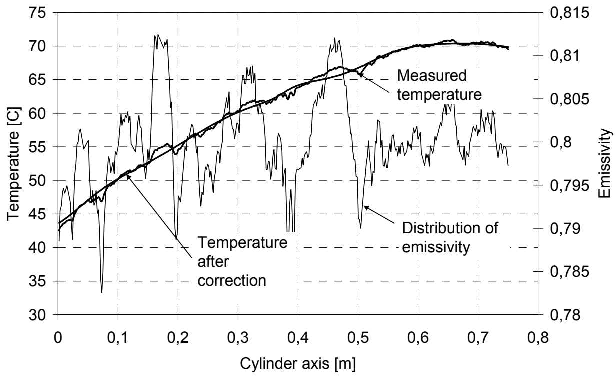

Fig. 7. Results of temperature correction for linear temperature distribution along cylinder axis.

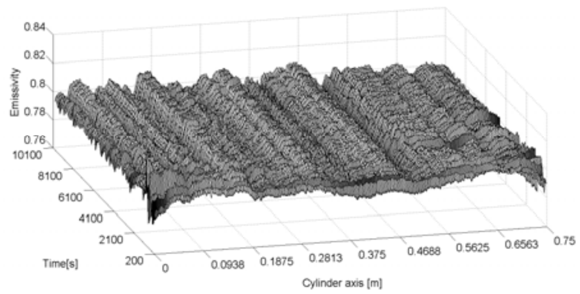

Fig.8. Variability in time map of emissivity variations along cylinder axis.

Assuming constancy of dirt the cylinder surface above figure confirms the phenomenon of changes the level of emissivity with temperature. Relatively high calculated emissivity is due to state of the cylinder surface, which because of other laboratory test was painted in black.

Conclusions

The paper drew attention to the issue of temperature disturbance coming from surface emissivity changes during non-contact temperature measurement by infrared camera. Feature of such disturbances is their random occurrence (in industry conditions) and the dependence of the temperature level of the object. Hence arose a need for method to eliminate this type of interference without changing the proper temperature distribution. Presented method use the Artificial Neural Network and the golden section search for temperature approximation. Both algorithms need to solve the optimization problem is not more than 0.05 seconds.

Acknowledgments.

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