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Andrzej Frączyk*, Jacek Kucharski*, Tomasz Jaworski*, Piotr Urbanek*

Rotation Speed Control within Computer-Based Measurement and Control System

1. Introduction

Among many fields of application of induction heating an important part concerns heating of moving charges. One of the examples is induction heating of rotating steel cylinder used in many branches of industry e.g. in paper making, textile or gum industry. In order to obtain as uniform temperature distribution as possible along the cylinder axis, several heating inductors have to be applied. It forms a set of heating zones, which allow considering this plant as multi-input multi output structure. As rotation speed of the cylinder is one of the important parameter of paper making machine and also influences its static and dynamic properties it becomes another quantity which has to be precisely measured and controlled. In Computer Engineering Department TUL the semi-industrial set up of induction heated rotating steel cylinder has been developed [1]. Several system identification methods [2] and temperature control algorithms [3] along with signal processing methods [4] have been evolved within computer-based data acquisition and processing system being an important part of the set up. In this paper another control loop dedicated to speed monitor and control and implemented in this system has been described.

2. Semi-industrial experimental setup

Induction heated steel cylinder is a central part of the experimental set up whose general block diagram is given in Figure 1. Analyzed technological process performed using heated cylinder is monitored and controlled by a computer-based system in which three main functional channels can be distinguished as follows:

- cylinder surface temperature measurement and control channel, which is the main loop of the entire system, governing to some extend other subsystems,
- stabilized power generation channel,
- cylinder rotation speed measurement and control channel.

* Computer Engineering Department, Technical University of Lodz, Poland

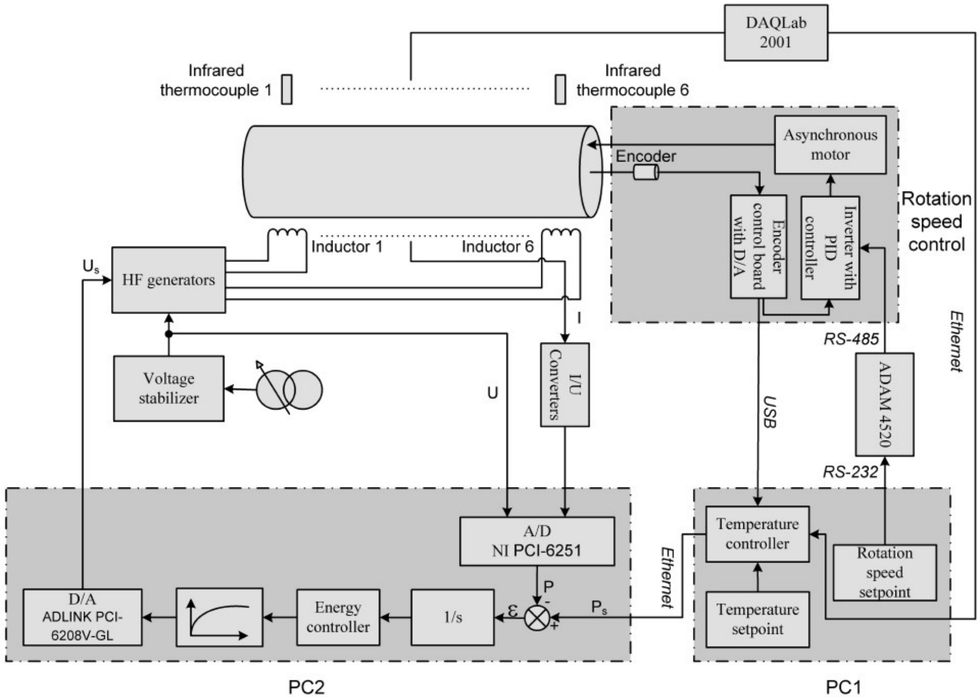

Fig. 1. Block diagram of the computer-based data acquisition and processing system for induction heated rotating steel cylinder

Information on the temperature of cylinder surface is gathered by a set of non-contact temperature sensors Omega OS36 whose voltage output signals correspond to that of K-type thermocouple. These signals are provided for the computer-based data acquisition system via IOTech DaqLab 2001 measurement device connected with the main system server PC1 by Ethernet interface. Using this information as well as information about actual rotation speed of the cylinder obtained from the rotation speed control subsystem the temperature controller produces a proper excitation for the power generation block.

Required value of the heating power becomes a set point for another control loop – power generation loop governed by the PC2 computer. After comparing with actual value of the power resulting from supply voltage and current measured by A/D NI PCI-6251 data acquisition board the high frequency generators are fed with proper value of DC voltage. However, because of nonlinearity of the generators some pre-processing is required before DC voltage value calculated by PID control algorithm can be sent to them by D/A Adlink PCI-6208V-GL board. Moreover, AC voltage stabilizer ENICA ENI-ZL250/40 is necessary to ensure proper supply in varying load conditions.

The last part of the system, being of main interest of this paper, concerns rotation speed of the cylinder. This is one of the crucial parameter both from technological point of view and from the operation of the rest of the system. Rotation speed is measured by the encoder

MOK40-5000-5-BZ-N supplemented by a dedicated microprocessor-based controller. The controller produces two forms of the measured signal: digital information of the actual rotation speed transmitted via USB interface to the temperature control subsystem as pointed above and an analog 0–10V_{DC} signal sent to Hitachi SJ200 inverter governing asynchronous induction motor which drives the cylinder. Another PID controller implemented within Hitachi device was applied in this loop in order to ensure stabilization of rotation speed under various load conditions of the cylinder. Set point value of this loop comes from the main temperature control subsystem transmitted via RS 232/485 interface. The PID controller produces the proper values of supply voltage and frequency which is given to the induction motor. Properties of this part of the system are discussed in more detail in the latter part of the paper.

3. Rotation speed control system

In Hitachi SJ200 inverter the frequency value is used typically as an input signal allowing a user to set required motor speed. However form the point of view of analyzed system it would be more convenient to be able to express this required value directly as a rotation speed value. Thus a relation between the frequency at an input of the Hitachi controller and a resulting rotation speed of the cylinder should be determined in the form of a static open loop characteristic of the device comprising the inverter, the motor and the cylinder. It has been done experimentally and obtained results are given in Figure 2.

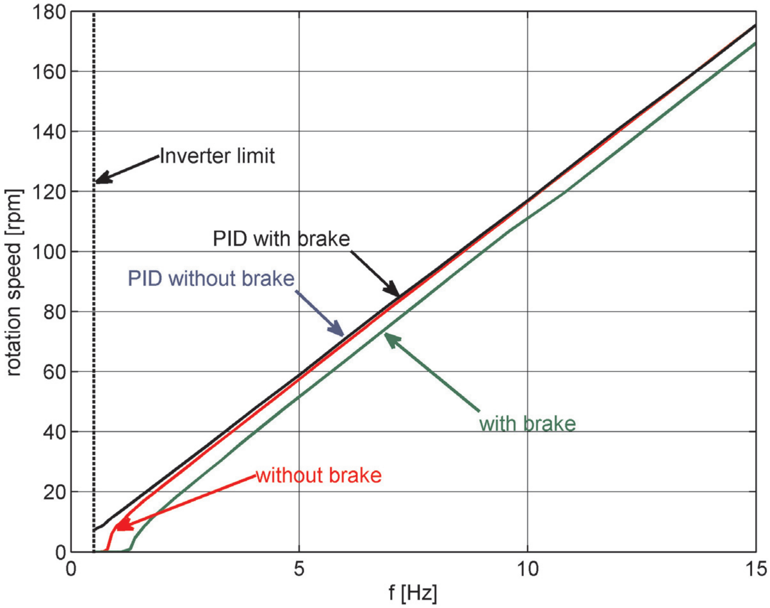

Fig. 2. Rotation speed of the cylinder as a function of the frequency being an input signal of the Hitachi SJ200 inverter

Since in typical operating conditions the load of the rotating cylinder can vary in a quite broad range the characteristics were measured for two extreme cases: in one case the cylinder rotates unloaded and in the other a load is realized by a mechanical brake. These experiments were performed using two structures of the system. First, a typical solution was implemented when the induction motor was supplied in open loop while in the second option closed loop PID control was applied. In an open loop structure it can be noticed from figure 2, that in both load cases the characteristics reveal some nonlinearities especially for low rotation speed values. Moreover, braking the cylinder causes an additional static error in the whole operating range. On the other hand an activation of PID controller fed by analog signal coming from the encoder makes the system insensitive to a load as well as ensures its linear characteristic (in Figure 2 characteristics in loaded and unloaded case with PID controller active are almost indistinguishable).

Such a linearized static characteristic of the closed loop system can be used to determine an inverse function which maps rotation speed, n, to frequency, f, of voltage supplying induction motor in the form:

$$f = 11.71 \cdot n \tag{1}$$

The efficiency of the proposed solution can be checked by a comparison of the reference (required) value of speed n_r with the actual speed of the cylinder n obtained in various operating conditions and measured by the encored. Thus the relevant error E has been defined as:

$$E = \sqrt{\left(\frac{n_r(f) - n(f)}{n_r(f)}\right)^2} \cdot 100\% \tag{2}$$

and results are given in Figure 3.

It can be noticed that the closed loop PID speed control along with the function (1) assure a static error of the system not exciding 10% regardless the operating conditions. Advantages of the proposed control system are especially visible for the case of cylinder braking where differences between required and actual rotation speed without control system are unacceptable.

However, the PID algorithm in the closed loop influences the entire system dynamics. As portrayed in Figure 4 step response of the system reveals some oscillations but they are attenuated quickly as well as an observed overshoot is not to high.

An important advantage of the proposed solution can be clearly observed when permanent load is applied to the rotating cylinder. Such a case is illustrated in Figure 5. After a step change of load appears the system without PID controller is not able to compensate the disturbance and consequently rotation speed of the cylinder significantly reduces. Using the proposed closed loop structure enables to avoid such an error – after a small descent the rotation speed comes back to the set point value.

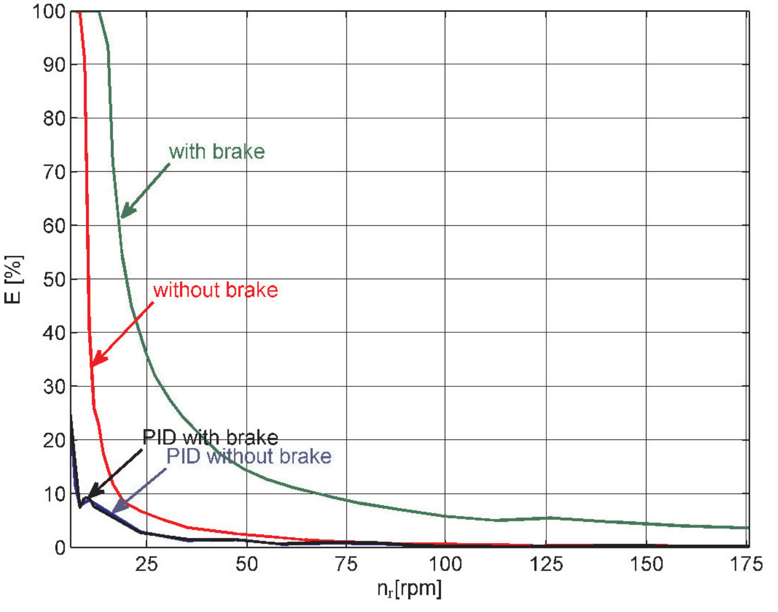

Fig. 3. Rotation speed error *E* as a function of the required speed value for different operating conditions

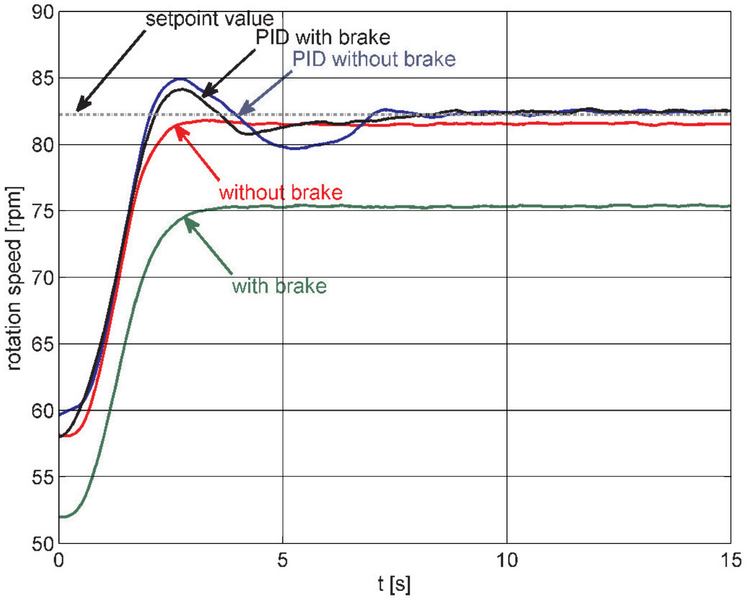

Fig. 4. Step input response of the closed loop speed control system

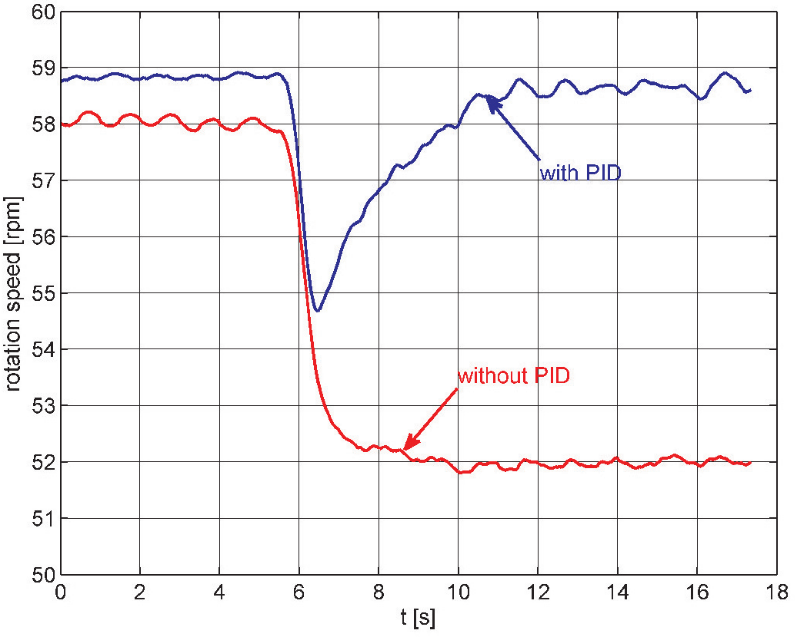

Fig. 5. An attenuation of load disturbance in open and closed control loop

4. Conclusions

Computer-based data acquisition and processing system dedicated to monitor and control of the induction heated rotating steel cylinder has been supplemented by an additional functionality. Another closed loop has been implemented both in hardware and software layers for control of rotation speed of the cylinder. The actual rotation speed of the cylinder is measured by the encoder while the inverter supplying the induction asynchronous motor serves as an actuator. The communication between the two as well as characteristic linearization is realized by the PC playing the role of a supervisory element of the entire system. In such a loop PID controller built-in the inverter was activated and properly tuned. Performed tests and experimental results proved that proposed solution assures high accuracy of rotation speed of the cylinder in various operating conditions.

Acknowledgements

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