PEDAGOGICAL MODELS STEPPING HEATING FURNACE USAGE IN LESSONS MANAGEMENT METALLURGICAL AGGREGATES

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Abstract

The requirements of technical practice for the quality of university graduates continue to grow. The quality of teaching and the related working possibilities of students after graduation largely depend on the degree in which the curriculum corresponds with techniques currently used in practice. Besides excursions to specialized firms, a significant factor is the opportunity to learn about the studied techniques and technologies through various models. In this respect, an irreplaceable role belongs to physical models which students prefer due to their clarity and authenticity. In a laboratory environment, the exact physical realization of pedagogical models of most metallurgical technologies is not fully possible. Material heating, a very common technology utilized in metallurgy, can be successfully implemented in laboratories under certain restrictions. For this purpose, we built an electrical analogue of multi-zone walking beam heating furnace which allows students to easily implement certain measurements that are rarely feasible in real practice. This provides the necessary data for identification, modelling and simulation of processes which take place in the furnace. Students thus can design and implement both continuous and pulse controls and optimize the operation of the entire aggregate.

Keywords: Pedagogical Model, Simulation, Lectures model.

1. INTRODUCTION

When studying subjects and topics associated with automated systems for controlling metallurgical aggregates and technologies, a vital role can be assigned to the clearness of teaching that increases with using models of actual metallurgical aggregates and their service devices. Studied fields in the area of metallurgy have their own specific particularities. The studied technologies are tied with metallurgical aggregates which are characterized by extremely large sizes and extensive technological units that usually handle products with high temperatures while consuming an extremely large amount of energy. They include complex chemical and physical processes that are accompanied by intensive mechanical operations. Advancements in computer technology also enable rapid development of computer simulation models; real physical models, however, appear to be clearer in more aspects. Our experience shows that students remember the experiments on physically existing devices better than the results of simulations [1]. For this reason, within the project [2], we created the model of walking beam heating furnace in our laboratories. Model options, however, are always limited by the space, available energies as well as strict safety requirements during the lessons. The same applies in the implementation of the model of multi-zone walking beam heating furnace. In this case, gas heating is replaced with electric heating by halogen bulbs, temperatures vary at much lower levels than on any actual object, and dimensions of the furnace model and the heated material are much smaller than in reality. Nevertheless, the model provides students with the best conditions for practical training with reference to the control options for heating furnaces while achieving sufficient accuracy and clearness. The model allows students to easily implement common tasks of furnace control as well as certain measurements that are only exceptionally possible in real practice.

2. THE DESIGN OF THE MODEL OF WALKING BEAM HEATING FURNACE

The furnace is designed simply but in a manner that closely mimics the operation of actual multi-zone walking beam heating furnaces. Dimensions of the working space are similar to a real furnace; the furnace height, width and length is 9 mm, 8 mm and 5 mm, respectively. The furnace consists of a steel structure with a shell filled with fireproof ceramic and glass wool so as to ensure similarity with the reality as regards heat accumulation and heat dissipation through the furnace wall. The heated material is represented by steel rods, 8 mm in length, with a circular diameter from 5 mm to 6 mm. The material may also be of another profile. Movement of the heated material through the furnace is ensured by a chain conveyer; the material is placed on the conveyer from a magazine by a carousel feeding machine at the appropriate moment. At the exit from the furnace, the heated material is moved by a discharge handling mechanism from the chain conveyer into a collecting space behind the furnace from where it can be transported for further processing. The furnace design including service units is evident from **Fig. 1**. For safety and technical reasons, the model is not provided with conventional gas burners; heating of the furnace and inserted material takes place in three heated zones using three sets of electrically operated halogen radiators (heaters) which are located in the ceiling of the furnace.

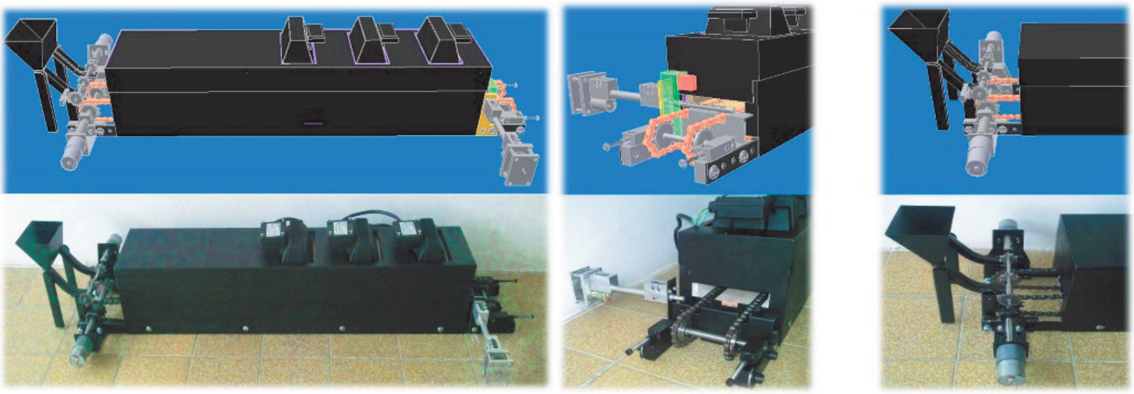


Fig. 1 Design of the heating furnace

3. THE CONTROL OF THE HEATING FURNACE MODEL

The heating furnace model includes several control systems so as to ensure a smooth transfer of the heated material from the input magazine to the collecting space when reaching the specified heating parameters. A schematic diagram of the comprehensive control system linked to the furnace model is shown in **Fig. 2**.

3.1. The control of the feeding mechanism, movement through the furnace and discharge handling mechanism

Drives of the transport systems are realized through DC motors. Automatic control of the feeding mechanism operates on the principles of sequential logic circuits. The drive is triggered by a pulse from a master control system and the transport of one piece of material intended for heating is terminated by another pulse which is generated by a position sensor reading the feeding mechanism rotation to its end position. The required material transport through the furnace is controlled by the length of the pulse switching on the chain conveyer drive, generated by the master control system. The control system of the discharge handling mechanism switches on the actuator upon indicating the existence of the heated material at the furnace outlet area. The heated material is then continuously moved into the collecting space behind the furnace. In this position, indicated by a sensor, the drive is stopped. Subsequently, the discharge handling mechanism starts moving reversely and its motion is terminated upon reaching the starting position which is also indicated by a position sensor.

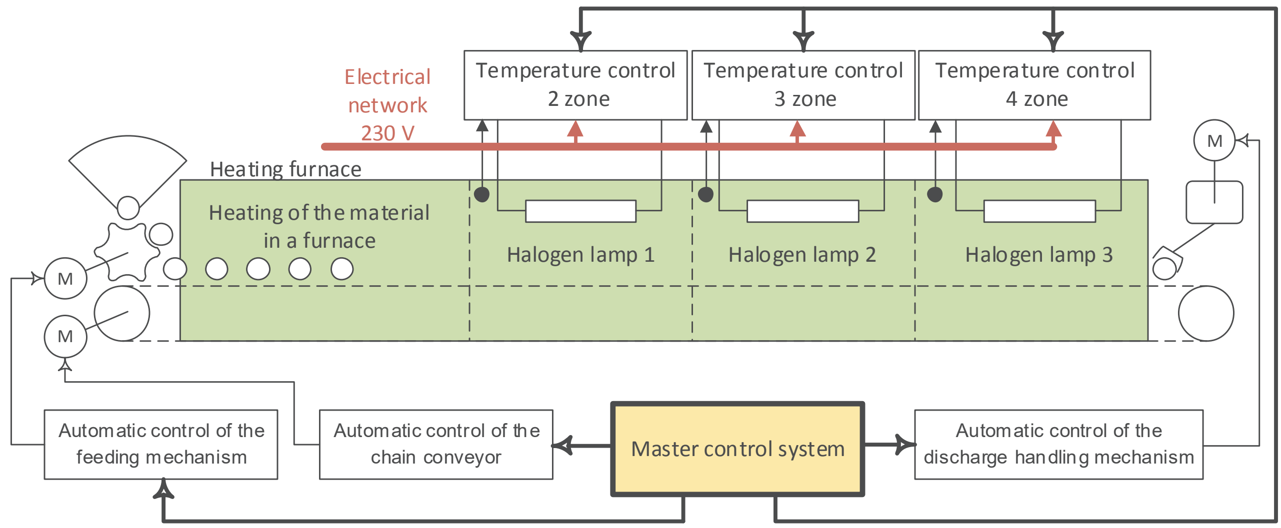


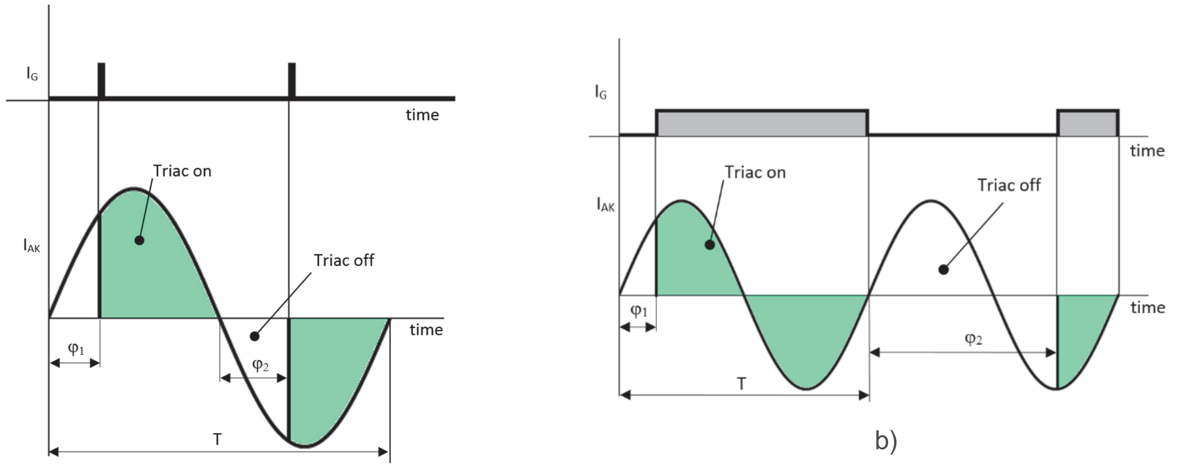
Fig. 2 Schematic diagram of the control system for the heating furnace model

3.2. Temperature control in individual heated zones of the furnace

In practice, there are two basic ways of how burners operate - continuous operation and pulse operation. Students should have the opportunity to familiarize with both types; for this reason, the control of halogen radiators, powered by alternating current, had to be solved as a phase control (analogy to the continuous operation of burners) or a control with pulse width modulation (analogy to the pulse operation of burners). Both of these control methods are implemented using a single-chip microcomputer; on principle, in terms of frequency, they require that the electrical appliance behaves as a low-pass filter which is fully met by halogen radiators. The total amount of energy consumed during heating in the furnace in the time interval from t0 to t1 is approximately given by the following relationship (where k is the summary coefficient):

$$E = k\int_{t_0}^{t_1}\left[I_0 \sin\left(\frac{2\pi}{T}\cdot t\right)\right]^2 dt \qquad (1)$$

The phase control of heat sources in the furnace



b)

a)

Fig. 3 The time course of the triac switching mechanism

The principle of phase control consists in the fact that the course of electrical energy delivered to the heat source is sinusoidal just partly. The actuator is realized using an electronic component, bidirectional triode thyristor / triac, that conducts electrical current from the time of switching until the sine wave supply voltage zero (zero current opens the triac) as shown in **Fig. 3a**. Triac closing is done by a control pulse to the control grid G. Due to the actual speed of recalculations in the microcomputer and the required accuracy of controlling the halogen heaters, we designed the phase control method as shown in **Fig. 3b**. This enables us to double the sensitivity when setting the heat source power. The time dependency of energy imparted into surroundings of the heater is strongly nonlinear and can be approximately obtained by solving equation (1) for the times t_1 and t_2 = 0 € (0; T). Regarding linearization, the best approach was to divide the energy interval E into "n" equidistant sections with subsequent reading of the corresponding time values. These values are stored in an array variable in the single-chip microcomputer and are thus quickly available to the control algorithm.

The control algorithm of the phase control of heat radiators receives the required value of instantaneous heater power from the higher-level system and determines the switching time and length of the power component with the triac. The switching instant must be synchronized with the time course of the network voltage supplied to power the heat radiator. This is ensured by a hardware interruption responding to the rising edge of the shaper output pulse. A successful phase control requires that the microcomputer of the furnace model detects network frequency and the actual phase shift in the measurement chain (mainly caused by using a transformer) before starting the heating process, based on the evaluation of synchronization pulses and measurements of an auxiliary sensor (its irradiation intensity depends on the instantaneous heater power). This operation may take place automatically. Circuit diagram for the phase control of thermal circuits of the heaters is shown in **Fig. 4**.

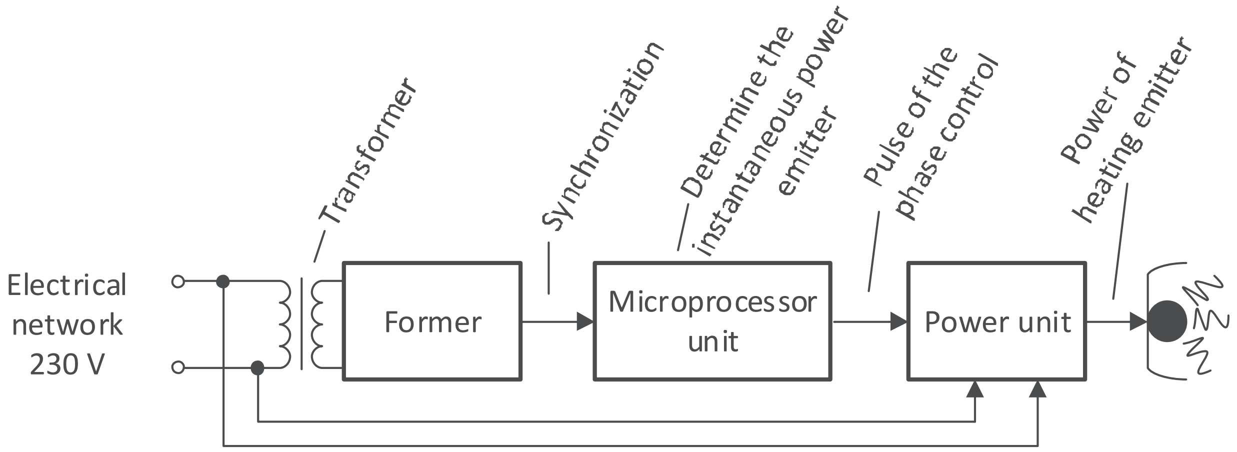
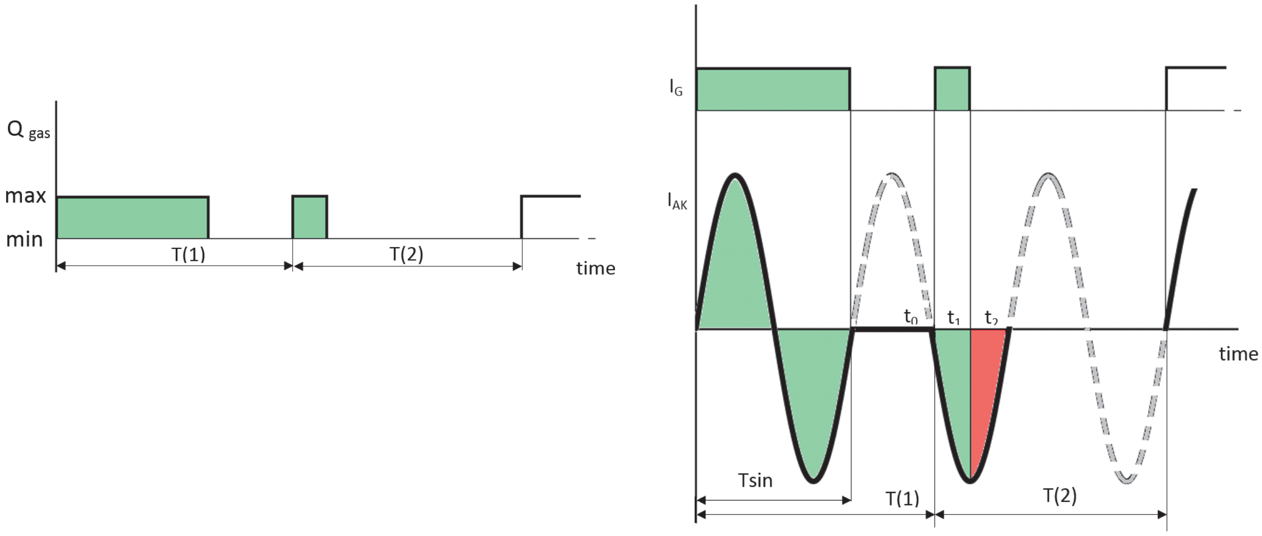


Fig. 4 Circuit diagram for the phase control of thermal circuits of the heaters

The pulse control of heat sources in the furnace

Since the metallurgical practice widely uses pulse burners, it was necessary to create this type of furnace heating also in our educational model. Gas burners utilize two levels of gas flow (minimum and maximum) which are always constant (see **Fig. 5a**). When heating by electric heaters powered by mains voltage, the situation is more complicated because the physical principle of the triac operation means that the power supply for the electric heater would be switched on at time t_0 in the period T(2) but the desired switch-off at time t_1 would be shifted to time t_2. In the illustrated case (see **Fig. 5b**) where the repetition period T is 1.5 times larger than the period of mains voltage T_{sin}, only four levels of radiated power (0 - 1/3 max - 2/3 max - max) could be distinguished.



a) b)

Fig. 5 The pulse control of heat sources in the real furnace a) and in the pedagogical model b)

Selection of period T is therefore subject to the frequency of voltage harmonic course in the electrical network and the required sensitivity of setting changes in radiated power. For example, in order to control the radiation power with minimum accuracy of 0.5 %, the period T must be chosen according to the following equation:

$$T \geq 50\ T_{sin} \qquad (2)$$

The period T upper boundary is limited by dynamic properties of the controlled system. This boundary is chosen so that the repeated changes in the working state of heaters (switching on, switching off) during the pulse control cause just negligible responses at the output of the controlled system.

3.3. Comparison of heating in the phase and pulse control

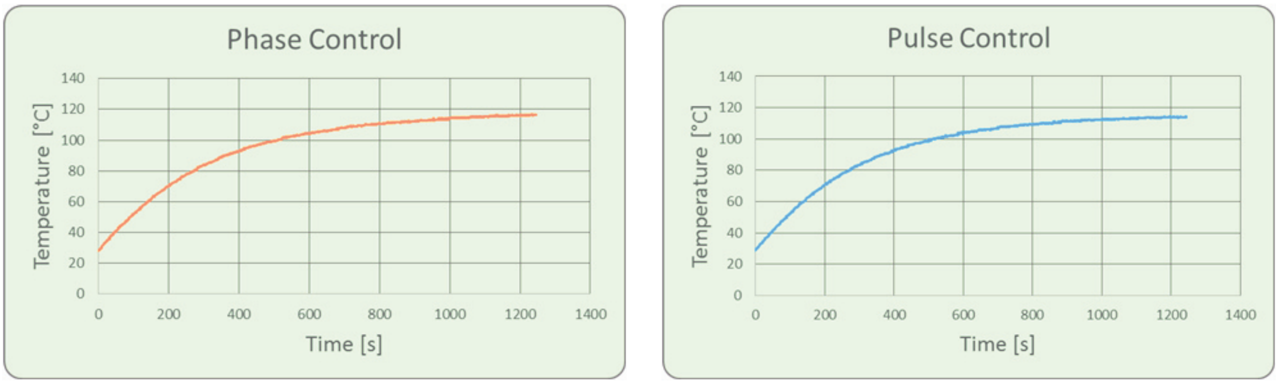


Fig. 6 Measurable waviness when the phase control and when the pulse control

The description of these approaches clearly shows that they represent two different types of heating. In both cases, however, the heating curve of the heated material should be very similar when respecting the given conditions. For this reason, the furnace model was subject to measurements under the phase control and pulse control while all other heating conditions were the same. This could be simply achieved as follows: the furnace was thermally stabilized in all of its zones and the heated material, equipped with a temperature sensor representing the temperatures measured by a resistance thermometer, was transported to one of them at a constant speed. The results are presented in **Fig. 6a** and **Fig. 6b**. It is evident that both heating processes are very similar and that the heating curves do not show any measurable waviness when the pulse heating control is used. From the pedagogical point of view, the model is therefore suitable and well characterizes a real object even at negligible dimensions in comparison with reality.

4. CONCLUSION

Constant demands of the students for a deeper connection between the theoretical teaching and practice in the metallurgical industry led to an effort to create a physical model of actual heating furnace in school laboratories, allowing a trustworthy implementation of the theoretical projects of controlling real metallurgical aggregates. This model allows us not only to control the material heating in the furnace but also to control the service units. It was verified that the model realistically simulates the use of both continuous and pulse electric burners through the electric analogy. In addition, the device is made so that its operation is safe while maintaining the greatest possible compliance with the actual object. The versatility of the device should also be seen in the fact that it can be easily implemented at the lowest level using a microcomputer and that this microcomputer can also be just a mediator between the model and the control system represented, for example, by a powerful PLC. Similar problems are resolved also in literature [3], [4], [5].

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