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Mathematical modelling and parameter identification of a stainless steel annealing furnace

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ABSTRACT

A new, comprehensive mathematical model of continuous annealing furnaces is developed, under consideration of both the radiative and convective heat transfer of the furnace components. Based on measured normal operating data from an industrial stainless steel plant, parameter identification is basically carried out using a nonlinear least-squares optimization algorithm for the whole annealing furnace, to estimate optimal values of uncertain parameters, such as emissivities. Due to the complexity of the model, a sequential approach for parameter identification is proposed and implemented, *i.e.* the parameter set is divided into different subsets, and the parameter estimation is carried out sequentially in several steps and iterations. The performance of the model with the estimated parameters is then evaluated on a different test data set. It is shown that the obtained model can predict temperature evolutions along the furnace in good agreement to measured data, under both steady-state and transient conditions. The presented model is suitable for controller design and process optimization.

1. Introduction

1.1. Continuous annealing furnaces

Continuous annealing furnaces are widely used for heat treatment after cold rolling in flat steel production, with the aim to produce steel strips of high tensile strength and high formability. Commonly used continuous annealing lines are either vertical or horizontal, depending on the strip-guiding method through the furnace; see Fig. 1. Through the global furnace structure, the number and length of heating and cooling areas, different annealing treatments can be achieved. With both types, it is possible to operate at high or low temperature level.

Some furnaces have enclosed heating burners to avoid chemical reaction of the strip with hydrogen or oxygen at high temperatures. Thereby, the combustion takes place inside a pipe to avoid getting waste gas into the furnace, and the heat exchange between heat pipe and strip is mainly radiative. Alternatively, the heating power is generated by the electric method. In both cases, the furnace can be also filled with an expansive inert gas instead of ambient air to reduce the chemical reactions. In a closed furnace there is no significant air flow inside the furnace room and the heat transfer is mainly radiative. Furnaces with internal combustion have much greater air flow and, depending on the burner type, a significantly higher air turbulence. In this case, the convective heat transfer between gas and strip and gas and wall cannot be neglected.

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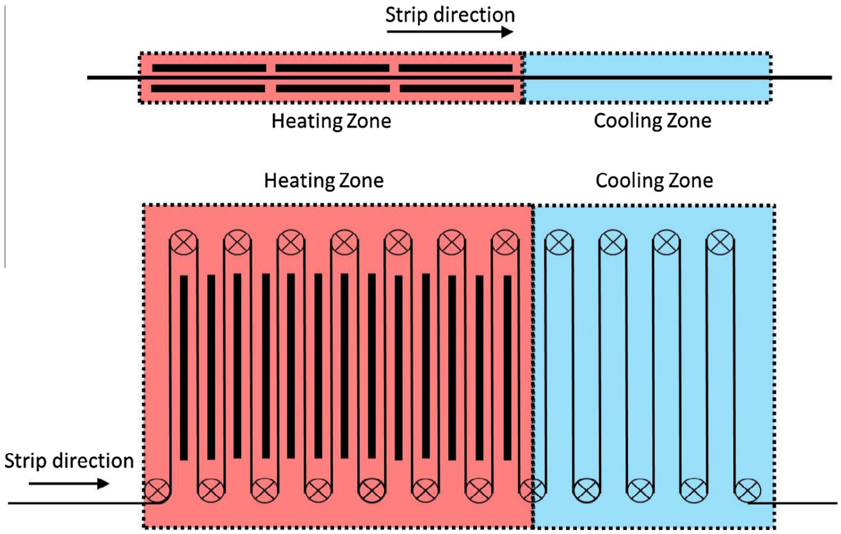

Fig. 1. Schematic view of a horizontal (*upper diagram*) and vertical (*lower diagram*) continuous annealing process.

Usually, the strip temperature within the furnace is not accessible to measurements. Only the strip temperature at the exit of the furnace is measured by radiation pyrometry, but it is well known that such measurements are often unreliable, due to radiative interference and inefficiency of installed shieldings [7,33].

1.2. Motivation and control objectives

There is a continuous interest in the process industry to use the fewest possible resources to heat up strip coils. Even small improvement of control parameters, control structure or process scheduling that allows a reduction in energy consumption can lead to cost savings and indirectly to a reduction of the climate pollution.

The simplified furnace design shown in Fig. 2 is the target plant of this study. It is direct-fired with natural gas for a clean combustion. The considered furnace has three connected chambers and the strip is running from the first to the third chamber. Cooled transport rolls are integrated between the chambers for supporting and guiding the strip. The furnace is divided into several zones, numbered in the direction of the strip movement, and having different lengths. The goal of furnace is to heat up flat stainless steel as fast as possible to a reference temperature, with a ramp to spike profile, so that there is no soaking zone.

At normal operation, no additional fresh air is blown in, so that the exhaust gas flow is a result of combustion only. If the burners' power decreases, exhaust gas flow decreases too. The used FLOX burners [39] have no visible flame for a furnace operating area above 850 °C. They are arranged in pairs over the whole length of the furnace with varying number per zone. The burners in zone 1 are arranged at the end of zone because the first meters are used as a pre-heating area.

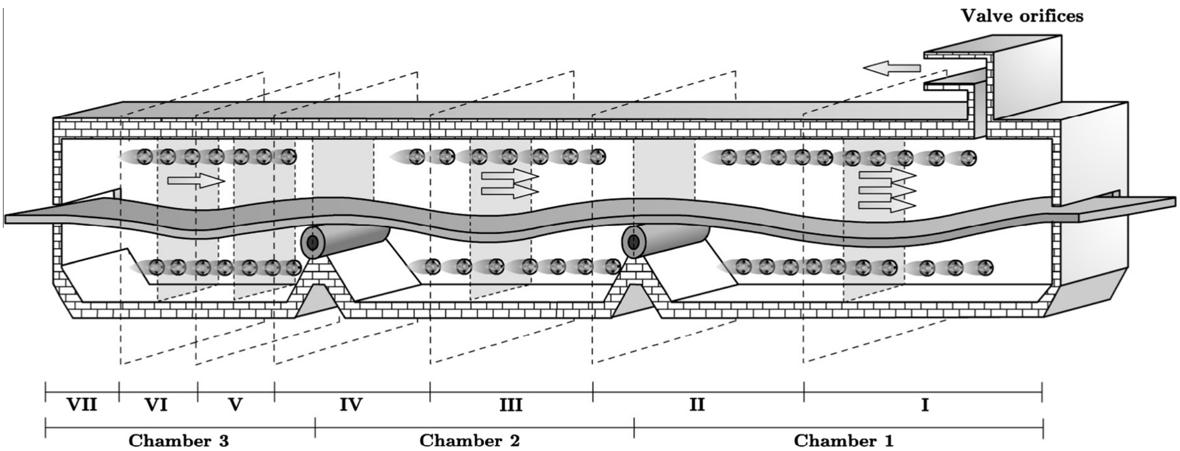

Fig. 2. A horizontal annealing furnace.