A Knowledge-Based Approach for Microwire Casting Plant Control

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ABSTRACT

This chapter presents the main ideas and preliminary results of an applied research project concerning the development of an intelligent plant for microwire casting. The properties of glass-coated microwires are useful for a variety of sensor applications. On the other hand, the process of casting can be one of the methods of nanotechnology and advanced materials. In microwire continuous casting, the main control problem is to maintain the optimum thermal and flow conditions of the process, in order to fabricate the microwire of a given stable diameter. Unlike a conventional casting plant, we propose to use a video camera to take the picture of the molten drop and to control the casting process by means of a knowledge based system. For this reason, a model, that is capable of taking into account the current features of the process and of describing the shape of the drop at each time, is developed. The model presented here should allow us to estimate the geometry of the metal-filled capillary and predict the diameter of microwire at each time during the casting process.

INTRODUCTION

The chapter provides the first results of an ongoing applied research which deals with the development of a knowledge based plant for the fabrication of glass-coated microwires. Glass-coated microwires are manufactured by means of the Taylor-Ulitovsky technique (Larin et al., 2002). Such microwires show magnetic properties of great technological interest, like magnetic bistability, giant magnetoimpedance effect, soft magnetic and memory shape properties. The above properties are quite useful for a variety of sensor applications. The investigation into technology and physical properties of glass-coated microwires is presently attracting much attention because of their use in sensor devices (Cobeno et al., 2001) and fiber-based products. For example, the new generation of multi-functional ternary composite materials will be made of microwires, the bio-based polymers and paper.

Glass-coated microwires consist of an inner metallic nucleus covered by a Pyrex-like coating. The typical limits for the metallic core diameter are between 1 and 50 microns. In microwire continuous casting, the main control problem is to maintain the optimum thermal and flow conditions of the process, in order to fabricate the microwire of a given stable diameter. To control the process, the human operator uses indications of a microwire resistance meter. The typical accuracy of the resistance meter is of the order of 5% to 10% within quite narrow limits. On the one hand, it is too difficult to improve and expand the capabilities of the meter. Because of this, the operator cannot use the information from that meter in a wide range of diameters. In other words, an acceptable control of the casting process based on the measured resistance is only possible within some limits. On the other hand, a highly qualified and experienced human operator is capable of maintaining the casting process under control only by using the information captured by his eyes. That information is with respect to color, position, and shape of the molten drop during the casting. However, the quality of such a control is poor (and hence, the quality of microwire).

According to reasons stated above, in this chapter, an approach for microwire casting plant control is suggested. In order to construct a knowledge-based system for the casting plant control, we consider the concepts of machine vision and fuzzy logic control. Our goal is to develop and exploit human operator knowledge. At a first stage, the proposed approach must help (assist) the operator to cast high quality microwire of different diameters. At the same time, the operator's experience and knowledge will be accumulated on the system during continuous casting. At the second stage, we intend to provide an experimental plant capable to cast almost automatically high quality microwires in a wide range of diameters.

BACKGROUND

The aim of modeling is capturing the essence of phenomena behavior. When complete knowledge of a process eludes us, we build models in order to obtain some measure of control over that process. A model is never entirely correct but it is useful if it explains and predicts the behavior of the process within the limits of precision required for the task. It is essential that the users of the model understand well the conditions over which the model has been developed and consequently the regimes of its validity. If the phenomenon to be modeled is understood well enough to construct a model and if its mathematical formulation is suitable to be analytically or numerically solved, then the resulting model is a powerful tool as it enables us to explain and predict system behavior within the bounds of the validity of model.

The process of microwire casting is qualified with a highly elevated level of complexity. It represents a joining of interactions, such as mechanical, thermal, electrodynamical, physical, and chemical. More than that, those interactions are not just multiple but are overlapped during the time of casting. It can be supposed that a model of casting might be derived from the underlying properties of the process. However, even under various approximations, the final model will be too difficult, of high order, nonlinear and so on.

Having a high degree of complexity, the creation of a mathematical complete and proper model for the automation and optimization of the process of microwire casting represents a highly difficult problem (Berman, 1972). We believe that pure physical and mathematical evaluation of the discussed process doesn't represent a practical solution.

It is well-known that in many cases the control of a process by a human operator is more successful than any automatic control (Kickert & Van Nauta Lemke, 1976). On the other hand, a lot of human experience in the area of microwire casting has been accumulated, which can be explored in order to automate, at least partially, and optimize the control of respective process. The process put into discussion cannot be treated through the prism of some precise categories of conventional theories. The human operator doesn't supervise the casting process on the basis of sophisticated rules. The operator is largely helped by his own experience. Namely the experience and the specific accumulated knowledge enable to maintain and predict the parameters of the process checked up in the admissible limits even in conditions of uncertainty.

As the strategy, human operator uses, is vague and qualitatively described, the use of fuzzy logic control in the casting plant should be a good choice, in our opinion. Fuzzy control is a practical alternative for a variety of challenging control applications since it provides a convenient method for constructing nonlinear controllers via the use of heuristic information. Such heuristic information may come from an operator who is acting as a "human-in-the-loop" controller for a process. Since fuzzy logic is dealing with linguistic information, it can be used as a basis for knowledge-based systems. In the fuzzy control design methodology, we ask human operator to write down a set of rules on how to control the process, and then we incorporate these into a fuzzy logic-based system that emulates the decision-making process of the human (Driankov et al., 1993; Patyra et al., 1996; Passino & Yurkovich, 1998). On the other hand, a knowledge base is not a rule base (Siler & Buckley, 2005).

The fuzzy logic control represents a technology that works in conditions of uncertainty and noise. The development of systems based on the fuzzy logic started together with the appearance on the market of the sufficient performed processors and circuits. Currently, applications of this kind exist in different areas (Krause et al., 2007), especially in industrial ones (Terano, 1993; von Altrock, 2007). The explanation is very simple: fuzzy logic offers efficient and elegant solutions for diverse systems of supervision (multivariable control).

On the other hand, machine vision is successfully used today in industrial applications. This approach has become a vital component in the design of advanced systems because it provides means of maintaining control of quality during manufacture (Davies, 2004).