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Monitoring and control for thermoplastics injection molding A review

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Abstract

Thermoplastics injection molding has found increasing use in several industry sectors. To achieve high effectivity of the process and desirable quality of the manufactured product, correct and precise parameters' setting is critically important. As injection molding is a sophisticated process it is often hard to take care of all the changes occurring during its application. However, implementation of artificial intelligence (AI) methods in control and monitoring systems of injection molding machines can increase controllability and additivity of the process. This paper gives an overview of different studies related to research on the topic of monitoring and control systems for injection molding and explains why application of AI methods would be beneficial.

Keywords: Injection molding; Artificial intelligence methods; Intelligent process monitoring and control; Intelligent heat management.

1. Introduction

Today more than one third of polymeric products is produced with use of injection molding [1]. It is a complicated process, as the molten polymers undergo complex thermo-mechanical changes. As injection molding is mostly used for mass production, repeatability and quality of the final product is very important. *"Improper settings of process variables will produce various defects in the final product"* [2, 3] and result in increased amounts of waste and scrap. As need for control of the injection molding process is high, the first step in this case is to precisely design, measure and monitor the process to make the key process variables observable and controllable [4]. This will allow to increase controllability and repeatability of the overall process, leading to possibility of lowering probability of unnecessary in-process variations.

The process of injection molding includes four main stages: plasticization, injection, cooling and ejection. Among these four, the cooling stage takes from 50% to 80% of the cycle time [5]. It has always been of a high interest to shorten overall cycle time, as *"the cost-efficiency of the process is dependent on the time spent in the molding cycle"* [6]. One of the ways to shorten the cycle time and, in particular, the cooling stage, without compromising quality of manufactured parts is use of rapid heating and cooling systems, which can include application of variotherm technology and conformal cooling/heating channels.

Process monitoring and control, as well as use of variotherm technology or conformal cooling/warming channels would benefit from application of artificial intelligence methods in order to function in the most optimal way. The following sections will explain importance of monitoring and control systems, give examples of research on these systems and explain why AI methods are of a high importance for the injection molding.

2. Injection molding process variables and artificial intelligence methods

According to Karbasi and Reiser [4], the injection molding process includes three nested process loops shown in Fig. 1. The first loop called machine control includes control of **machine parameters**, such as speed, pressure and temperature.

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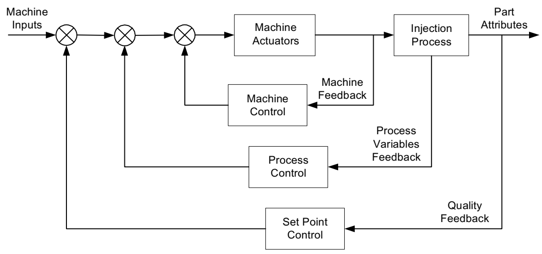

Fig. 1. Injection molding control loops [4].

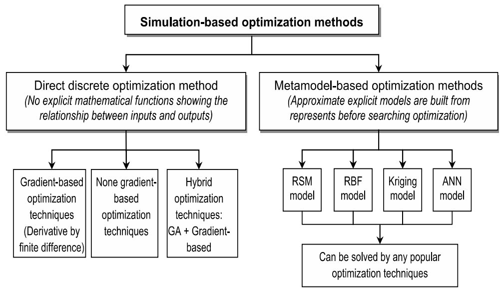

Fig. 2. Classification of optimization methods [12]

The middle one (process control) includes such **variables as in-mold temperature and pressure**. The last loop, which is called set point control, takes care of **part quality feedback**.

Machine control loop is the most developed one, as process variables are handled by the machine manufacturers. The middle loop, on the other hand, is less developed, however, there is significant amount of research going on, while the third one is the least developed, as related development has started only in previous decade [4]. In order to increase controllability of injection molding further work on the three loops is necessary [7]. Among possibilities for process monitoring and control development is application of so-called methods of machine learning or artificial intelligence, for example, neural networks. This would allow to adjust values of necessary variables without involvement of machine operators if conditions change during the manufacturing process. These methods can also be used in rapid heating and cooling systems in micro injection molding [8, 9], as well as in injection molding of bigger components, such as LCD TV frame [10] and automotive interior part [11], for example.

Fast adaptation of important variables to the changed process environment would allow to avoid quality failures in micro injection molding, as well as in molding of large components. This can be done by building a model of the injection molding process or its parts and using the model to adjust current process parameters in order to receive an optimal output during the manufacturing. In other words, through building a self-optimizing injection molding process.

2.1. Artificial Intelligence methods

According to Dang [12], there are two main groups of simulation-based optimization methods, which are direct discrete optimization and metamodel-based optimization methods. The methods and their short description is shown in Fig. 2, where GA stands for genetic algorithm, RSM for response surface methodology, RBF for radial basis function and ANN for artificial neural network. Of course, these are not all the simulation-based optimization methods used.

Among others, in the metamodel-based methods group ANN is mentioned. This is one of the artificial intelligence methods that can be applied to build mathematical models of injection molding process with consideration of the most important parameters.

When the data is analyzed and model is build, the model can be used in order to adjust the current parameters' values to receive a high-quality product as model and process output, as well as to shorten the cycle time.

AI methods give better results when it comes to process modelling and forecasting, as they have higher precision and lower error values compared to conventional modelling methods. In addition, they are not as resource consuming as direct discrete optimization methods [12]. In order to build the model different artificial intelligence methods can be used to process big amounts of data received during the process run.

Artificial neural networks (ANN) is a method that was used for modelling and forecasting in many areas of science and engineering [13]. ANN is a method used for information processing, which includes use of nonlinear and interconnected processing elements called neurons. These elements are organized in separate levels connected with layers' weights. ANNs often consist of three layers: the input layer, the hidden layer and the output layer [14]. At first, the data is "fed" to the network's first layer, in the second layer, it is processed and the model is built, in the third layer the forecast based on the model is handed out as a result of the algorithm's work.

ANFIS or adaptive neural-based inference system is one more method used to create the models and forecasts for certain processes. This method is a composition of artificial neural networks and fuzzy logic approaches. It identifies a set of parameters that the model will be based on using a hybrid learning rule. *"It can be used as a basis for constructing a set of fuzzy If-Then rules with appropriate membership functions in order to generate the previously stipulated input–output pairs"* [14, 15].

Genetic programming can be applied to achieve the same goals. It is a methodology which gives possibility to generate algorithms and expressions to find solution of existing problem. These expressions are represented by a tree structure consisting of leaves/terminals and functions/nodes. When a population of the genetic programming tree is defined procedures similar to the ones used in genetic algorithm are applied. These procedures include defining the fitness function, genetic operators (crossover, mutation and reproduction) and the termination criterion.

These are only three examples of AI methods possible to be applied for injection molding, however, they need to be chosen carefully to fit a purpose of research, as well as parameters or factors used in the model.