ELSEVIER

Computer-Aided Design 37 (2005) 645–662

COMPUTER-AIDED DESIGN

www.elsevier.com/locate/cad

Automatic layout design of plastic injection mould cooling system

C.L. Li*, C.G. Li, A.C.K. Mok

Department of Manufacturing Engineering and Engineering Management, The City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong, China

Received 22 March 2004; received in revised form 29 July 2004; accepted 10 August 2004

Abstract

This research extends our previous investigation of the automation of the preliminary design stage to the layout design stage of the cooling system design process. While the functional aspects of the cooling system are considered during the preliminary design stage, the layout design stage addresses both the functionality and manufacturability of the design. A graph structure is devised to capture a given preliminary design and a graph traversal algorithm is developed to generate candidate cooling circuits from the graph structure. Heuristic search is employed to develop the cooling circuits into the layout designs by generation of tentative manufacturing plans. A framework for fuzzy evaluation of the layout designs is developed to rate the various design alternatives generated. An experimental system is implemented to verify the feasibility of the approach, and examples generated from the system are presented to illustrate the major steps of the automatic design process.

Keywords: Design automation; Automatic design synthesis; Plastic injection mould; Cooling system design

1. Introduction

The function of the cooling system of a plastic injection mould is to provide thermal regulation in the injection moulding process. When the hot plastic melt enters into the mould impression, it cools down and solidifies by dissipating heat through the cooling system. As the cooling phase generally accounts for about two-thirds of the total cycle time of the injection moulding process, efficient cooling is very important to the productivity of the process. The cooling system also plays an important role in the product quality. A cooling system that provides uniform cooling across the entire part ensures product quality by preventing differential shrinkage, internal stresses, and mould release problems. In addition to the functional aspects, the design of a cooling system should also consider the manufacturability of the system to control the cost of mould construction.

The process of cooling system design is a complicated process and can be distinguished into three phases: preliminary design, layout design, and detail design. Although, CAD/CAM systems are widely used in the design of injection moulds, they are mainly limited to providing geometric modeling tools in the detail design phase. Specialized stand-alone or add-on software packages that provide interactive geometric modeling tools for designing various components or sub-systems of the mould structure are also commercially available. However, limited research works on automation tools that can play a more active role in the preliminary and layout design phases have been reported. In a previous research project, we developed a feature-based method which creates the preliminary design automatically [1,2]. Given a plastic part with a complex shape, the feature-based method decomposes the part into simpler shape features, called cooling features. Cooling sub-circuits are then generated automatically to provide the required cooling function for each recognized feature. In the present research, automation in the design process is extended to the layout design phase. Techniques are developed which generate the layout design automatically from the preliminary design by considering both the functional and manufacturing aspects of the cooling system.

* Corresponding author. Tel.: +852 2788 8432; fax: +852 2788 8423.
E-mail address: meclli@cityu.edu.hk (C.L. Li).

0010-4485//$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cad.2004.08.003

2. Related work

There are four major areas of research related to plastic injection mould cooling system, namely, computer-aided engineering (CAE) analysis, design optimization, new fabrication technology, and automatic design synthesis. Most of the early research work [3–7] focused on CAE analysis. After more than two decades of extensive research, commercial CAE packages such as MOLDFLOW and Moldex3D are now widely used in practice to analyze a given design. These CAE methods predict the temperature profile that changes with cooling time. Efficiency and quality can thus be estimated before the actual mold fabrication. While CAE methods are able to analyze a given design, they do not suggest design changes when problems are detected from the results of an analysis. Optimization methods [8–10] are reported which utilize the CAE analysis results to optimize a design. Given an initial cooling configuration design, an objective function is formulated as a measure of the temperature uniformity and cooling efficiency. The objective function is expressed in terms of parameters relating to the configuration of the cooling system and processing conditions. By integrating an optimization algorithm with a cooling analysis algorithm, the initial design can be fine-tuned to optimize the cooling system design.

Recently, methods that build better cooling systems by using new fabrication technology have been reported. Instead of the conventional hole-drilling method to produce straight-line channels, Sachs et al. [11,12] reported a method that takes the advantage of solid freeform fabrication technology to produce conformal cooling channels. Such channels maintain a constant distance from the mould impression, so that accurate temperature control is possible, even for a part with a complex shape. It has been reported that a more uniform temperature distribution and better dimensional control of the moulded part can thereby be achieved. Sun et al. [13] used CNC milling to produce U-shape milled grooves for cooling channels. This technique is similar to the conformal cooling method, in that the channels are able to follow the shape of the mould impression. As with the conformal cooling method, an improvement in temperature control has also been reported.

The focus of our work is in the automatic design synthesis of the cooling system, which is an area that has not been well investigated. In our previous work [1,2], a feature-based technique for automatic preliminary design generation was developed. The work reported in this paper concentrates on the automation of the layout design. The automatic layout design process is formulated as a heuristic search process. Design automation by heuristic search is a commonly used technique, and has been investigated by the author in the design automation of mechanical devices [14,15]. The heuristics that guide the layout design process are based on fuzzy evaluation of the cooling performance and manufacturability of candidate designs. Automatic manufacturability analysis in various application domains has been studied extensively, and Grupta et al. [16] reported a comprehensive survey. The evaluation method developed in this research was inspired by the method reported by Ong and Chew [17] in the manufacturability evaluation of machined parts and setup plans. The use of fuzzy logic in the evaluation was inspired by the successful applications of fuzzy logic in various aspects of injection mould design research, including parting direction determination [18] and mouldability analysis [19].

3. Overview of the method

In the preliminary design stage, the major issue to be addressed is the functional requirement, that is, the cooling requirement, of a given plastic part. The preliminary design specifies the type (e.g. U-circuit, parallel channels, bubblers, cooling towers, etc.), size (e.g. channel length and diameter), and the approximate locations of the cooling elements that form the cooling sub-circuits. Each sub-circuit provides the cooling function that carries away the heat from a region of the part. Our previous research [1,2] shows that the preliminary design can be determined mainly from the geometric shape of the part, and a feature recognition approach for automating the design was developed. Given the preliminary design, complete cooling circuits are developed in the layout design phase by connecting the individual sub-circuits and cooling elements together. The layout design process considers the manufacturability and the feasibility of the physical realization of the cooling circuits.

In the current research, the investigation is focused on cooling systems that do not use parallel cooling and have only one cooling circuit. The major items to be addressed include: the location of the main cooling elements, the channels that interconnect the cooling elements and the sub-circuits, and the locations of the inlet and outlet of the cooling system. The design of each item is inter-related and the layout design process is divided into four major stages of operation.

1. The derivation of a graph structure that represents the preliminary design and modification of the graph to facilitate subsequent operation.
2. The generation of candidate cooling circuits from the graph structure.
3. The generation of layout designs from the candidate cooling circuits by developing tentative manufacturing plans.
4. The evaluation of the candidate layout designs with respect to cooling performance and manufacturability.

The first stage of the design process is a preparation step, which serves to derive a representation of the preliminary design in a form that facilitates the subsequent operation.