OPTIMIZATION OF POLYMER INJECTION MOLDING PROCESSES

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Annotation : This study addresses the optimization of injection molding processes for polymer materials. The main stages of the process, including mold filling, packing under pressure, and cooling, are analyzed. The influence of key process parameters such as melt temperature, mold temperature, injection pressure, and cooling time on product quality and production efficiency is determined. Special attention is given to the improvement of cooling systems, optimization of mold design, and the application of computer-aided engineering (CAE) methods. The proposed approaches enable a reduction in cycle time, minimization of product deformation, and optimization of energy consumption. The obtained results can be applied in industrial practice to improve the quality and productivity of polymer product manufacturing.

Keywords: mold cooling, cooling system, optimization methods, heat exchange, natural cooling, thermal efficiency, polymer molding, cooling process, energy saving.

When a new product is developed, quality, price, and time for market introduction are important factors determining whether or not the product will be successful. Simulation and optimization algorithms can be development tools that make the difference between success and failure. The progress in the efficiency versus the cost for the computers has been an important contributor to the growing interest for optimization within the engineering industry. Using simulation tools with which the physical behavior of a product is analyzed is indeed important when there are many different parameters influencing the behavior. However, it is hard to predict which parameter is the most important, and which value it should have in order to obtain the best result possible.

To use optimization methods in the product design process has several benefits. Before getting the answer to the question of how the product should be designed in order to improve a chosen characteristic, the engineer is forced to define the problem in a structured way like deciding which parameters should be used, how the design should be evaluated and what restrictions that should be used? Also, when the optimization has been carried out, information about the problem can be further analyzed by looking at the sensitivities and interval of the objective function, which gives the engineer a deeper understanding of the
physical behavior of the product. Optimization is a mathematical approach to tackle a design problem and it can be defined as the act of obtaining the best result possible under certain circumstances. In other words, the aim is to maximize or minimize an objective function by altering a set of design variables without violating any given constraints. Today, optimization is widely used. In many different areas, a number of algorithms can be found, some have a true mathematical approach whereas some are mimicking different phenomena in nature. A good introduction to the area of engineering optimization is given by Arora [56].

1.1 Formulation of an optimization problem

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An example of an optimization problem formulated in words is to minimize the weight of a beam subjected to a transversal load, by changing the cross-section of the beam without exceeding a certain stress limit. A standard formulation of an optimization problem is writtenas [56]:

Find a vector $x = (x_1\ x_2\ \dots x_n)$ (1)

which minimizes $f(x)$ (2)

such that $h_1(x) = 0, \quad i = 1,2 \dots . I$ (3)

$g_1(x) \leq 0, \quad j = 1,2 \dots . J$ (4)

$x_k^1 \leq x_k \leq x_k^n, \quad k = 1,2 \dots . n$ (5)

where **x** is a vector of design variables which is bounded by side constraints x^l and x^u, $f(\mathbf{x})$ is the cost, or objective, function, and where $h(\mathbf{x})$ and $g(\mathbf{x})$ are the vectors describing the equality and inequality constraints respectively. This is called a constrained problem, but if no equality or inequality constraints exist, it is called an unconstrained problem.

1.1.1 Design variables

The design of a product can be changed by assigning different values to the so-called design variables. They should be independent of each other, and a given set of design variables gives a certain point in the design space, that is, a design point. If proper design variables are not selected for a problem, the formulation will be incorrect or, maybe not even possible at all. In a first stage, it is wise to choose many design variables in order to have as many degrees of freedom as possible in the problem, even if it can be a disadvantage too, since the computational effort is increasing.

The design variables can be either continuous or discrete, and some typical design variables for a structural problem are dimensions like lengths, radii, thicknesses, material properties like Young's modulus and density. Not all optimization algorithms can handle discrete design variables. Nevertheless, many dimensions and properties are in fact discrete. For example, if Young's modulus is chosen as variable, one must see to that the optimized modulus is commercially available.

1.1.2 Constraints

A design point can either be feasible or infeasible. A feasible design meets all the requirements. One which fails to meet one or more of the requirements is called an infeasible design. The restrictions defined for a design are called constraints and they must also be influenced by one or more of the design variables. Some examples of constraints include: upper limit of the stress, a critical vibration frequency as well as upper and lower values for the design variables.

Figure 2 shows a typical design space with two variables and where three constraints are defined, the lower limit of x^l_1 and the upper limit of x^u_2, which are called side constraints, and one inequality constraint $g_1(x)$.

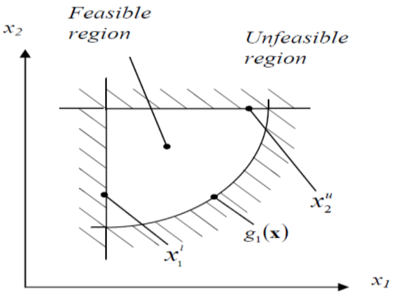

Figure 1. Constraint surfaces in a two-dimensional design space.

1.1.3 Objective function

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In order to compare different designs, an objective function must be defined. This function must be dependent on the design variables. Otherwise it is not a meaningful objective function. This function can be either minimized or maximized. Some examples of objective functions are the weight of a Formula One Grand Prix sway bar, which should be minimized, and the load capacity of a bearing, which should be maximized.

In Figure 2, an objective function is added to the design space, and it is plotted for constant values *fuf*$_2$,, and *f*$_3$ where the objective function is descending as *f1>f2>f3*. The optimal design is found at **x**=**x***.

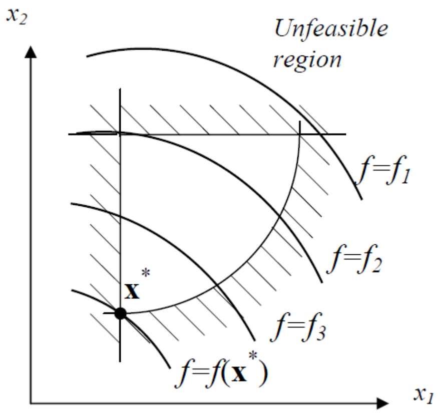

Figure 2. Contours of the objective function together with the constraint surfaces.

1.2 The solution process

Many methods with the purpose to find the optimum design have been developed over the years. So-called topology optimization uses the topology of the structure as design variables and by using this method, elements defining the structure are deleted or repositioned, and the optimized structure often appears as a framework. It could for example indicate where to put beam profiles in a vehicle in order to minimize the weight and to fulfill a certain stiffness criterion. Size optimization is another category of optimization methods. It is the most commonly used method in industry and in the literature. If this kind of method were used in the example above, the cross-section geometry of the beam profiles would be used as design variables.

The most common way to separate different optimization methods is to distinguish between optimality criteria methods (also known as indirect methods) and direct search methods. Optimality criteria methods are based on conditions that a function must satisfy at its optimum point, while the direct search methods are based on a chosen initial design and an iterative procedure is followed in order to find a better design.

REFERENCES

1. Rakhimov, A. A., & Sattorov, M. Sh. (2020). Technology of Plastics Processing. Tashkent: TTYMI Publishing House. — Covers the technological fundamentals of plastic injection, cooling, and molding processes.
2. Usmonov, B. S., & Jurayev, I. M. (2019). Fundamentals of Mechanical Engineering Technology. Tashkent: "Fan va texnologiya" Publishing House. — Provides practical approaches to mold materials, cooling systems, and thermal processes.
3. Toshpolatov, D. A. (2018). Modeling of Technological Processes. Tashkent: "Muhandis" Publishing House. — Presents theoretical foundations of digital modeling and optimization methods.

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4. Rakhmonov, S. N. (2021). Thermal Engineering and Cooling Systems. Tashkent: TDPU Publishing House. — Describes heat transfer, natural convection, and cooling efficiency issues.

5. Gulomov, A. T. (2017). Computer-Aided Engineering Analysis (CAE Systems). Tashkent: "Innovatsiya" Publishing House. — A practical guide to thermal analysis using SolidWorks, ANSYS, and other CAE systems.

6. Xu, G., & Wang, G. (2015). Optimization design of conformal cooling channels in injection molds based on numerical simulation. Applied Thermal Engineering, 87, 398–408.

7. Li, H., Zhao, G., & Liu, X. (2018). Analysis of temperature field and cooling time in injection molding process. Polymers, 10(9), 1047.

8. Yusupov, A. A., Yuldashev, X. X. Composite Materials: Scientific-Technical and Applied Journal. — Improving the cooling efficiency of molds in the production of complex-shaped plastic parts.

9. Yusupov, A. A., Yuldashev, X. X., Juraqulov, I. Ch. (2024). Current Issues of Innovative Technologies in Materials Science, Welding Production, and Material Processing in Mechanical Engineering. — Mathematical modeling of the cooling process in manufacturing complex-shaped plastic parts (p. 513).

10. Yusupov, A. A., Yuldashev, X. X. (2024). Current Issues of Innovative Technologies in Materials Science, Welding Production, and Material Processing in Mechanical Engineering. — The importance of cooling channels in the production of complex-shaped plastic parts.

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