Valve Gate Optimization for Injection Molding of an Automotive Instrument Panel

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Abstract

Injection pressure, an important factor in injection molding process, should be minimized to enhance injection molding quality. In this study, we decided the locations and open timings of valve gates to minimize the maximum injection pressure. To solve this problem, we integrated MAPS-3D (Mold Analysis and Plastic Solution-3Dimension), a commercial injection molding analysis CAE tool, using the file parsing method of PIAnO (Process Integration, Automation and Optimization) as a commercial process integration and design optimization tool. In order to reduce the time for obtaining the optimal design solution, we performed an approximate optimization using a meta-model that replaced expensive computer simulations. To generate the meta-model, computer simulations were performed at the design points selected using the optimal Latin hypercube design as an experimental design. Then, we used micro genetic algorithm available in PIAnO to obtain the optimal design solution. Using the proposed design approach, the maximum injection pressure was reduced by 35.1% compare to the initial one, which clearly showed the validity of the proposed design approach.

Introduction

A big sized injection mold used the valve gate to reduce the number of cycles in injection process. Through the valve gate, the molten plastic resin is charged into the mold cavity and the injection time of the plastic resin is determined by the open timing of the valve gate. At the location and the open timing of the valve gate, the pressure drop occurred in the cavity. In other words, the injection pressure is controlled by the location and open timing of the valve gate.

The injection pressure is an important injection process condition to affect the impact strength and the clamping force. The injection pressure could be controlled by the location and the open timing of the valve gate. Through reduction of the injection pressure, the energy consumption could be reduced by reducing the clamping force. Also, the quality of the injection molding parts could be enhanced by improving the impact strength. Therefore, we need techniques which can control the injection pressure.

In the previous researches, Spina compared the pressure change according to the presence of the valve gate in the hot runner system. [1] Lee et al. proposed the method of the injection molding using the CAE programs. [2] Lee et al. performed the reduction of the injection pressure and weld lines through the location and diameter in the runner system. [3] Cho et al. proposed the method which automated the injection filling analysis process and reduced the injection pressure by changing the gate location. [4]

The previous studies had the inconvenience of doing the filling analysis procedure manually. Also, a large injection molding part needs a lot of time to do the injection filling analysis. Therefore we need the techniques which could automate the procedure and reduce the computational cost.

In this study, we automated the procedure of the instrument panel modeling of the runner system and filling analysis. We determined the location and the open timing of the valve gate using meta-model based design optimization.

Injection Molding Model & CAE Analysis

To filling analysis of the instrument panel, we used MAPS-3D (Mold Analysis and Plastic Solution-3Dimension), a commercial injection molding analysis CAE tool. [5] Figure 1 shows the model of the instrument panel and the initial location of the valve gate. The filling time was set in 7 sec. The number of elements in the model is composed of about 1,300,000.

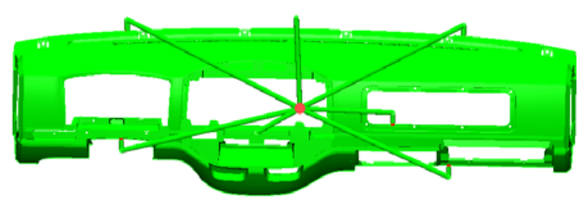


Figure 1. The shape of the instrument panel and runner system

Design Problem

Design Requirements

By minimizing the maximum injection pressure, the clamping force is reduced. The energy consumption would be much lighter. Also, the injection molded parts quality could be improved by increasing the impact strength. According to change the location and open timing of valve gate, the cavity pressure is changed. Figure 2 shows the injection pressure curves at the initial design. The initial value of valve gate location is the location of the initial model and that of the valve gate open timing is decided by the automated function of the MAPS-3D. The automatic function is that the valve gate is open when the plastic resin is arrived the entrance of the valve gate. First, the valve gate 1 is open and then 2-3-4-5-6-7 valve gate opens sequentially. The pressure drop points (P_2-P_3-P_4-P_5-P_6-P_7) appear in the valve gate open timing. Therefore we determine the maximum pressure as the objective function.

Design Variables

In order to minimize the injection pressure, we have decided 13 design variables which are 7 locations and 6 open timings of the valve gate without the valve gate1 open timing because the valve gate1 was always opened. The upper and lower boundary conditions and initial value of the design variables are shown in Table 1. The candidate range of the valve gates is shown in Figure 3. We selected 11, 22, 11, 22, 16, 42 and 42 points as candidate points for each gate 1, 2, 3, 4, 5, 6 and 7. Each candidate point is in the available range and placed at same distances from the center of the available range. For the valve gates open timing, the lower boundary conditions are 1 sec faster than the initial values except valve gate 5 open timing.

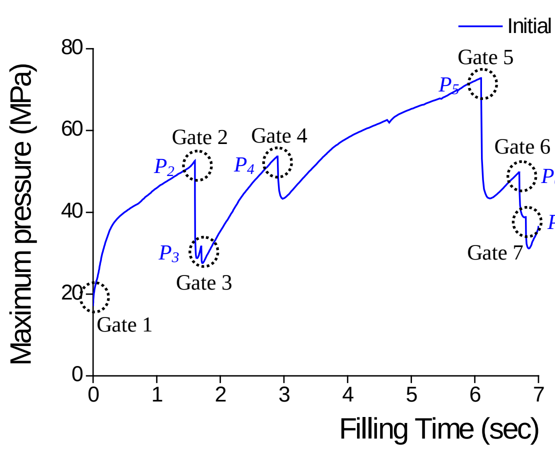


Figure 2. Pressure curve of the instrument panel at the initial variable values

Table 1. The upper and lower boundary conditions and initial value of the design variables in this work

Design variable		Lower bound	Initial	Upper bound
x_1	Gate1_node	1	6	11
x_2	Gate2_node	1	4	20
x_3	Gate3_node	1	6	11
x_4	Gate4_node	1	1	22
x_5	Gate5_node	1	10	16
x_6	Gate6_node	1	20	42
x_7	Gate7_node	1	23	42
x_8	Gate2_time	0.6	1.6	1.6
x_9	Gate3_time	0.7	1.7	1.7
x_{10}	Gate4_time	1.9	2.9	2.9
x_{11}	Gate5_time	3.1	6.1	6.1
x_{12}	Gate6_time	5.7	6.7	6.7
x_{13}	Gate7_time	5.8	6.8	6.8

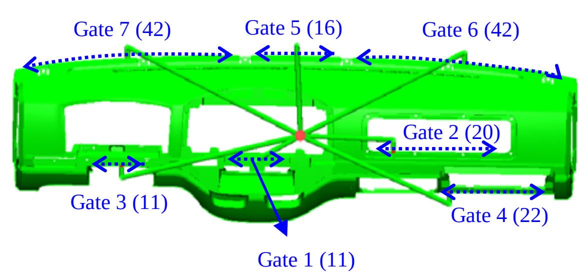


Figure 3. The instrument panel and runner system

The open timing of the valve gate 5 is 4 sec faster than the initial value. The upper boundary conditions are same as the initial values. The injection pressure increases rapidly when the plastic resin is charged around the entrance of the valve gates. This is the reason why we selected the lower and upper bound.

Formulation

To satisfy the requirements, the design problem of the instrument panel formulated as a mathematical problem, equation (1) can be expressed as:

$$
\begin{aligned}
&Find && x_n \ , \quad n = 1,2,3,\cdots,13 \\
&to\ minmize && P_{\max} \\
&subject\ \ to && x_n^L \le x_n \le x_n^U
\end{aligned} \qquad (1)
$$

Optimization of the Instrument Panel

Automation

To automatically connect the MAPS-3D to the optimizer, PIAnO (process integration, automation and opti-mization) [6] was employed as a design framework.

Design of Experiments

The OLHD is a method that combines optimal DOE and LHD to overcome a weakness in LHD. [7] LHD may create a design in which all of the points are located along the diagonal of the design space, resulting in an experimental design with poor statistical qualities. OLHD constructs an optimal design set as it controls the design points located randomly in the design space. In this study, we use the optimal latin hypercube design (OLHD) for design of experiments. [8] We extracted 130 experimental points in this study.

Approximate Model

In 1951, the kriging model was proposed by Krige who had studied mining engineering. [9] Then Methron founded and improved the kriging model as mathematically. [10] The kriging model was applied to engineering by Sacks. [11] Simpson compared to some approximate models and confirmed that the kriging model had good predictive performance in the problem which had lots of design variables and nonlinear system. [12] In this study, we selected the kriging model to make approximate model because the responses show nonlinear values according to change of the valve gate locations and open timing.

Optimization Algorithm

To minimize the injection pressure, we used the micro genetic algorithm which is equipped in PIAnO. This method is one of the global optimization techniques. The micro genetic algorithm has an advantage, which the algorithm could find the optimization values as low computational time because of performing evolutionary algorithm using the small number of populations.

Optimization Results

We determined 130 experimental points using the OLHD. Then we automated the modeling of the runner system and the filling analysis procedure using the PIAnO. The relation between the experimental points and response values, are used to generate a metamodel of each response using the kriging model. The metamodel is carried out the micro genetic algorithm in the PIAnO. The results of the optimization are shown in Figure 4. Using the kriging model, the optimum value of the maximum injection pressure that is the design requirement is reduced by 35.1%. However, this result is the response of the metamodel. Finally we compare the response of the metamodel with the result of the MAPS 3D analysis. The optimum value of the maximum injection pressure is reduced by 34.2%.

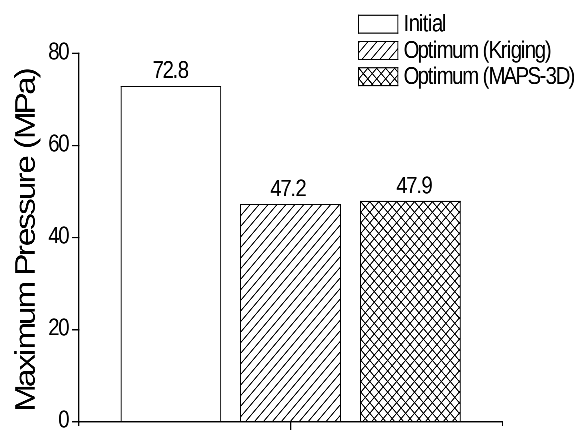


Figure 4. Comparison of the maximum injection pressure values among the initial, optimum kriging and MAPS-3D models

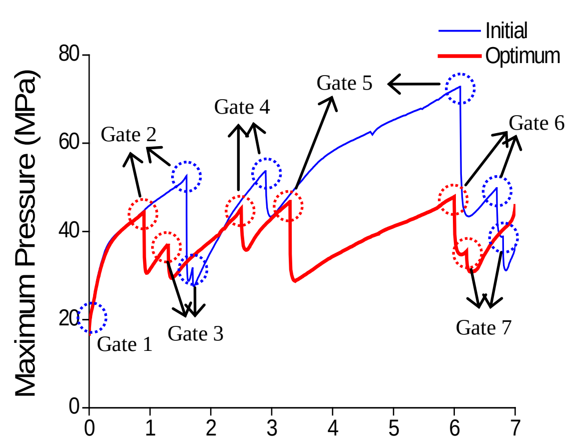
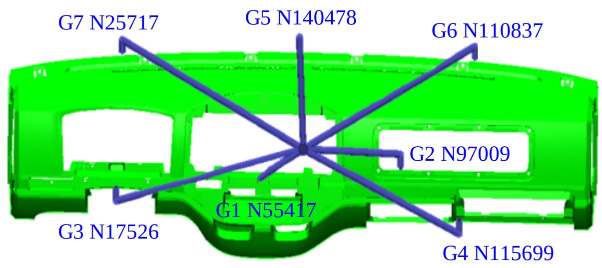
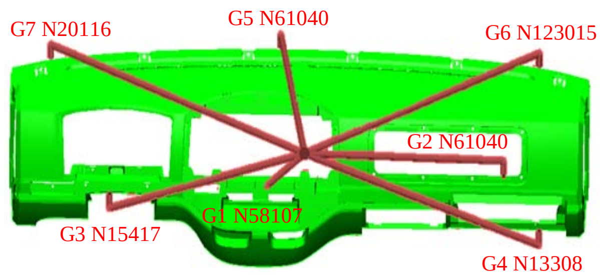


Figure. 5 Pressure curves of the instrument panel between initial and optimum variable values



a) Initial



b) Optimum

Figure 6. The valve gate locations between the initial and optimum

Table 2 Optimum design variable values among the initial, lower and upper bound values

Design variable	Lower bound	Initial	Optimum	Upper bound
x_1	1	6	7	11
x_2	1	4	19	20
x_3	1	6	4	11
x_4	1	1	18	22
x_5	1	10	9	16
x_6	1	20	32	42
x_7	1	23	7	42
x_8	0.6	1.6	0.9	1.6
x_9	0.7	1.7	1.3	1.7
x_{10}	1.9	2.9	2.5	2.9
x_{11}	3.1	6.1	3.3	6.1
x_{12}	5.7	6.7	6.0	6.7
x_{13}	5.8	6.8	6.2	6.8
Injection Pressure	-	72.8	47.9	-

So, we show that the approximate model is very accurate. We compare the initial value of the injection pressure with the optimum value as shown in Figure 5. Also, we show the valve gate locations of the initial and optimum values of the valve gate locations in Figure 6. We show the optimum, initial, lower and upper bound values in Table 2.

Conclusion

We have performed the approximate optimization to determine the 7 valve gate locations and 6 valve gate open timing for minimizing the maximum injection pressure of the automotive instrument panel.

1. To automatically connect the MAPS-3D to the optimizer, PIAnO was employed.
2. We extracted 130 experimental points using OLHD and built the kriging model which presented the relation between the design variables and the responses.
3. The result of the approximate optimization showed that the maximum injection pressure, 47.9 MPa, was reduced by 34.2 % compared to initial value. So, we determined the valve gate locations and open timing for minimizing the injection pressure.

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References

1. R. Spina, "Injection Moulding of Automotive Components: Comparison between Hot Systems for a Case Study", J. Mater. Process. Technol., 155, 1497 (2004).
2. C. W. Lee and Y. J. Hur, "Intelligent Design System for Gate and Runner in Injection Molding", J. of the KSPE, 18(9), 192 (2001).
3. H. S. Lee, Y. S. Kim, H. K. Lee and G. E. Yang, "Injection Molding Analysis of Automobile Front Bumper Fascia Using CAE", Transactions of KSAE, 3, 1147 (2004).
4. S. B. Cho, C. H. Park, B. G. Pyo, B. O. Rhee and D. H. Choi, "Optimization of Gate Location in Injection Molding Parts using Micro GA", Spring Conference Proceedings, 1946, KSAE (2011).
5. Mold Analysis and Plastics Solution-3 Dimension, MAPS-3D User's Manual, VMTech Co. Ltd. (2009).

6. PIAnO (Process Integration, Automation and Optimization) User's Manual, Version 3.3, PIDOTECH Inc. (2011).
7. M. H. McKay, R. J. Beckman and W. J. Conover, "A Comparison of Three Methods for Selecting Values of Input Variables in the Analysis of Output form a Computer Code", *Technometrics* 21(2), 239 (1979).
8. J. S. Park, "Optimal Latin-hypercube Designs for Computer Experiments", J. Statist. Plann. Inference, 39(1), 95, (1994).
9. D. G. Krige, "A Statistical Approach to Some Basic Mine Valuation Problems on the Witwatersrand" ,J. of the Chem., Metaland Mining Soc. of South-Africa, 52(6), 119 (1951).
10. G. Metheron, "Principles of geostatistics economic geology", Economic Geology, 58(8), 1246 (1963).
11. J. Sacks, W. J. Welch, T. J. Mitchell and H. P. Wynn, "Design and analysis of computer experiments", Statistical Science", 4(4), 409 (1989).
12. T. W. Simpson, T. M. Mauery, J. J. Korte and F. Mistee, "Comparisons of response surface and kriging models for multidisciplinary design optimization", Proc. 7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis & Optimization, AIAA, 1, 381 (1998).
13. K. Krishnakumar, "Micro-Genetic Algorithms for stationary and non-stationary function optimization", Intelligent Control and Adaptive Systems, 1196, 289 (1989).

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