CASE 38

Optimization of Casting Conditions for Camshafts by Simulation

Abstract: We attempted to optimize the casting process of a camshaft by taking advantage of parameter design using simulation, analyzing how we prevent gas from being dragged in a casting die when filling it with molten iron.

1. Introduction

A camshaft, one of the most vital parts of an automobile engine, is commonly made of cast iron. If there are casting defects on the machined surfaces of frictional areas such as a cam, functional deterioration of an engine takes place, thereby causing quality assurance cost. To reduce this, we need to eliminate casting defects in essential formed areas of a camshaft.

A camshaft is cast by pouring cast iron melted at a high temperature, called *molten iron,* into a cavity of a die called a *shell mold.* This casting method and flow of molten iron are shown in Figure 1. Molten iron poured from a pour basin is gradually charged from a gate located at the bottom to a hollow area for a camshaft. Since casting conditions such as constituents or the temperature of molten iron are varied within a certain range under control, we need to design a casting method robust to variability in these conditions.

2. Casting Function and Evaluation of Casting

If we eliminate gas from entering molten iron when poured, casting defects in formed areas can be prevented. To do so, ideally, no turbulence in molten iron flowing through the gate should occur. The Reynolds number, Re, expressed as an index, indicates the degree of fluid turbulence:

$$\mathrm{Re} = V\frac{d}{\nu} \tag{1}$$

where V is the flow velocity of molten iron (m/s), d the diameter of the gate section (m), and ν the coefficient of dynamic viscosity (m^2/s). The Reynolds number of molten iron flowing through the gate can be obtained by the flow speed of molten iron computed by simulation.

Considering that a smaller Reynolds number indicates less fluid turbulence, ideally, we should lower it as much as possible. However, if it is extraordinarily small, other casting defects could be caused. Therefore, based on our prior experience with similar products, a Reynolds number of 4800 is considered ideal. So we evaluate the casting function by using a Reynolds number of molten fluid flowing through the gate as a nominal-the-best measurement characteristic.

Since analyzing time is regarded as an issue when casting simulation is implemented, we improved our analysis workflow beforehand. Primarily, we attempted to highly streamline the analysis by optimizing the element size to be divided in a three-dimensional model. In creating the model, we used a three-dimensional CAD system called I-DEAS and shortened the modification time of the model by taking advantage of the parametric geometry controls in the history editing function.

 Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

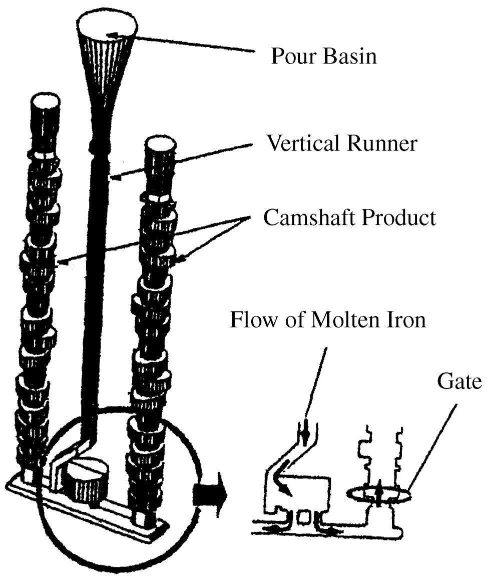

Figure 1
Method and flow of camshaft casting

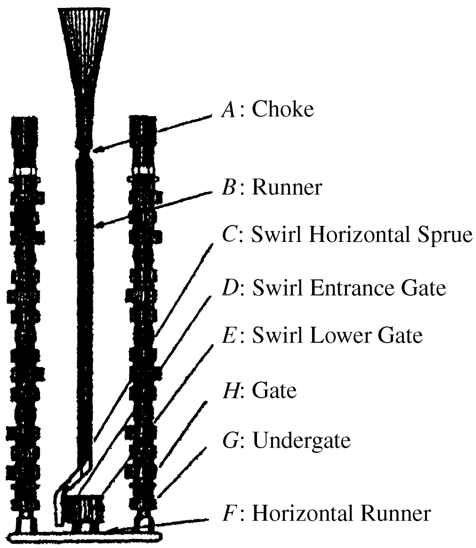

Figure 2
Control factors

3. Control and Noise Factors

Figure 2 shows the control factors selected from sectional dimensions (areas) of principal parts, A to H, which were considered to greatly affect the flow speed of molten iron flowing through the gate (Figure 1). Each level chosen for simulation is shown in Table 1. Considering that the variability in casting needs to be included in simulation and there is an asymmetric characteristic in the right and left runners, we selected a temperature of molten iron, I, charging rate of molten iron, J, and side of a runner used (right or left), K, in Table 1 as noise factors. To evaluate turbulence due to the anisotropy of a product, we chose five levels only for the filling rate of molten iron.

4. SN Ratio and Sensitivity of Reynolds Number

After allocating the control and noise factors to an L_{18} orthogonal array, we conducted casting simulation and computed Reynolds numbers. Table 2 shows the experimental data for experiment 1. Using these, we calculated the SN ratio and sensitivity as follows.

Total variation:

$$S_T = 5749^2 + 5900^2 + \cdots + 3104^2 + 3879^2 = 545{,}917{,}217 \qquad (f = 20) \tag{2}$$

Variation of general mean:

$$S_m = \frac{(5749 + 5900 + \cdots + 3104 + 3879)^2}{20} = 531{,}738{,}281 \qquad (f = 1) \tag{3}$$

Error variation:

$$S_e = S_T - S_m = 545{,}917{,}217 - 531{,}738{,}281 = 14{,}178{,}936 \qquad (f = 19) \tag{4}$$

Error variance:

$$V_e = \frac{S_e}{19} = \frac{14{,}178{,}936}{19} = 746{,}260 \tag{5}$$

SN ratio:

Table 1
Control and noise factors and levels

Factor	Level 1	2	3	4	5
Control factors					
A: choke	Down	Std.[a]	—	—	—
B: vertical runner	Down	Std.[a]	Up	—	—
C: swirl horizontal runner	Down	Std.[a]	Up	—	—
D: swirl entrance gate	Down	Std.	Up[a]		
E: swirl lower gate	Down	Std.[a]	Up		
F: horizontal runner	Down	Std.[a]	Up		
G: undergate	Down	Std.[a]	Up		
H: gate	Down	Std.[a]	Up		
Noise factors					
I: temperature of molten iron when poured	Down	Std.[a]	—	—	—
J: filling rate of molten iron (%)	35	40	45	50	55
K: side of a runner	Left	Right	—	—	—

[a] Initial level.

Table 2
Analysis results for casting of camshaft (experiment 1)

		K_1 (35%)	K_2 (40%)	K_3 (45%)	K_4 (50%)	K_5 (55%)
I_1: lower temperature of molten iron	J_1 (left)	5749	5900	4722	4552	4070
	J_1 (right)	5732	5728	5484	4967	4712
I_2: standard temperature of molten iron	J_1 (left)	6162	6127	6298	5138	5062
	J_2 (right)	6069	5278	4392	3104	3879

$$\eta = 10 \log \frac{\frac{1}{20}(S_m - V_e)}{V_e} = 10 \log \frac{\frac{1}{20}(531{,}738{,}281 - 746{,}260)}{746{,}260} = 15.51 \text{ dB} \quad (6)$$

Sensitivity:

$$S = 10 \log \tfrac{1}{20}(S_m - V_e) = 10 \log \tfrac{1}{20}(531{,}738{,}281 - 746{,}260) = 74.24 \text{ dB} \quad (7)$$

5. Optimal Configuration and Confirmation

Figure 3 shows the response graphs for the SN ratio and sensitivity.

To make our casting method robust to the variability in casting conditions and prevent casting defects, we needed not only to mitigate the variability of Reynolds numbers, but also to lower the absolute values. Therefore, considering that we should determine the optimal configuration based on a criterion of a higher SN ratio and lower sensitivity, we selected the combination $A_2B_2C_3D_3E_2F_2G_1H_2$. Using estimations of the SN ratio and sensitivity under this configuration, we estimated the gains. Then, to ver-

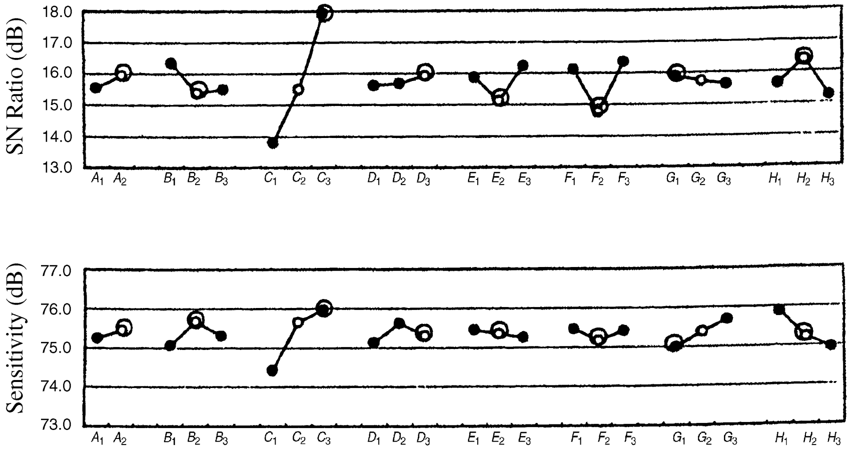

Figure 3
Response graphs

Table 3
Results of confirmatory experiment (dB)

	SN Ratio		Sensitivity	
Configuration	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Optimal	17.10	18.09	75.67	75.27
Current	14.52	12.95	75.73	75.78
Gain	2.58	5.15	−0.06	−0.51

ify the validity of these estimations, we conducted a confirmatory experiment under the optimal configuration.

Table 3 shows the results of the confirmatory experiment. This reveals that an improvement of approximately 5 dB is expected, whereas the gains in SN ratio do not have good reproducibility. The actual casting method reflecting the optimal configuration had reduced the occurrence rate of casting defects, and the casting cost was reduced by 34%. As a side effect, we can anticipate a shorter development cycle time by applying this engineering process to preliminary studies before mass production of a new product.

Reference

Kazyuki Shiino and Yasuhiro Fukumoto, 2001. Optimization of casting conditions for camshafts. *Quality Engineering*, Vol. 9, No. 4, pp. 68–73.

This case study is contributed by Kazuyuki Shiino.