PROCESS MANAGEMENT IN THE CAST IRON FOUNDRY

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Abstract

In the paper results of the research on quality level of the chosen assortment of casts were presented and a method for evaluating the effectiveness of quality assurance systems operating in foundries was proposed. It has been shown that the obtained improvement in the quality of cast processes and products was a consequence of the implementation of the process management principles in the cast iron foundries and the use of FMEA method to improve product quality. For each stage of the production process the risk of nonconformities was determined, which contributed to increased knowledge of the on-going processes. The matrix taking into account the place of nonconformities occurrence, the cause and the risk degree of nonconformities in the process were shown.

Keywords: quality, cast iron, FMEA method

1. INTRODUCTION

The process approach aims at effective management of the whole organization and proceeding processes. The result of one process leads to the occurrence of another one. In addition, they are connected due to the feedback, that is carrying out one process in an appropriate way influences the course of the other ones. Both systematic identification and rational management of all processes, and mutual interaction between them are indispensable in the company [1]. Process-oriented management in a foundry has an influence on reducing the incompatibilities, improving the control of technological processes quality and products, which are manufactured in these processes and finally, ensuring that all acquired resources are well-managed. A lot of factors impact the a cast product quality. From the technical side, quality is keeping parameters which have been ordered from a foundry by a customer. The most common requirements set to the casts include: keeping dimensions and shape, hardness and smoothness of a surface, lack of visible or hidden incompatibilities, strength, leaktightness, an appropriate structure and a chemical constitution of a cast material [2]. Any departures from the established arrangements make up an incompatibility which has to be eliminated. In this paper, the problem of eliminating errors (which lead to manufacturing incompatible products) in production has been dealt with, with regard to a selected assortment of a company. Methodology can be adopted to all company products, contributing to reduction in an incompatibility level in general.

2. IMPROVING QUALITY OF PRODUCTS

For research purposes, a family of products in the object of study has been distinguished, for which a process-mapping has been made. Identification of incompatibilities allocated to a particular process in a given family of products has been prepared for the defined processes. As a result of the conducted studies, a juxtaposition of the incompatibilities allocated to a particular process has been obtained, Fig. 1. The quantification of the incompatibilities has been presented according to the Pareto-Lorezna principle [3+5]. Conclusions drawn from Fig. 1 include confirming the occurrence of about 72% of the incompatible products out of 100% in the initial processes P1-P6. Therefore, the quality of an examined product is formed in basic foundry processes. The next step in the analysis is determining the risk of errors occurrence in the selected processes.
The FMEA method is responsible for estimating risk. It helps to make a decision which assists process optimization thanks to determining a risk coefficient of RPN error occurrence, which is calculated (1) as an SEV (priority number of error severity for a customer), OCC (priority number of error occurrence), DET (detection priority number, probability of error detection):

$$RPN = OCC \times DET \times SEV$$

RPN value, in the case of estimates of particular coefficients in the 1÷10 rate, can be included among RPN=1 values, which means minimal risk and RPN=1000, which in turn means certainty of error occurrence [6÷8]. The results of the FMEA method use for risk estimation for P1-P6 processes are presented in Table 1.

Successive processes presented in the FMEA analysis have been combined with the incompatibilities which occur most often, indicating potential causes and effects of errors. The indices estimated in a given way allow taking precautionary and correcting actions in adjusting to a specification of each process. P3, P4, P5 turn out to be key areas in a covered case. The indices calculated in the FMEA method warrant creating a diagram which allows for risk comparison in particular stages of the production process in relation to the incompatibilities distinguished in Table 1. Processes which have directly the highest risk include respectively P5 - the process of casting the moulds with liquid metal, P4 – the process of assembling moulds and P3 – the process of making cores and particular parts of the moulds. The study conducted in this way helps to fulfil a basic assumption of improving quality in the process approach to managing iron foundry, which is the identification of the incompatibilities in a fixed area (time and place) of doing work.

3. ANALYSIS OF CHANGES IN QUALITY LEVEL AFTER IMPLEMENTING THE PROCESS-ORIENTED MANAGEMENT

The analysis rests on verifying the effectiveness of the actions which are to improve quality resulting from accepting recommendations of the process approach (including correcting and preventive actions from the FMEA method). In the first stage of the study, the incompatibility level on a chosen production line, where an analysed family of products is manufactured, was analysed (the incompatibility level before conducting the actions for improving quality was measured – X1 trial) . The second stage of the study is quality measurement after implementing the recommendations which result from introducing the principles of the process-oriented management (X2 trial). According to the principles of the process-oriented management, the cast production process was divided into the following stages: P1-P12. A basis for the analysis of the quality of cast products was the assumption concerning essential change of percentage values of the examined incompatibilities for the analysed family of products as a result of taken organizational actions which aim at improving the processes.
<table>
<thead>
<tr>
<th>No.</th>
<th>POTENTIAL INCOMPATIBILITY</th>
<th>POTENTIAL EFFECT</th>
<th>SEV</th>
<th>POTENTIAL CAUSES</th>
<th>OCC</th>
<th>CURRENT CONTROL</th>
<th>DET</th>
<th>RPN</th>
<th>RESULTS OF ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>P3</td>
<td>Mould shift</td>
<td>Violating the mould form, lack of coaxiality</td>
<td>7</td>
<td>Unskilfulness of foundry moulding shop workers, inattention</td>
<td>4</td>
<td>Wz – store cards Setting control Process observation Spot check Final research</td>
<td>6</td>
<td>168</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Sand holes</td>
<td>Irregularity of a casting surface</td>
<td>7</td>
<td>Violation of a casting surface, overdrying of a mould and a core</td>
<td>7</td>
<td></td>
<td>3</td>
<td>147</td>
<td>7</td>
</tr>
<tr>
<td>P4</td>
<td>Fash</td>
<td>Metal allowance in a place of assembling a mould</td>
<td>9</td>
<td>Unskilfulness of foundry moulding shop workers, Inaccurate moulds assembling</td>
<td>7</td>
<td>Current control of actions Spot check according to instructions Control before delivering ready moulds to a next internal customer</td>
<td>2</td>
<td>126</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Mould shift</td>
<td>Violating the mould form, lack of coaxiality</td>
<td>7</td>
<td>Unskilfulness of foundry moulding shop workers, Inattention</td>
<td>4</td>
<td></td>
<td>6</td>
<td>168</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Sand holes</td>
<td>Irregularity of a casting surface</td>
<td>7</td>
<td>Violation of a casting surface in course of moulds assembling</td>
<td>7</td>
<td></td>
<td>3</td>
<td>147</td>
<td>7</td>
</tr>
<tr>
<td>P5</td>
<td>Mechanical damage</td>
<td>Cracks, knocking off, bruising of a cast</td>
<td>10</td>
<td>Too low casting pressure, low temperature of a mould, incorrect mould pouring techniques</td>
<td>7</td>
<td>Chemical constitution control (records in heat/melt book) Tapping temperature control Temperature control according to instructions before a pouring process Current control</td>
<td>3</td>
<td>210</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Misrun casting</td>
<td>Visible defect in cast mass</td>
<td>10</td>
<td>Too low casting pressure, small speed of mould pouring (metallostatic pressure), caster’s low skills, improper technique of abutment flow pouring</td>
<td>6</td>
<td></td>
<td>3</td>
<td>180</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Sand holes</td>
<td>Irregularity of a casting surface</td>
<td>7</td>
<td>Violation of a casting surface in course of moulds assembling</td>
<td>7</td>
<td></td>
<td>3</td>
<td>147</td>
<td>7</td>
</tr>
<tr>
<td>P6</td>
<td>Mechanical damage</td>
<td>Cracks, knocking off, bruising of a cast</td>
<td>10</td>
<td>Cleaning intensity, exposing the cast to strokes before heat treatment, workers’ carelessness, organization of a cleaning process</td>
<td>5</td>
<td>Setting control Observation of a control process before delivering products to the P7 process</td>
<td>3</td>
<td>150</td>
<td>10</td>
</tr>
</tbody>
</table>
After obtaining the results in the first trial 1, correcting and preventive measures were implemented in the areas of the discussed processes. Those included trainings (mainly caster trainings), changes in production engineering (redesigning a gating system), a change of the supplier of the moulding materials used on a production line, modernization of the line where moulds and cores are produced, modification of the procedures of proceeding with the product before submitting it to heat treatment. The analysis was conducted on the basis of 48 measurements in successive batches (before and after introducing the changes). Two populations of the following decompositions \( N(m_1, \sigma_1) \) i \( N(m_2, \sigma_2) \) were obtained, null hypothesis concerning the equality of average values of the analysed populations \( H_0: m_1 = m_2 \) was formulated, regarding the hypothesis that average value of \( m_1 \) population is bigger than \( m_2 \); \( H_1: m_1 > m_2 \). The hypothesis \( H_1 \) put in this way means actually a lower incompatibility level in the X1 trial. The use of the \( T \) (2) statistics for verifying the significance of the changes in the incompatibility level of cast products has been adopted. Since the population decompositions are unknown and the assumption \( n_1 > 30 \) i \( n_2 > 30 \) is fulfilled, \( T \) [6, 9] gauge can be used. \( T \) (2) gauge, assuming \( H_0 \) authenticity, has a normal distribution - \( N(0,1) \).

\[
T = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_{(1)}^2}{n_1} + \frac{S_{(2)}^2}{n_2}}}
\]

(2)

The following results have been obtained for the analysed family of products:
\( H_0: m_1 = m_2, \; H_1: m_1 > m_2, \; \alpha=0,01, \; t_\alpha = 2,35 \)

\[
t_e = \frac{5,78 - 4,77}{1,234516 + 1,789998} = 4,012816
\]

For \( P_{1-P_5} \):
\( t_e > t_\alpha \) performed (4,012816 > 2,350) \( H_0 \) has to be rejected and \( H_1 \) hypothesis about reducing the incompatibility level should be accepted

\[
t_e = \frac{9,53 - 7,29}{4,806036 + 3,898259} = 5,37098091
\]

For \( P_{1-P_12} \):
\( t_e > t_\alpha \) performed (5,37098 > 2,350) \( H_0 \) has to be rejected and \( H_1 \) hypothesis about reducing the incompatibility level should be accepted.

On the basis of the conducted study the effectiveness of the actions, focused on improving the quality and taken as a result of implementing the assumptions of the process-oriented management, has been ascertained. The incompatibility level in each of the X2 trials is lower, in a significant way, than the incompatibility level in the X1 trial. After applying the changes in the areas of mould-making, casting and knocking out the casts from the moulds, the incompatibility level has been reduced by about 25% to the analysed family of products.

Thus, verification of the effectiveness of the adopted solutions in improving the processes is possible.
4. EFFECTIVENESS OF QUALITY MANAGEMENT SYSTEM

Among many evaluation methods, cost account methods and statistical methods are particularly effective. Due to the application of the statistical methods, evaluation time is shortened and we have a large reliability of the evaluation results. When populations are numerous and mass, the statistical methods are the only accepted methods of the effectiveness evaluation. The effectiveness evaluation methods of the quality system at the production stage include cost account methods, seven QC tools, random sample methods of examined measurable characteristics. The effectiveness evaluation methods can be applied on particular stages of the cast realization, starting from marketing, through the design stage, purchase and deliveries, production and finishing with exploitation, where methods of reliability studies can be applied. Two kinds of criteria were used in the study: an economic criterion, costs of the defects and the incompatibilities of the manufactured cast products (serial and individual) were used here and next, they were applied to the adopted acceptable level. On the basis of iron foundry data, the effectiveness of the quality system in the case of the costs of casts incompatibilities in the period of 6 years was evaluated. The data used for the analysis has been shown in Table 2. The analysis has been presented graphically in Fig. 2.

Tab. 2 Iron foundry data

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Delivery faults</th>
<th>Internal faults</th>
<th>Guaranteed repairs</th>
<th>Faults cumulated costs</th>
<th>Faults planned costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.70</td>
<td>0.20</td>
<td>0.60</td>
<td>1.50</td>
<td>0.90</td>
</tr>
<tr>
<td>2</td>
<td>0.65</td>
<td>0.17</td>
<td>0.65</td>
<td>1.47</td>
<td>0.80</td>
</tr>
<tr>
<td>3</td>
<td>0.26</td>
<td>0.14</td>
<td>0.28</td>
<td>0.68</td>
<td>0.70</td>
</tr>
<tr>
<td>4</td>
<td>0.20</td>
<td>0.08</td>
<td>0.20</td>
<td>0.48</td>
<td>0.60</td>
</tr>
<tr>
<td>5</td>
<td>0.50</td>
<td>0.40</td>
<td>0.30</td>
<td>1.20</td>
<td>0.50</td>
</tr>
<tr>
<td>6</td>
<td>0.20</td>
<td>0.02</td>
<td>0.20</td>
<td>0.42</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Cumulated costs of casts incompatibilities $R(t)$ have been adopted as an assessment characteristic, and anticipated permissible incompatibilities costs $P(t)$ have been adopted as an evaluation criterion. This analysis showed that up to the third year, the quality system of the iron foundry had been ineffective $R(t) - P(t) > 0$. Up to this point, the foundry has been implementing new procedures and new solutions in
quality management. It contributed to reaching the state where the anticipated incompatibilities costs turned out to be higher than the actual ones $R(t) - P(t) \leq 0$. From the third year, the value of the adopted price characteristics of the effectiveness of the quality system is contained in the effectiveness area. The effectiveness evaluation of the quality system is necessary and indispensable in order to improve companies and adjust them to a competitive struggle on the market. In the fifth year, big investments were made in the company. They were connected with extending the assortment from the produced casts to precision castings for motor industry. New machines and technologies were purchased, what in turn had a big influence on process destabilization in the initial stage. The cumulated incompatibility costs, mainly internal, and external in a smaller degree (warranty repairs), definitely exceeded the anticipated incompatibility costs.

5. SUMMARY

As a result of the conducted research, it has been proved that basic assumption of improving quality in the process-oriented management of a foundry is the incompatibility identification in appointed time and place. Twelve processes have been distinguished in the research. The studies, which were to examine the incompatibility structure for a chosen family of products, were conducted for these processes. It is possible to divide realized operations into particular processes (P1-P12). Using classic instruments of the quality management (the FMEA method) and process-mapping techniques allows us to confirm that there are determined actions, which influence the process of forming the moulds quality, in particular defined processes (P1-P12). The process-oriented management based on particular actions, which are interconnected, leads to distinguishing control-operating factors, that is feedbacks, and operating them to obtain higher quality of work which is being done.

LITERATURE