Quality problems root cause identification and variability reduction in casting processes

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Abstract

Increasing customer requirements and production costs force casting manufacturers to adopt a methodological approach to manufacturing processes, in order to deliver increasingly more repeatable, predictable and competitive products. One of the methods of achieving such results is the reduction of variability of manufacturing processes and the optimization of their control. This paper presents the possibilities granted by the Six Sigma methodology in efficient identification of special factors influencing pre-heat of ceramic moulds and casting parameters, in the minimization of the frequency at which they occur, and in the reduction of key process parameters variability. This paper also shows the usability of the method in achieving measurable business advantages for the company using the example of one DMAIC methodology based project realized in the Investment Foundry Department of WSK "PZL-Rzeszow" S.A.

Keywords: precision casting, statistical process control, Six Sigma, DMAIC, variability analysis

1. Introduction

The quick identification of quality issues caused by technological processes is currently one of the most important tasks for the technological supervision staff. The traditional approach to quality and problem solving using the "do and see what comes out of it" must, because of high costs, be replaced with methods that guarantee obtaining statistically significant solutions. One method, that can surely be included in this type, is the Six Sigma methodology, that has been used to improve the quality and business indicators for companies like Motorola or GE since mid-80s.

In the United Technologies Corporation (UTC), of which WSK PZL-Rzeszow" is a part, the Six Sigma program has been in operation since 2002 under the name Procert, constituting one of the main tools of ACE (Achieving Competitive Excellence). The most general, and yet most accurate definition of the Six Sigma methodology states, that it is a way of improving the business activities of a company. In general, it is a method based on

numbers, data and facts, that in five consecutive stages of a DMAIC project (Define, Measure, Analyze, Improve, Control), allows to obtain an implemented and verified solution with a properly matched control standard.

Six Sigma helps to avoid the majority of errors committed during the realization of projects such as: lack of a precise, data-based, definition of the problem; lack of a precisely defined project scope; lack of analysis of the customer feedback; lack of measurement system verification or not entirely thought through, not facts based technological trials.

In the organization area, Six Sigma is a chance to improve the quality of teamwork, communication, employee competence, knowledge about product and processes, customer satisfaction.

2. DMAIC Methodology

The aim of DMAIC methodology is the satisfaction of customer requirements and the support of business development

through the elimination of defects and variability reduction, based on facts and data, and using proper statistical tools.

The **DEFINE** step precisely defines the problem, which is to be solved by the project. In the described example this is the unacceptable number of scrap castings identified as micro porosity in the turbine blade airfoil during X-Ray inspection for one of the manufactured parts. In this step, the time and process boundaries, required human and technical resources and the approximate savings arising from the problem solution are set and defined. All of this allows to determine, whether the disputed problem is significant for the organization from the business viewpoint and from the customer perspective in the context of his requirements.

The next step is the **MEASURE** phase, which is aimed at the transformation of a business problem into a statistical problem through the gathering of proper data. In order to do this, basing on facts and not assumptions, a detailed map of the technological process has been worked out during an ''area inspection'' (Fig. 1).
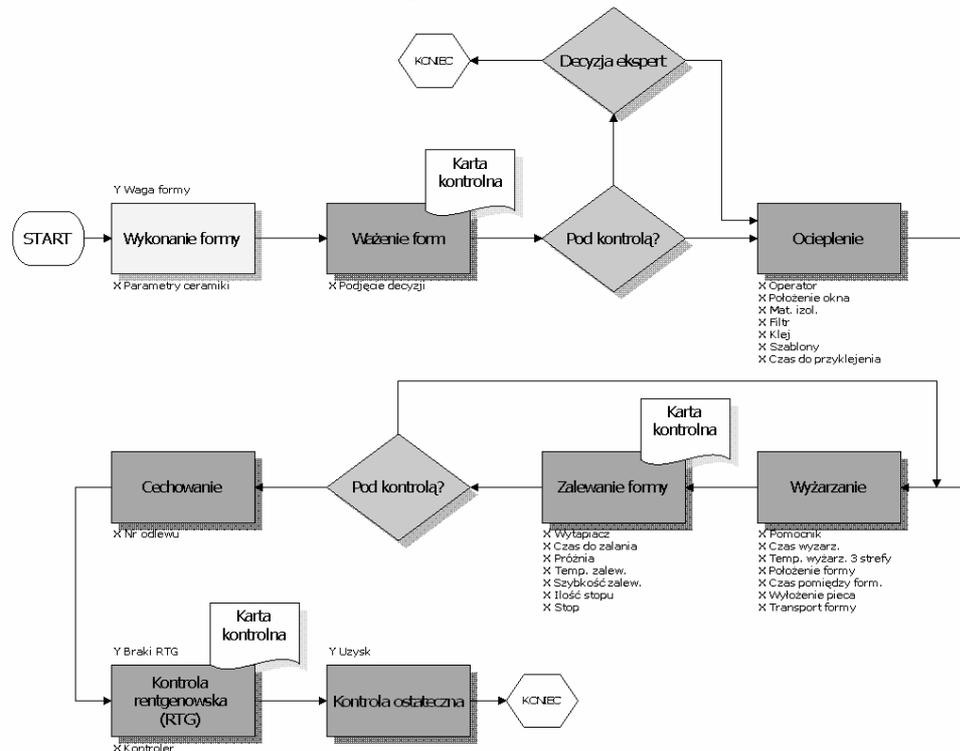

Fig. 1. Pre-heat and casting process map

For the identified areas, which could potentially be responsible for generating porosity, an analysis of inputs and outputs capability has been performed (Table 1).

Table 1. A comparison of key parameters capability

Characteristic	Capability
Mold weight	1,06 Cpk
Preheat time	**0,38 Ppk**
Preheat temperature	1,76 Ppk
Time between molds	**0,48 Ppk**
Time to pour	**0,30 Ppk**
Casting temperature	1,93 Cpk
Pour rate	1,34 Cpk
Charge weight	1,53 Cpk

Reaching the root cause of the problem is of special importance in the case of complicated processes like casting, in which the end effect being a metallurgical defect may be caused by a whole spectrum of different factors.

The initial analysis of respective characteristics capability showed, that the problems identified as porosity may be connected to mold temperature. A significant part of the root cause analysis process is the identification of the time the defect is generated. In order to do this, a CUSUM control chart (Fig. 2) has been used. This type of control chart is good at detecting small shifts away from the target [1, 2].

In order to check, whether in the defined timeframe of quality defects occurrence a special condition has existed, event and maintenance logs for the process equipment have been reviewed.

A direct comparison of the input parameter trends with the X-Ray defects rates did not indicate, in an unequivocal manner, the root cause of the defects (Fig. 3). The obtained Pearson correlation coefficient values have not exceeded 0,20.

All of the gathered data served as input for an initial FMEA (Failure Modes and Effects Analysis). FMEA is a tool allowing the identification, analysis and prioritization of problems. It requires an assessment of the problem's significance, the frequency of it's occurrence and the evaluation of the current control system, that is preventing it. Basing on FMEA, experiments have been conducted in order to confirm the correctness of proposed provisional problem solutions. To obtain a

statistical model of the process, it has been necessary to conduct a Response Surface Regression analysis basing on the gathered data.
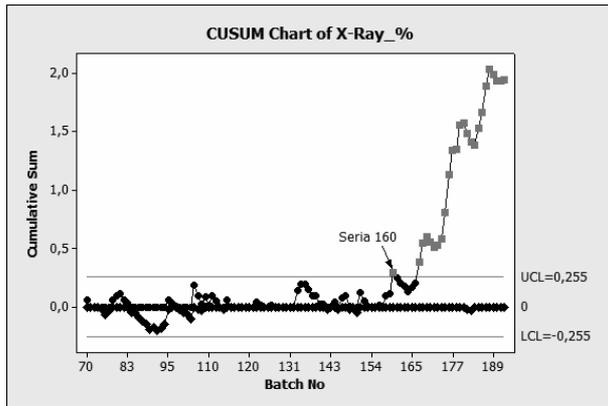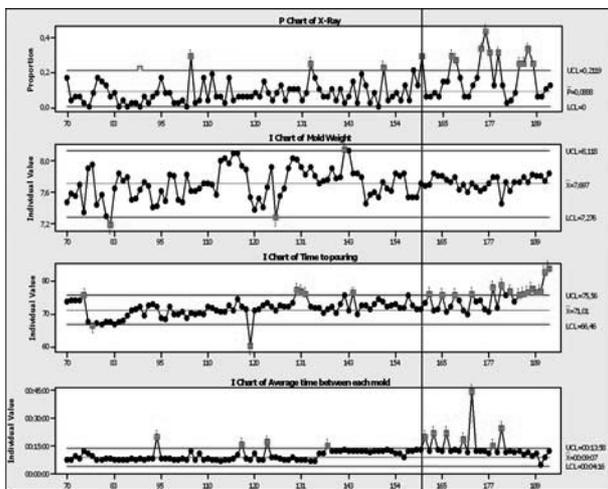

Fig. 2. CUSUM control chart

Fig. 3. Process parameters trends comparison

The **ANALYZE** phase serves to identify the root causes basing on the numbers, facts and data gathered. The conducted Response Surface Regression analysis for one casting campaign, for which two different preheat temperatures in the middle zone of the pusher preheat furnace together with different times between molds in the furnace have been used (4 batches total – 192 castings) indicated, that the input variables included in the analysis explain the defects in 85% (with a model fit of R^2=96,13%). With the help of a tool optimizing the response from the regression model (Fig. 4) it has been stated, that:

1. Raising of preheat temperature to 1150°C lowers the scrap rate at X-Ray.
2. The most defects are occurring in the first row of molds from the door of the CGE furnace (position 1,2). This might indicate mold cooling caused by lack of proper sealing of the furnace door or by extended door opening times.
3. In the examined range (7,4-8,0 kg) the mold weight does not influence the X-Ray scrap rates.
4. Extended mold preheating times, above 7,5 hours causes an increase in the scrap rates.
5. The time between taking a mold out of the furnace and actual casting should be as low as possible.

6. The casting rate should not be greater than 2,03 seconds.
7. The alloy quantity required for casting should not be lower than 10,2 kg.
8. The optimal time of mold preheating in the 3rd furnace zone is 23 minutes.
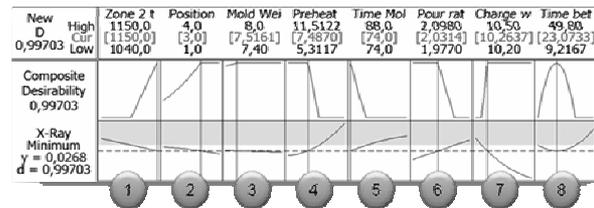

Fig. 4. Response Surface Regression Optimizer

The preheat furnace mold positioning included in the regression analysis allowed additional information to be obtained – the distribution of good X-Ray parts in the function of their positioning in the furnace in correspondence to the furnace door (Fig. 5).
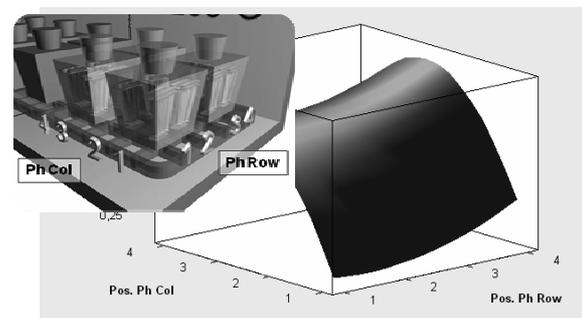

Fig. 5. Distribution of good parts in a mold in the function of their location in the preheat furnace

The result showed, that a probable cause of the quality problem is the thermal insulation of the pusher preheat furnace door.
The FMEA analysis has been updated at the end of the ANALYZE phase – the result is shown in Table 2.

Table 2. FMEA results

Root cause	Provisional action	Target action
Single control and steering thermocouple per zone, different work temperatures for the preheat furnace final zone	1. Increasing the preheat furnace middle zone temperature to 1150°C In order to extend the time a mold is exposed to high temperature, 2. Mold preheat time correction	1. Increasing the preheat furnace middle zone temperature to 1150°C In order to extend the time a mold is exposed to high temperature, 2. New control system for the preheat furnace
Different preheat temperature than originally approved, shorter time	1. Increasing the preheat furnace middle zone temperature to 1150°C 2. New mold insulation scheme	New control system for the preheat furnace
Preheat furnace lining and seals control	1. Increasing the preheat furnace middle zone temperature to 1150°C 2. Preheat furnace door lining repair	New preventive maintenance schedules for the preheat furnace
Mold cooling because of the lack of immediate preheat furnace door	Additional operator for door operation during mold removal and transfer to the casting furnace	Moving the preheat door furnace control to the casting furnace operator

The preparation, evaluation and implementation of solutions belongs to the **IMPROVE** phase. During this stage of the project, technical solutions to the problem have been generated from the root causes list (Table 2 – FMEA, column 3). Then, basing on a pilot lot, the solutions were checked for results and the ability to be implemented. A list of implemented solutions is presented below:

✓ Increasing the temperature of the preheat furnace middle zone from 1040 to 1150°C in order to increase the influence of the heat zone on the ceramic mold.

✓ Change of the mold insulation scheme to compensate for the preheat furnace final zone temperature distribution changes (basing on the comparison of current X-Ray images and images from the time of process approval, and the conducted furnace temperature distribution evaluation).

✓ Implementation of alloy melting curve in order to standardize the final preheat furnace zone mold dwell times in such a way, that they are not shorter than 12 minutes allowing a proper preheat

✓ Preheat furnace door insulation seal improvement (prevents mold cooling)

✓ Moving preheat furnace door control in order to enable their immediate closing after mold removal (prevents the cooling of remaining molds)

Figures 6-7 show sample results from statistical tests for the most significant solutions. In the case of preheat temperature increase to 1150°C in the preheat furnace middle zone, the variability as measured by X-Ray strap rates was reduced almost 3 times. A similar effect was achieved with the preheat furnace door lining repair.
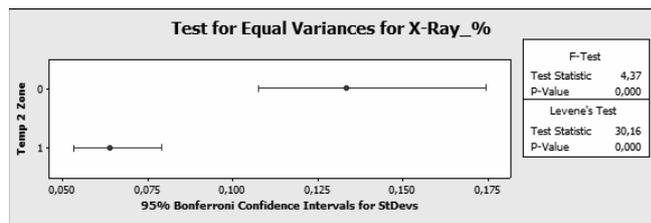

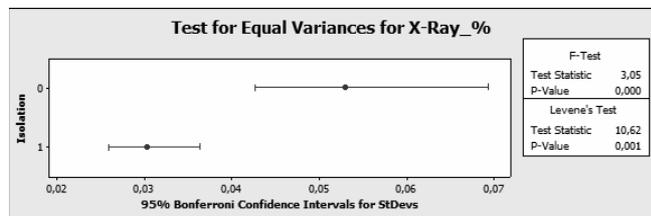Fig. 6. F-test for the preheat furnace middle zone temperature change

Fig. 7. F-test for the strap quantities before and after preheat furnace door repair

The last phase of the project is the CONTROL phase. It's objective is the verification of obtained results (measures assigned to the project), setting of new standards to maintain them in the future, evaluation of business results and the closing of the project. The main results of this project are the decrease of variability for all the key input parameters characteristics for the processes in question (Table 3), and over 10 fold reduction in scrap parts per lot (Fig. 8).

In order for this effect to be maintained, new control plans for the key characteristics have been devised, taking into consideration the rules for making decisions and performing corrective actions in the case of nonconformances.

Corrections have been implemented in the preventive maintenance instructions for the process equipment, especially for the preheat and casting furnaces in order to minimize the possibility of special conditions occurring.

Casting manufacturing technologies have been updated to the new standards with the simultaneous introduction of visualization for the most sensitive operations performed manually (Cookbooks).

Table 3. Comparison of key characteristics capability before and after the completion of the project

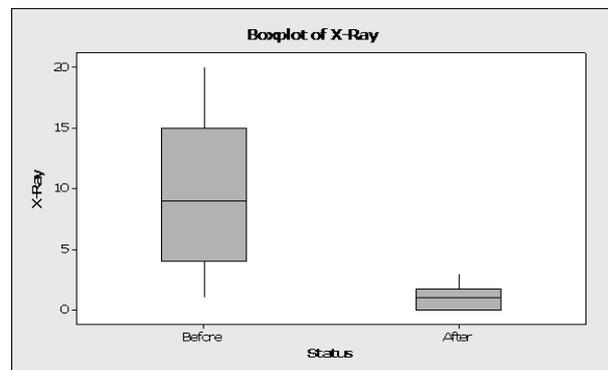| Characterisctic	Capability before	Capability after
Mold weight	1,06 Cpk	1,57 Cpk
Preheat time	**0,38 Ppk**	**0,68 Ppk**
Preheat temperature	1,76 Ppk	1,82 Ppk
Time between molds	**0,48 Ppk**	**0,78 Ppk**
Time to pour	**0,30 Ppk**	**0,83 Ppk**
Casting temperature	1,93 Cpk	2,11 Cpk
Pour rate	1,34 Cpk	1,43 Cpk
Charge weight	1,53 Cpk	1,35 Cpk

Fig. 8. Quality effect of the project

3. Summary

The application of DMAIC methodology with it's statistical tools allows an efficient identification of quality issues and reduction of process parameters basing on data, numbers and facts. It gives measurable financial profits in reducing the costs of poor quality and a number of non-financial benefits such as developing teamwork skills, improving project team members' competencies, deepening the process knowledge together with the knowledge of root problem causes.

„If we do not measure, we do not know. If we do not know, we cannot act. I we do not act, we are running a risk of losses"

M.J. Harry

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