ARCHIVES
of
FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 7
Issue 3/2007

25 – 28

5/3

IX - *MR* Control Chart as a Tool in Assessment of the Cast Iron Properties Stability

F. Binczyk*, J. Szymszal, A. Smoliński
Chair of Metal Alloys and Composites Engineering, Silesian University of Technology,
Krasińskiego Str. 8, 40-019 Katowice, Poland
*e-mail: franciszek.binczyk@polsl.pl

Received on: 10.04.2007; Approved for printing on: 27.04.2007

Abstract

The study offers a statistical assessment of the stability of a technological process of melting and pouring low-carbon grey iron assigned for casting of brake discs. Some specific characteristics were presented that should be taken into consideration when statistical methods are used for technology improvement. The stability of the cast iron melting process was evaluated using data read out from the thermal analysis curve and true data, i.e. the results of spectrometric analysis of the chemical composition and measured values of the mechanical properties. The method for assessment of process stability was discussed on the example of carbon content and Brinell hardness. The examined parameters of the technological process of grey iron melting and casting are independent of each other (the results of carbon content determination in successive melts, the results of hardness measurements, etc.). Therefore, for analysis, the *IX - MR* type charts were chosen, where single measurements of the selected property (n = 1) serve as a *measure of location*, while a *measure of variability* are the, so called, *Moving Ranges* (MR), which are an absolute value of the difference between the two successive measurements.

Keywords: Statistical process assessment, Control charts, Grey cast iron, Thermal analysis, Hardness

1. Introduction

There are various factors which tend to disturb the smooth run of every technological process. These disturbances can be of either random (common) or special character. The disturbing factors included in the first group usually occur in a large number and should be identified immediately. Each of them considered separately has a negligible effect on the process variability (e.g. incorrect assembly of foundry mould). On the other hand, factors of the second type are of a causal and systematic character. They change the quality of product or the quality of process (e.g. unexpected damage to the inoculant metering device).

A very handy tool in identification of the special disturbances are control charts by means of which one can learn about the, so called, natural process behaviour. In numerical assessment, control charts are used when the results of the measurements of the properties to be checked are available.

The essence of an analysis done with the use of control charts serving as a tool consists in establishing, basing on the plotted graphs, if there are any reasons to suspect that the monitored process may be out of control, and if so, in eliminating any possible special disturbances that might be responsible for this state.

2. The principle of using control charts

The main condition that should be satisfied when control charts are used is to have a normal distribution of the obtained results. At present, this hypothesis is most often verified by the non-parametric tests, like: *Pearson's chi-square* (χ^2) *test*, *Kolmogorov-Smirnov λ test* [1], or by graphic methods using a *normal probability diagram* [2]. After checking the hypothesis of a normal distribution of the results obtained for the examined property, the computations are started to present the chart in the form of a graph, which in an unambiguous way will let us see the behaviour of the process under control. On the graph in the control chart there are four basic lines: *centre line (CL*) - shows the mathematical mean of all the results plotted, *upper control limit (UCL)* and *lower control limit (LCL)* - calculated from the specially developed formulae, defining the ranges within which the values of the examined characteristics of the descriptive statistics should be comprised (e.g. mean values, ranges, or standard deviations). The last of the lines shows a *graph of the measured characteristic* of the examined property in the form of points placed in a row.

The control procedure usually consists (specially at a preliminary stage of the process) in checking if any of the eight *reference graphs* described by the Polish Standard PN-ISO 8258 happens to be present [3]. For this purpose, the area between the control limits is divided into six zones, each of a 1σ width, where the two zones adjacent to the centre line are designated as C, the other two lying on both opposite sides of the centre line are designated as B, and the next two as A. An example of the control chart with adjustable graph and division into zones is shown in Figure 1.

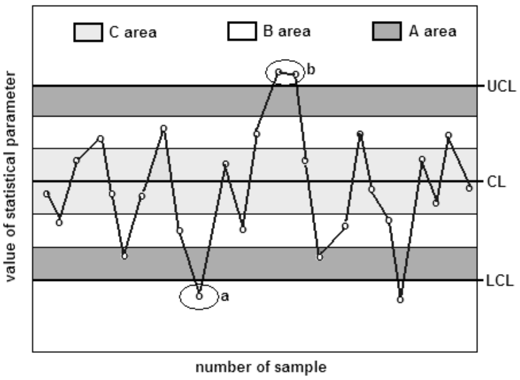

Fig. 1. Example of control chart : a) single signal, b) group signal

Knowing the properties of a normal distribution (on which the reference run tests are based), we also know that **about 68%** of the results should fall inside zones C, and only about **4,3%,** inside zones A [3].

According to the standard, the process is considered **out of control**, when the following events occur on the diagram:

- one or more points falling outside zone A,
- two of the three points in a row falling inside zone A,
- six points in a row steadily increasing or decreasing,
- fourteen points in a row alternating up and down,
- four of the five points in a row falling inside zone B or outside this zone,
- eight points in a row falling on both sides of the centre line but none of them inside zone C.

If the values of the statistical parameters are comprised within the range of control limits, it is assumed that the process is, in principle, stable and in control. On the other hand, going outside any of these limits is a signal of some disorders. A signal on the control chart monitoring process disorders can occur as a single event or can form a group of events [4].

The occurrence of a group of signals indicates either the lack of quick response to a single signal, or inefficiency of attempts to keep the process in control.

The analysed parameters of the technological process of iron melting and casting are independent of each other (the results of carbon content measurements in the successive melts, the results of hardness measurements, etc). Therefore, for analysis, the *IX - MR* type charts were chosen, where single measurements of the selected property serve as a *measure of location*, while a *measure of variability* are the, so called, *Moving Ranges* (MR), which are an absolute value of the difference between the two successive measurements. An average value of these moving ranges is the point of departure for computation of the location of control limits on the chart.

The individual values are computed in the following way:

- for chart $I\overline{X}$ - the next point X_i :

$$CL = \overline{X} = \frac{\Sigma X_i}{n};$$

$$UCL = \overline{X} + 2,66 \cdot \overline{MR};$$

$$LCL = \overline{X} - 2,66 \cdot \overline{MR};$$

- for chart MR - the next point $MR = \left| X_i - X_{i-1} \right|$:

$$CL = \overline{MR} = \frac{\Sigma MR}{n-1};$$

$$UCL = 3,27 \cdot \overline{MR};$$

$$LCL = 0;$$

3. The choice of process parameters

The investigations were conducted at one of grey cast iron foundry. The subject of the investigations was grey cast iron containing: from 3,25 to 3,45% C, 1,9 to 2,0% Si, from 0,5 to 0,7% Mn, 0,15 to 0,25 % Cr, 0,15 to 0,25 % Cu, up to 0,08% S, and up to 0,1% P.

The aim of the present study was to make a statistical assessment of the stability of a technological process of melting and casting low-carbon grey iron. As an example of the variables, the content of carbon in cast iron and hardness HB were chosen. For analysis were used the results recorded in melt history and data read out from the graph of Derivative Thermal Analysis (DTA - *Polish abbreviation ATD*). As a reference served the data compiled in an in-plant standard, determining the *Upper Specification Limit (USL)* and *Lower Specification Limit (LSL).*

4. The results of investigation and analysis

The analysis covered the period from October till December 2006. A database was created using a licensed version of the Microsoft Office Excel V 2000 calculation sheet [5]. In accordance with the statistical procedure, the assessment of process stability done by the method of control charts began with checking the hypothesis of normal distribution of the analysed results. This was achieved using as a tool the “normal probability graph” applied in the form of a Shapiro-Wilk test [2]. In each case, the normal distribution of results was stated which, according to the procedure, enabled some selected parameters of the technological process to be assessed for stability.

To make the statistical analysis easier and more efficient, the control charts were divided into three time-period groups corresponding to the melts conducted in October, November and December.

The obtained values of UCL and LCL as well as the upper and lower specification limits USL and LSL determined by the process regime were plotted on the graph of factors analysed in the successive periods, obtaining ultimately an $I\overline{X}$ control chart and MR chart. The control charts developed in this way are shown in Figures 2 to 5. The area between UCL and LCL, determining the characteristic limits of descriptive statistics, was divided, in accordance with the principles adopted in the analysis, into three zones: C, B and A, each of a 2 sigma width.

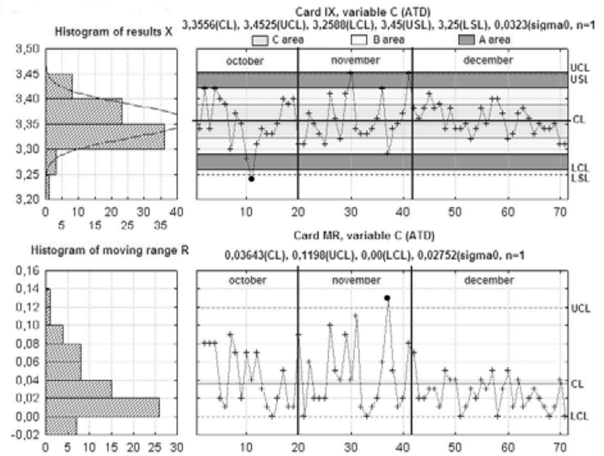

Fig. 2. The results obtained on IX and MR charts for carbon content based on DTA diagram

The $I\overline{X}$ chart of the estimated carbon content derived from the DTA diagram (Fig. 2) indicates the lack of stability of this parameter in October - one result falling outside zone A. Full stability was obtained in December with zero results falling outside the range of upper UCL and lower LCL.

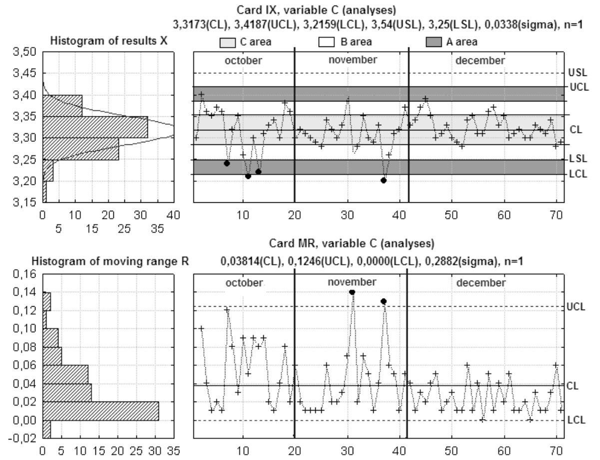

Fig. 3. The results obtained on IX and MR charts for carbon content analysis

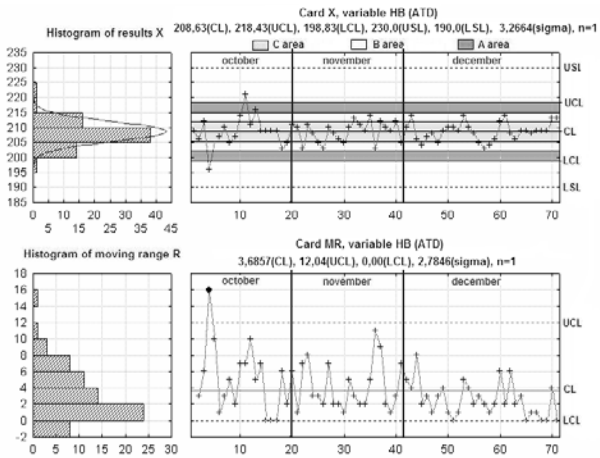

Fig. 4. The results obtained on IX and MR charts for HB hardness measurements based on DTA diagram

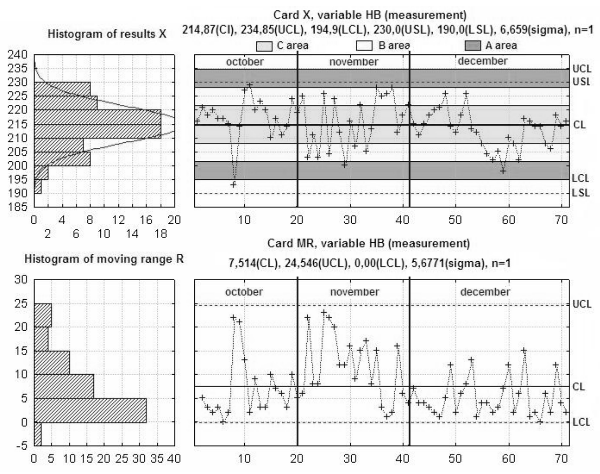

Fig. 5. The results obtained on IX and MR charts for HB hardness measurements

As regards the true carbon content (Fig. 3), a serious process disorder was observed in the month of October and one single signal was recorded in November, according to the event visible on *MR* chart. The obtained results of the carbon content measurements were in four cases lower than the values demanded by the specification. The best results of the stable carbon content were obtained in December. Similar results were obtained as regards the estimated stability of cast iron hardness HB.
More information on carbon content stabilisation and hardness measurements follow from the data analysed in Figures 6 to 9.

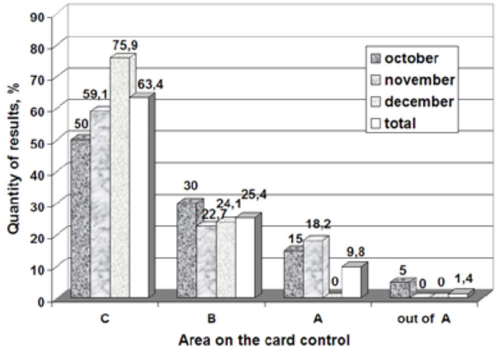

Fig. 6. The comparison of results for C_{ATD} in area on the control chart

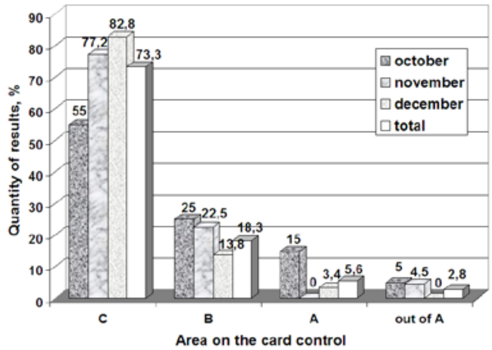

Fig. 7. The comparison of results for $C_{anal.}$ in area on the control chart

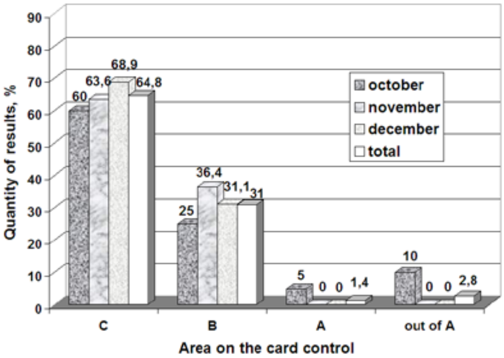

Fig. 8 The comparison of results for HB_{ATD} in area on the control chart

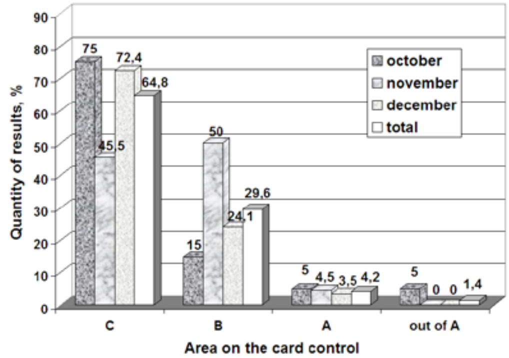

Fig. 9. The comparison of results for $HB_{mesur.}$ in area on the control chart

The diagrams show percent fraction of the measurement results in four zones of the control chart, i.e. C, B , A and outside A, as determined by the statistical **"sigma"** parameter**.** The results were given for each reported month and for the whole period.

In accordance with the formula of normal distribution, the process may be considered stable when at least 68% of the measurement results are falling inside zone C. So, from the total of all results it follows that as regards carbon content and hardness, the technological process can be considered stable. On the other hand, a very definite lack of stability in the analysed parameters was observed for the carbon content in October and for hardness HB in November.

5. Summary

On the example of IX and MR control charts it has been proved that it is possible to quickly assess a selected technological process and, basing on the obtained results, take immediately the necessary corrective measures. With the process well in control, it is necessary to find out and fix the position of a centre line together with control limits and change them only in cases well justified, e.g. after changing the production regime or the technological process.

References

[1] M. Maliński, J. Szymszal: Współczesna statystyka matematyczna w medycynie w arkuszach kalkulacyjnych., Wyd. Śl. Akademii Medycznej, Katowice ,1999, (in Polish).

[2] Greber T.: Jak czytać karty kontrolne Shewharta. Normalizacja, 11 ,1999, (in Polish).

[3] J. Szymszal, L. Blacha.: Wspomaganie decyzji optymalnych w metalurgii i inżynierii materiałowej. Wyd. Pol. Śl., Wyd. II., Gliwice ,2005, (in Polish).

[4] Praca zb. pod red. Tabora A.: Zarządzanie jakością, tom 3. Metody oceny jakości w materiałoznawstwie, Wydawnictwo Politechniki Krakowskiej, Kraków, 1999 (in Polish).

[5] J. Wilkenbach: Exel 2003 PL – Bible, wyd. Helion, Gliwice, 2004, (in Polish).