Optimisation of the Turbo Blowers cooling process functionality using OSPC

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Abstract. With the start of a new industrial revolution, meaning the forth level of automation, that includes data lake integration on a local server or cloud options, the need for analysing the gathered data has emerged. The classic methods of statistical analysis are now applied on data collected from servers, and the online statistical approach has emerged by using an Online Statistical Process Control (OSPC) tool. The paper aims to present the statistical methods used for Turbo Blowers optimisation of the cooling process of steam in a closed water-steam circuit, in the metallurgy industry. By using the OSPC connected to a server, data was gathered and processed in order to optimise the cooling process of the steam, in order to provide the end user with the required amount of compressed air without jeopardising the equipment.

1. The role of statistics in industry

With new era of digitalization, the data from all kind of processes in industry are more accessible. The big challenge of today is to find the most comfortable way to interpret a large amount of data and to extract precious information about equipment stability and process optimisation. Due to this, in the past few years, on the market are accessible a huge number of various software’s tools, that assists process engineers into daily activities.

For statistical approach of the processes the offline and online tools are accessible.

The difference consists in the way that the data from the equipment’s are transferred to the software tool and not from the point of view of the analysis methods. The online statistical process control can be effectively used to develop and maintain the on-line process analyzers. Process variables that also characterize and influence the product quality can have a significant role in controlling and optimizing processes. Off-line laboratory tests take a long time and these delays can cause control problems that lead to economic losses. For a control tools, the real-time approach, is the best choice because of their fast response time. [1]

In the same line, the fundamental objective of statistical quality control is to quickly detect the effect of unassigned causes or changes in the process, so that corrective actions can be taken at the appropriate time. [2]
OSPC provides information for quality control as well as for monitoring and controlling systems. It is known that the processes contain variations, but there must be a difference between the variation of the common causes and the variation of the special causes. This difference helps to eliminate or reduce variance types and finally to improve processes. By various control diagrams it can be distinguish the variation between common causes and specifically causes. Before deciding that a process is under control, the variations due to special causes must be eliminated. To improve a process, you need to investigate the factors that affect each outcome.

2. The optimisation of the capacitor component for Turbo Blowers

Turbo blower is a critical equipment which help to maintain the iron in liquid state inside the blast furnace (BF). The hot metal appearing through the reduction of ore burden with reducing gases who are produced by the reaction of oxygen with coke and coal. This oxygen is part of enriched hot air blast which is blown and distributed at the bottom of the BF through the straight pipes and blowpipes. Turbo blowers provides the need volumes of air enriched with oxygen to maintain this process inside BF. Generally, this process can be described schematic as in Fig.1. [3]

An air blast system of a blast furnace consists of eight main components: air blower, cold blast main, hot blast stove along with its combustion system, hot blast main, bustle pipe, blow pipes and tubers, and control instruments. [3],[4],[5]

Because the Turbo Blowers is a critical equipment the visualization of the parameters and the analysis of the stability is very important. Due to the complexity of the equipment only a part of it was selected for this analysis, meaning the condenser. This paper aims to approach one component, namely, who is capacitor. This is a crucial part of the equipment and its purpose is to cool the steam in order to return the water back in the closed circuit.

2.1. Block Scheme

In order to understand the process involved, a block schematic of the equipment is presented in the figure below.
Further on the diagram that highlights the process of the air injection in blast furnace is presented in Fig. 3.

![Fig. 3 Schematic diagram of the process](image1)

Legend:
- M01, M02 – Air Flow meter
- TS1, TS2 – Turbo Blower

This equipment works with two turbo blowers, in parallel in order to supply the necessary air flow in the blast furnace. The turbine works by taking the steam input and generating compressed hot air from the steam pot. The steam pot works by taking the water from the Degasser and heating it with natural gas. After the fumes are evacuated from it, the steam then returns to the Turbo blowers.

The capacitors job is critical, and he takes the steam from the Turbo blower. After that cools it with water from the Water-Cooling Tower and the steam turns into water. After all of this, is pumped into the Water-Cooling Tower.

### 2.2. Block Capacitor
In the figure below it is shown the schematic principle of capacitor function.

![Fig. 4 Schematic diagram of the role of the capacitor](image2)

### 2.3. Relevant parameters for this study

![Fig. 5 Relevant parameters for this study](image3)
The parameters considered for this analysis are presented in the figure above. It must also be mentioned the fact that there are two input ways (left and right), both monitored separately.

Fig. 6 Diagram of the data collected from equipment

Fig. 6 shows how data are collected from the equipment. OPC is a software interface standard that enables the communication between Windows programs and the industrial equipment. OPC is an acronym which comes from “OLE (Object Link and Embed) for Process Control” and it is implemented in a server/client pair. The above drawing describes the functional architecture. The OPC SERVER ch comes from “OLE (Object Link and Embed) for Process Control” and it is implemented how data are collected from the equipment and capability parameters. These parameters are described in Table 1.

3. OSPC approach for the optimisation of capacitor functionalities

The OSPC method to optimize processes consist in data interrogation in real-time by using the process and capability parameters. These parameters are described in Table 1.

| Capability Parameters | Performance Parameters |
|-----------------------|------------------------|
| s - standard deviation | S - standard deviation of the individuals in the subgroup |
| T - tolerance         | T - tolerance          |
| USL - value of the upper specification limit | USL - value of the upper specification limit |
| LSL - value of the lower specification limit | LSL - value of the lower specification limit |
| $\bar{x}$ - average of measurement values | Avg - Average |
| $s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$ | $S = \frac{m_1^2 - \frac{m_1^3}{m_0}}{m_0 - 1}$ |
| $s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2$ | Avg $g = \frac{m_1}{m_0}$ |
| $\bar{x} = \frac{1}{n}\sum_{i=1}^{n}x_i$ | $m_0 = \sum x_i^0$ |
| USL $= \bar{x} + 3s$ | $m_1 = \sum x_i$ |
| LSL $= \bar{x} - 3s$ | $m_2 = \sum x_i^2$ |
| $C_p = \frac{USL - LSL}{6s}$ | $m_3 = \sum x_i^3$ |
| $C_{pu} = \frac{USL - LSL}{6s}$ | $m_4 = \sum x_i^4$ |
| $C_{pk} = \min\{C_{pu}, C_{pu}\}$ | USL-LSL |
| $C_m = \frac{USL - LSL}{3s}$ | $P_p = \frac{3S}{S} P_{pu} = \frac{Avg LSL}{3S}$ |
| $C_{pm} = \frac{6S}{C_p}$ | $P_{pk} = \min\{P_{pu}, P_{pu}\}$ |
| $C_r = 100 \frac{100}{C_p}$ | USL-LSL |
| $Z_{min} = \min(Z_{L}, Z_{U})$ | $P_{pm} = \frac{6S}{P_p}$ |
| $Z_L = \frac{\bar{x} - LSL}{s}$ | $100$ |
| $Z_U = \frac{USL - \bar{x}}{s}$ | $P_r = \frac{100}{P_p}$ |
| $P_{2u} = \frac{USL-Avg}{s} P_{2l} = \frac{Avg-LSL}{s}$ | $P_{2min} = \min\{P_{2u}, P_{2l}\}$ |
| Skew $\Rightarrow \beta_1 = \frac{m_3m_0 - 3m_2m_1 + 2m_1^3/m_4}{m_0^2(m_2 - m_1^2/m_0)^2}$ | $P_{2min} = \min\{P_{2u}, P_{2l}\}$ |
| Kurtosis $\Rightarrow \beta_2 = \frac{m_4m_0 - 4m_3m_1 + 6m_2m_1^2/m_0 - 3m_2^2/m_0^2}{m_0^2(m_2 - m_1^2/m_0)^2}$ | $P_{2min} = \min\{P_{2u}, P_{2l}\}$ |

Table 1 Statistics - capability and performance parameters [8]
The optimization has the $3\sigma$ approach from Gauss bell, as can be seen in Fig.7.

Fig. 7 Gauss bell

The calculation of a sigma level gives a more accurate picture for obtains the desired target. The appearance of the quality characteristics given between the regulatory limits indicates the process performance of 3 sigma. If all the points on the X and Y axes are within the 3 sigma and vary randomly, the effective mean value of the variables may be significantly different from the specified nominal value of the variables. In this case, an adjustment of the variable is required to move the average closer to the face value. When the is an ideal goal or value for a parameter, always try to get results with the target average and minimum variance, not just values within the specifications. It is not enough to act only on the special causes of variation by adjusting the compensation process.

The importance of OSPC implementation is to use process capacity indices. There are several capacity indices, where the most commonly used indices are $C_p$, $C_{pk}$, $P_p$ and $P_{pk}$.

In Standard Practice for Process and Measurement Capability Indices is mentioned: „Process capability indices or potential process performance ($C_p/C_{pk}$) compare the variability of a process quality measure against product specifications or tolerances and assume the process is in a state of statistical control. $C_p/C_{pk}$ it is based on the average distance between adjacent points.” [7]

Benefits of OSPC are the follow: reduce problems, prevent process failures, improve quality, reduce process costs, optimize processes, increase overall equipment efficiency. [8]

| Part characteristic                                  | LSL | Target | USL | $C_{pk}$ | $C_p$ | Difference |
|------------------------------------------------------|-----|--------|-----|----------|-------|------------|
| Cooling water pressure before capacitor right        | 10  | 55     | 100 | -243,2083| 467,9207| 711,1290   |
| Cooling water pressure before capacitor left         | 10  | 55     | 100 | -111,8350| 211,3410| 323,1761   |
| Cooling water flow before capacitor left             | 10  | 20     | 30  | -93,1345 | 0,3732 | 93,5077    |
| Capacitor pressure 1                                 | 0,010 | 0,205 | 0,4 | -1206,9742| 54,4644 | 1261,4385  |
| Water temperature before capacitor left              | 40  | 60     | 80  | -7910,8  | 10214,5944| 18125,4143 |
| Water temperature after capacitor right              | 40  | 60     | 80  | -5501,6628| 10244,1364| 15745,7992 |
| Water temperature after capacitor left               | 40  | 60     | 80  | -4744,7895| 9169,3095 | 13914,0990 |
| Capacitor pressure 2                                 | 0,010 | 0,205 | 0,4 | -1191,9199| 63,2027 | 1255,1226  |
| Cooling water flow before capacitor right            | 10  | 20     | 30  | -6,8440  | 1,0589 | 7,9029     |
| Water temperature before capacitor right             | 40  | 60     | 80  | 0,000    | 0,000 | 0,000      |
| Feed temperature                                     | 40  | 50     | 60  | 127,4033 | 1767,0192| 1639,6159  |
| Cooling water pressure after capacitor left          | 10  | 55     | 100 | 50,0506  | 112,5159| 62,4654    |
| Cooling water pressure after capacitor right         | 10  | 55     | 100 | 66,5325  | 174,9384| 108,4059   |

Table 2. Capability parameters of the collected variables
The input/output parameters are inserted in OSPC software and the figures here below are showing the results after the statistical interpretation of the software.

**Input Parameters**

Fig. 8 Cooling water flow before capacitor right

Fig. 9 Cooling water flow before capacitor left

Fig. 10 Cooling water pressure after capacitor right

Fig. 11 Cooling water pressure after capacitor left

Fig. 12 Cooling water pressure before capacitor right

Fig. 13 Cooling water pressure before capacitor left
Fig. 14 Water temperature after capacitor right

Fig. 15 Water temperature after capacitor left

Fig. 16 Water temperature before capacitor right

Fig. 17 Water temperature before capacitor left

Output parameters

Fig. 18 Capacitor pressure 1

Fig. 19 Capacitor pressure 2
Fig.20 Feed temperature

The parameters collected using the OSPC software are presented in Fig.8 – Fig. 20. As it can be observed there are some deviation compared with the optimal values. In red marking, there are parameters that have an irregular peak value. It is possible that these deviations can occur sometimes due to different inputs from blast furnace, but this doesn’t affect the operating equipment. The OSPC software offer the possibility to predict from the statistical point of view the right operating ranges for all the involved parameters. All in all, in order to change the operating intervals, it is necessary to gather more data related to different operating scenarios for an even greater time frame (min 6 months). The above mentioned are necessary in order to have an optimal process without damaging the operating condition of the equipment.

4. Conclusion

Considering the parameters and the calculations done by the OSPC software, we notice that the parameters are well above the control limit set at that moment. This is because the capacitor functionality can be further improved to match the optimum operating condition. This equipment can sustain much higher loads. Due to the fact the two turbines that are working in parallel are not used at their full capacity, the output capacitor pressure and feed temperature are affected.

A solution for this issue is to do more simulations with different control limits which allows to calculate a wider Gauss curve.

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