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TPM INDICATORS AS PERFORMANCE MEASURES OF AN UPGRADED MANUFACTURING PROCESS

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Zinc oxide concentrate production is performed in the so-called rolldown process with the use of rotary furnaces. It is a complex technological process in which the zinc-bearing waste harmful to the environment is used as raw material. Incorrect process execution will cause a large number of unplanned stops. Three upgraded technological lines used for the production of concentrated zinc oxide at B. Recycling Sp. z o.o. company were analyzed. The purpose of the study was to determine the production process efficiency after implementation of the changes. In the study we used the Total Productive Maintenance method. We made the histograms for planned downtime and failures of individual technological lines for a period of one year and set the MTTF, MTBF and OEE indices. Analysis of results has allowed to propose a solution to shorten the failure duration.

Keywords: production process efficiency, TPM, performance measures

1. INTRODUCTION

The adaptation of production of zinc from zinc-bearing waste requires adapting the technology to the environmental protection provisions, mainly in relation to emission of pollutants and noise and waste disposal. Zinc-bearing waste is hazardous to the environment, in particular to aquatic resources. New legislation caused its processing to become – also for entrepreneurs – more cost-effective economically than storage. Therefore it was facilitated to acquire raw materials for the steel mill and it could be smoother than ever before. In the framework of further investments from the zinc steel mill the new B. Recycling Sp. z o.o. company was sepa-

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rated. The upgrade of the existing system forced by the regulations covered the conversion of:
– feeding nodes,
– cooling and dust collecting line,
– furnace fueling system (change from coal to gas),
– slag reception system,
– installation for pelleting of concentrated zinc oxide.

The sintering process has also been eliminated and the whole manufacturing process was automated. Figure 1 shows the diagram of the production system after the upgrade.

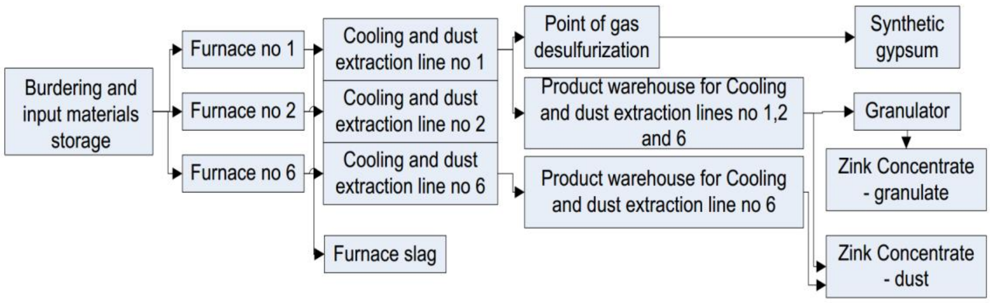

Fig. 1. Diagram of the concentrated zinc oxide production system after the upgrade [own elaboration]

There are three production lines in the company. Two of them are adapted to the manufacture of the concentrated zinc oxide from both dust and zinc-bearing sludge (lines 1 and 6), while the third only processes sludge (line 2). After the system upgrade it was necessary to examine the effectiveness of individual lines. The complex technological process and the specifics of the used equipment influence the large number of breaks in the system's operation. It was therefore decided that the analysis should focus on the planned downtime and breakdown of machinery and equipment included in the installation for the production of concentrated zinc oxide. TPM method elements were used (Michlowicz, Smolińska, 2014). For each technological line OEE, MTTR and MTBF indices were assigned.

2. TOTAL PRODUCTIVE MAINTENANCE

Today at the majority of modern enterprises the knowledge and application of the principles of LEAN management (Womack, Jones, 2009) is common. This is related, i.a., to the use of tools and methods of production process improvement from the Lean Toolbox set (Bicheno, Hollweg, 2008), the effectiveness of which is proven by many positive examples of application. Their implementation is often linked with high costs. One should also remember that each of the tools has a defined, relatively narrow application (e.g. the use of SMED makes sense in the case of multi-range production and only where there are at least a few set-ups within a shift). Therefore, the correct choice of method should be preceded by a comprehensive analysis, which includes the specifics of the particular production process (Michlowicz, Smolińska, 2015), (Hadaś, 2014), (Wojakowski, 2016).

The common assumption of Lean Manufacturing methods is to create, keep and improve the continuous flow of material in the production system (Nyhuis, Wiendhal, 2009), (Harris, Harris,Wilson, 2007). One of the methods of achieving this is to ensure the continuity of the work of machines, which is the primary purpose of the TPM (Total Productive Maintenance) method (Rother, Harris, 2010). It involves the use of the company human resources to identify the causes of waste and loss in the production process (Czerska, 2009) and the creation of system solutions for the identified problems (Kornicki, Kubik, 2009). It is caused, i.a., by the use of various indices, hence it is also an excellent method of availability analysis or machinery and equipment efficiency (Koliński, 2016). The main objectives of TPM are:
- elimination (or reduction) of failures,
- minimization (shortening) of repair times,
- elimination of micro downtime,
- reduction of losses.

The most popular indices used in the TPM method are MTTR, MTBF and the most characteristic one – OEE (Kubik, 2012).

MTTR (Mean Time to Repair) determines the average duration of the repairing operation of the machine or device (or their group). It is based on the formula:

$$\mathrm{MTTR} = \frac{\sum \text{repair times}}{\text{number of repairs}} \tag{1}$$

MTBF (Mean Time Between Failures) determines the average time between failures or micro downtime of the machine or device. It is based on the formula:

$$\mathrm{MTBF} = \frac{\sum \text{times of proper work}}{\text{number of proper work events}} \tag{2}$$

The main index of the TPM method is OEE (Overall Equipment Effectiveness), which determines, what percentage of theoretically achievable efficiency of machinery and equipment is currently being used. It is specified by specifying separately the percentage indices of availability (A), performance (P) and the quality (Q) (Kornicki, Kubik, 2009). Finally:

$$OEE = A \cdot P \cdot Q \cdot 100\% \tag{3}$$

The first step in the production process analysis should be to identify the losses and their correct qualification. Then it is possible to determine the OEE and which of the sub-indices (A, P or Q) has the greatest impact on the functioning of the production system.

3. ANALYSIS

The analysis was focused on the planned downtime and breakdowns of machinery and equipment included in the installation for the production of concentrated zinc oxide.

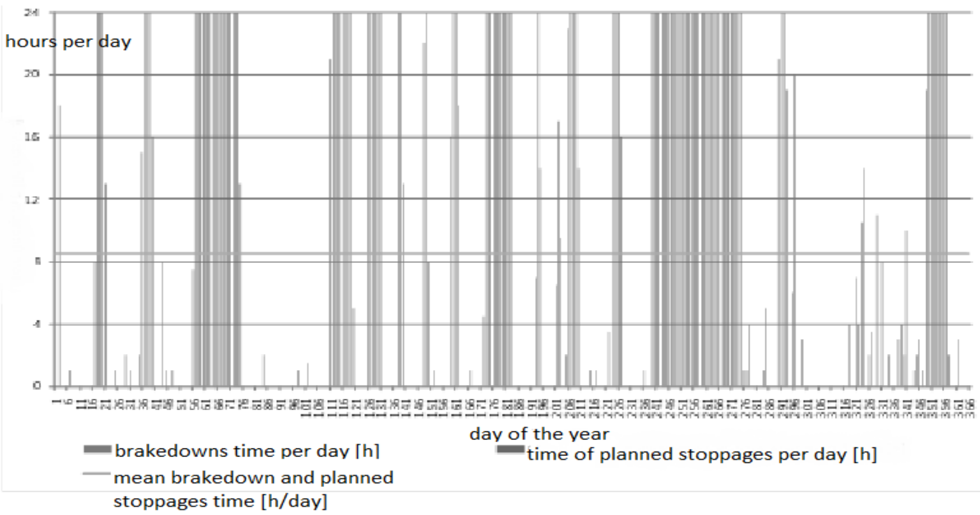

Fig. 2. Histogram of failures and planned downtime for the period of one year for line number two [own elaboration]

The data related to the duration and the reasons of system downtime was collected over a period of one year, separately for each of the three technological lines. It shows the course and results of the analysis for line No. 2 (the histogram was shown in Figure 2). The value of the indices is influenced by both the quantity and duration of planned downtime and failures, however, unplanned system downtime is more problematic for the company. Due to the number and diversity of their root causes, failures are divided by their area of occurrence. The results of the observations with their groups are shown in Table 1.

Table 1. Failures at technological line No. 2 [own elaboration]

Slag reception system	**time [h]**	**Quantity**
Shortening the slag trap chain	23	9
Total:	23	9
The percentage:	4.51%	
Rotary furnace		
Extinguishing	66	2
Removing	224	2
Warming up	32	2
Failure of the feeding head	1	1
Failure of the feeding conveyor	17.5	4
Taring the feed weight	5.5	5
Technological failure – the appearance of build-up	3	1
Total:	349	17
The percentage:	68.50%	
Exchanger coolers		
Failure of the cold cooler regeneration	10	2
Failure of the screw feeder	11	1
Failure of the hot cooler	14	2
Total:	35	5
The percentage:	4,51%	
Filter		
Replacement of the filter bag	13	6
Valve replacement	1	1
Failure of the screw feeder under the filter	6	1
Filter inspection	2	1
Total:	22	9
The percentage:	4.32%	
Pneumatic transport system of the product		
Failure of the line-plate feeder	52.5	13
Cleaning the pump	7	2
Total:	59.5	15
The percentage:	11.67%	
Fan		
Fan failure	1	1
Cleaning the fan blades	1	1
No compressed air	5	1
Total:	7	3
The percentage:	1.38%	
Other		
De-icing of air for the feed	1	1
Failures of the accompanying installation equipment	12	5
Total:	14	6
The percentage:	2.75%	

The most failure-prone system component is the rotary furnace. Its failures are 68.5% of the time of all faults. Generally, failures are 5.28%, and planned downtime is 11.37% of total system operation time.

3.1. Designation of the OEE index for the selected technological line

Designation of the availability A index

$$A_2 = \frac{A_{22}}{A_{21}} \cdot 100[\%] \tag{4}$$

where:
A21 – net operating time (available time) [h],
A22 – operating time (net operating time – planned downtime) [h].

The time of planned downtime in the analyzed period for technological line No. 2 was tpp2 = 996 [h].

The failure time of technological line No. 2 during the analysis period was taw 2 = 509.5 [h].

Calculation of the practical availability:

$$A_2 = \frac{A_{22}}{A_{21}} \cdot 100[\%] = \frac{7254{,}5}{7764} \cdot 100[\%] = 93{,}44\ [\%]$$

Designation of the performance of machinery and equipment at technological line No. 2

The furnace unit No. 2 runs with the assumed project performance. When upgrading, all machinery and equipment included in technological line No. 2 was designed for maximum design performance of the rolldown furnace No. 2 and therefore the performance index for the whole technological line No. 2 can be assumed as equal to P2 = 100 (%).

Designation of the quality factor

The quality factor has been calculated according to the following formula:

$$Q_2 = \frac{Q_{22}}{Q_{21}} \cdot 100[\%] \tag{5}$$

where:
Q21 – Zn content in feed [Mg],
Q22 – Zn content in product [Mg].

The quality factor has been calculated on the basis of the quantity of feed material and the content of the pure zinc and on the basis of the produced concentrated zinc oxide and content of the pure zinc (general data are shown in Table 2).

Table 2. Data for designation of the quality indicator for technological line No. 2 [own elaboration]

	Amount [Mg]	**Zn content [%]**	**Zn amount[Mg]**
Batch	58 839,159	17,52	10 308,621
Production	19 039,309	45,55	8 672,405

$$Q_2 = \frac{Q_{22}}{Q_{21}} \cdot 100[\%] = \frac{8672{,}405}{10308{,}621} \cdot 100[\%] = 84{,}13[\%]$$

Designation of the OEE index for technological line No. 2

$$OEE_2 = A_2 \cdot P_2 \cdot Q_2 \cdot 100[\%] = 0{,}9344 \cdot 1 \cdot 0{,}8413 \cdot 100[\%] = 78{,}61[\%] \quad (6)$$

3.2. Designation of the MTBF index for technological line No. 2

The MTBF was calculated using the formula:

$$MTBF_2 = \frac{t_{ppr2}}{n_{pp2}} \quad (7)$$

Where:
TPPR2 – the sum of the durations of proper operation for technological line No. 2 [h],
TPPR2 – the number of events of proper operation for technological line No. 2.

MTBF index for technological line No. 2:

$$MTBF_2 = \frac{t_{ppr2}}{n_{pp2}} = \frac{7254{,}5}{38} = 190{,}9 \text{ [h/year]} \quad (8)$$

3.3. Designation of the MTTR index for technological line No. 2

The MTTR was calculated using the formula:

$$MTTR_2 = \frac{t_{aw2}}{n_{n2}} \quad (9)$$

where:
taw2 – the sum of the durations of repairs of technological line No. 2 [h],
nn2 – the number of repairs of technological line No. 2.

MTTR index for technological line No. 2:

$$MTTR_2 = \frac{t_{aw2}}{n_{n2}} = \frac{509{,}5}{49} = 10{,}38\ [h/year]$$

In view of the fact that failures of the rotary furnace take the most of the time, a detailed analysis of this component at technological line No. 2 was conducted. General results are shown on the diagram in Figure 3.

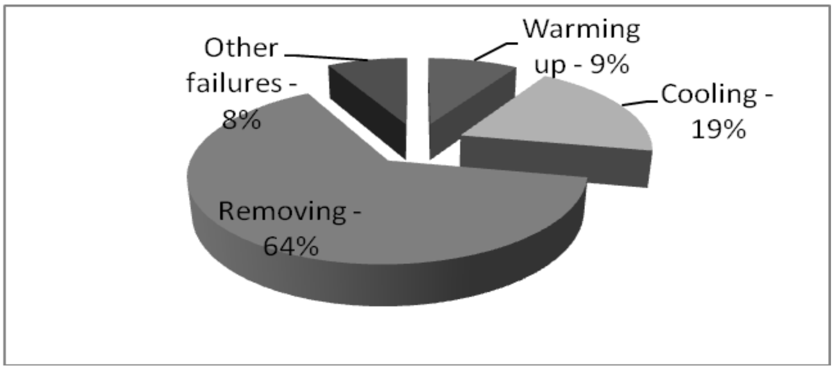

Fig. 3. Components of the rolldown furnace failure duration [own elaboration]

The MTTR for the analyzed line is determined according to the following formula:

$$MTTR_{P2} = \frac{t_{awP2}}{n_{nP2}} \tag{10}$$

where:
tawP2 – the sum of the durations of repairs of the rotary furnace No. 2 [h],
nnP2 – the number of repairs of the rotary furnace No. 2.

MTTR index for the rotary furnace No. 2:

$$MTTR_{P2} = \frac{t_{awP2}}{n_{nP2}} = \frac{349}{17} = 20{,}53\ [\frac{h}{year}] \tag{11}$$

4. SUMMARY

The value of the OEE index designated for line No. 2 suggests that the system has potential for improvements. The result of 78.61% can be considered satisfactory, however, it is relatively low in relation to the other two lines for which the OEE is 83.88% for line No. 1 and 83.83% for line No. 6. These are the results met at the global level. The cause of this difference is, i.a., the fact that another feed material was used and therefore the process was different. Nonetheless, the possibility to improve the process and the results should be sought. Similar analyses were conducted for the other production lines, i.e., line No. 1 and No. 6.

The analysis of index values for the three factors distinguished when designating the OEE, allows to indicate the quality as the area of the largest potential for improvement. But because in this case the quality indicator is directly linked to the nature of the technological process, it is proposed to focus on failures that affect mainly the availability index. This will probably mean lower costs than when interfering in the used technology. The most time consuming is the elimination of failures of the rotary furnace arising from accumulation of build-ups inside the furnace. Any such event requires cooling the furnace, removing the build-up and reheating. Such a downtime may take up to 18 hours. To shorten the duration of the furnace failure it was proposed to use an industrial cannon from the Winchester company in order to eliminate the soiling process and to accelerate the removal of the build-up.

5. CONCLUSION

One of the major goals of the study was to demonstrate, that the modernization of the zinc oxide manufacturing system structure allows for the achievement of desired performance indicators (among others, capacity and availability, what is expressed in the OEE indicator value close to the global level). In this case, the index of machine availability was particularly important. The TPM – Total Productive Maintenance method was used in the study.

The above analysis enabled to observe the number and frequency of failures of individual components included in technological lines No. 1, 2 and 6. The summary and assignment of failures to the individual technological line allowed to identify the units that require attention. This reduced the average failure time and thus increased the production capacity of the concentrated zinc oxide. The calculations show clearly that the rotary furnace at all the analyzed technological lines is a component subject to the largest possible number of failures, and it absorbs the most time to restore the availability of the entire technological line. For this reason, in order to increase the production capacity, it was proposed to eliminate its failure rate with the use of an industrial cannon from the Winchester company.

OEE indices calculated for each technological line allowed for the assessment of effectiveness of use of all machinery and equipment within the analyzed technological lines. The OEE index value for technological lines No. 1 and 6 are similar to each other and are respectively: OEE1 = 83.88 [%], OEE6 = 83.83 [%]. The overall performance index of technological line No. 2 was OEE2 = 78.61 (%). On the basis of the results obtained and the data from the literature (Michlowicz, 2015) it can be concluded that regarding the value of the OEE index, B. Recycling Sp. z o. o. company is in the global group (OEE above 80%).

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WSKAŹNIKI TPM JAKO MIERNIKI WYDAJNOŚCI USPRAWNIONEGO PROCESU PRODUKCJI

Streszczenie

Wytwarzanie koncentratu tlenku cynku następuje w tzw. procesie przewałowym z wykorzystaniem pieców obrotowych. Jest to skomplikowany proces technologiczny w którym jako surowiec wykorzystuje się szkodliwe dla środowiska odpady cynkonośne. Nieprawidłowa realizacja procesu powoduje występowanie dużej liczby nieplanowanych postojów. Analizie poddano trzy zmodernizowane linie technologiczne do wytwarzania koncentratu tlenku cynku w przedsiębiorstwie B. Recycling sp. z o o. Celem opracowania było określenie efektywności procesu produkcyjnego po wprowadzeniu zmian. W badaniach wykorzystano metodę Total Productive Maintenance. Sporządzono histogramy przestojów planowanych i awarii dla poszczególnych linii technologicznych dla okresu jednego roku i wyznaczono wskaźniki MTTF, MTBF i OEE. Analiza wyników umożliwiła zaproponowanie rozwiązania pozwalającego skrócić czas trwania awarii.

Słowa kluczowe: efektywność procesów produkcyjnych, TPM, mierniki wydajności