# IMPROVING THE PRODUCTIVITY OF OPERATION OF ROTARY FURNACES USING THE TPM METHOD

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**Abstract**

Zinc oxide concentrate production from industrial waste is performed in the so-called rolldown process – in rotary furnaces. It is a complex technological process. Incorrect process execution will cause a large number of unplanned stops that significantly affect production. The purpose of the work was to analyze upgrade of technological lines used for the production of zinc oxide concentrate at B. Recycling company. The detailed purposes of the study included the analysis of fault time, standstill of the planned technological lines no. 1 and 6 for processing of steel fly ashes, and line no. 2 for processing of zinc-bearing sludges. In the study the Total Productive Maintenance method elements was used. The histograms for planned downtime and failures of individual technological lines for a period of one year were developed and the MTTF, MTBF and OEE indices for three production lines were set. The results were analyzed. A solution was proposed to shorten the failure time of the above mentioned technological lines.

**Keywords**: Zinc from waste, TPM method, calculation of OEE, MTTR, MTBF indicators

## 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 are hazardous to the environment, in particular for aquatic resources. New legislation caused that its processing became – 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 [1]. In the framework of further investments from the zinc steel mill the new B. Recycling company was separated. The upgrade of the existing system forced by the regulations covered the conversion of:

- cooling and dust collecting line,
- furnace fueling system (change from coal to gas),
- slag reception system,
- installation for pelleting the concentrated zinc oxide.

Sintering process has also been eliminated and the whole manufacturing process was automated. The firm B. Recycling has taken the initiative of management of zinc-bearing waste from diffuse sources. To obtain the required level of carbon dioxide emission in waste gases, it was necessary to implement changes to the previously used technology and equip the plant with the system for absorption of sulphur dioxide from the emitted gases [2], [3]. The firm B. Recycling has implemented the project of modernization and assembly of rotary furnaces and all other elements of lines. The change of suppliers of zinc-bearing waste was a key issue. Activation of a mechanism stimulating system supply with wastes from different producers was a requirement necessary to keep supply continuity.

Due to the complexity of technological process for generation of zinc concentrate from different zinc-bearing waste, during system operation, there are many unwanted downtimes (shutdown, failures, lack of supplies) that has a significant impact on production efficiency.
Figure 1 shows the simplified diagram of the production system after modernization.

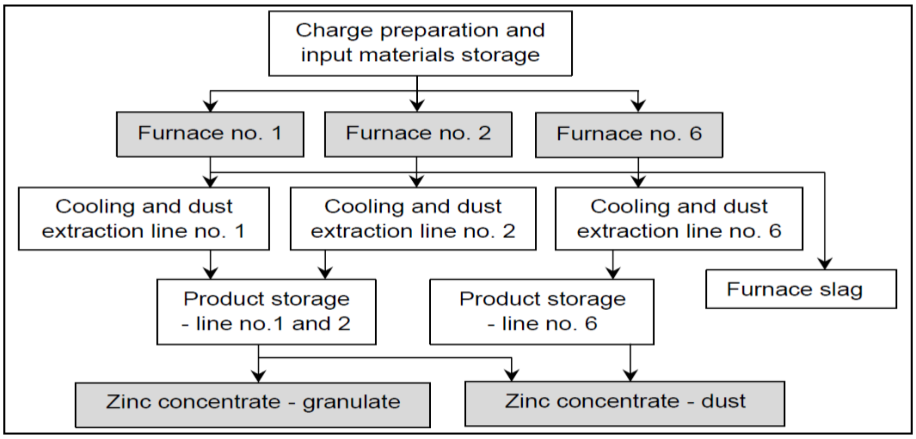


**Figure 1** Simplified diagram of the concentrated zinc oxide production system in roll down furnaces

There are three production lines in the company. Two of them are adapted to the manufacture of the concentrated zinc oxide from both the dust and zinc-bearing sludges (lines 1 and 6), while the third only processes sludges (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 operation. It has therefore been decided that the analysis should focus on the planned downtime and breakdowns of machinery and equipment included in the installation for the production of concentrated zinc oxide. TPM method elements were used [4], [5]. For each technological line OEE, MTTR and MTBF indices were assigned.

## 2. PRODUCTION SYSTEM EVALUATION INDICATORS - TPM METHOD

The common assumption of Lean Manufacturing methods is to create, keep and improve the continuous flow of material in the production system [6]. 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 [7]. It is caused by the use of various indices, hence it is also an excellent method of availability analysis or machinery and equipment efficiency [8]. The main objectives of the TPM are: elimination (or reduction) of failures, minimization (shortening) of the repair times, elimination of micro downtime and reduction of losses. The most popular indices used in the TPM method are MTTR, MTBF and the most characteristic one – OEE.

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 (1):

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

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 (2):

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

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). Finally:

$$OEE = Availability \times Performance \times Quality \times 100\ \% = A \cdot P \cdot Q \cdot 100\ \% \quad (3)$$

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 OF THE OPERATION OF PRODUCTION LINES

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. 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 [9]. 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 [10]. The following were monitored: rotary furnace failures, exchanger coolers failures, dust chamber failures, fan failures, filter failures, failures of pneumatic transport system of the product and slag reception system failures.

**Table 1** presents selected results of the system operation tests, and **Figures 2, 3** and **4** show the shares of shutdowns during the annual operation of the system.

**Table 1** Summary table of selected results for the tested technological lines

| | Unit | Technological line no. 1 | Technological line no. 2 | Technological line no. 6 |
|---|---|---|---|---|
| Proper work time | h/year | 5,634 | 7,254.5 | 6,631.5 |
| Proper work time | % | 64.31 | 82.81 | 75.70 |
| Planned stoppages time | h/year | 1,999.5 | 996 | 797 |
| Planned stoppages time | % | 22.83 | 11.37 | 9.10 |
| Breakdowns time | h/year | 1,126.5 | 509.5 | 1,331.5 |
| Breakdowns time | % | 12.86 | 5.82 | 15.20 |

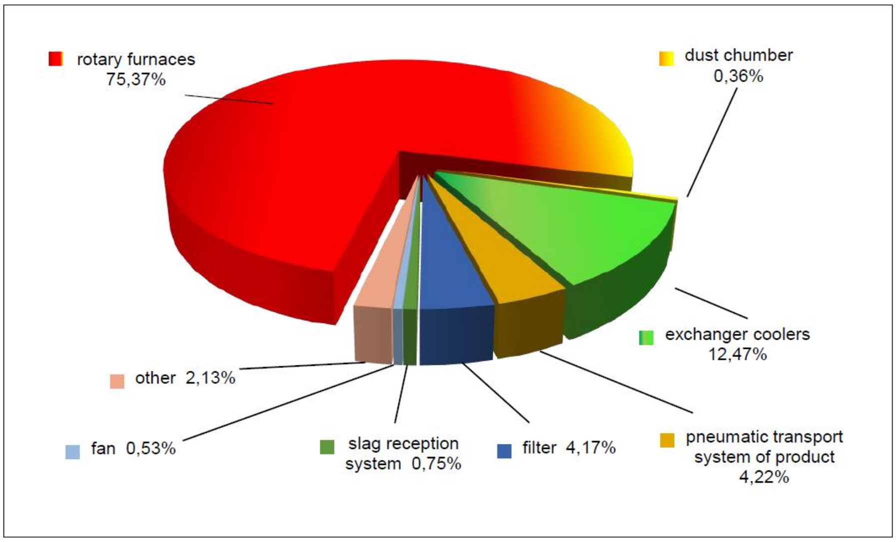


**Figure 2** Share of different failures - line no.1

### 3.1. Designation of the MTBF index for technological lines

The MTBF was calculated using the formula (4):

$$MTBF_i = \frac{t_{ppri}}{n_{ppi}} \tag{4}$$

where:

$t_{ppri}$ - the sum of the durations of proper operation for the *i* technological line (h),
$n_{ppi}$ - the number of events of proper operation for the *i* technological line.
MTBF index for each technological line (h/year):

$$MTBF_1 = \frac{5{,}634}{45} = 125.2\,, \quad MTBF_2 = \frac{7{,}254.5}{38} = 190.9, \quad MTBF_6 = \frac{6{,}631.5}{44} = 150.72$$

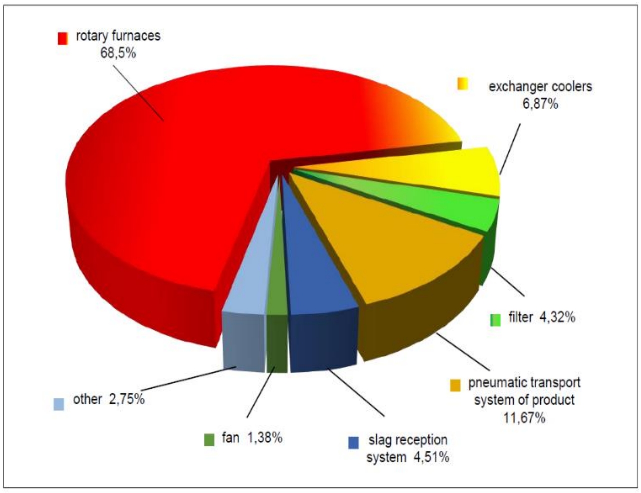


**Figure 3** Share of different failures - line no. 2

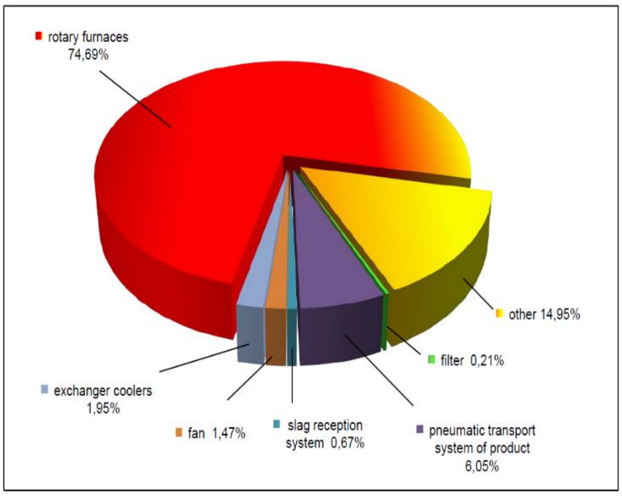


**Figure 4** Share of different failures - line no. 6

### 3.2. Designation of the MTTR index for technological lines

The MTTR was calculated using the formula (5):

$$MTTR_i = \frac{t_{awi}}{n_{ni}} \tag{5}$$

where:

$t_{awi}$ - the sum of the durations of repairs of the *i* technological line (h),
$n_{ni}$ - the number of repairs of the *i* technological line.

MTTR index for each technological line (h/year):

$$MTTR_1 = \frac{1{,}126.5}{53} = 21.25, \quad MTTR_2 = \frac{509.5}{49} = 10.38, \quad MTTR_6 = \frac{1{,}331.5}{51} = 26.1$$

### 3.3. Designation of the OEE index for technological lines

Designation of the availability factor A:

$$A_i = \frac{A_{i2}}{A_{i1}} \cdot 100\ \% \tag{6}$$

where:

$A_{i1}$ - net operating time (available time) for *i* technological line (h),
$A_{i2}$ - operating time (net operating time - planned downtime) *i* technological line (h).

$$A_1 = \frac{5{,}634}{5{,}949.24} \cdot 100 = 94.70\ \%, \qquad A_2 = \frac{7{,}254.5}{7{,}764} \cdot 100 = 93.44\ \%, \qquad A_6 = \frac{6{,}631.5}{7{,}007.44} \cdot 100 = 94.64\ \%$$

Designation of the performance of machinery and equipment factor $P_i$:

Due to the continuous nature of the process, it is difficult to pinpoint the exact values of the coefficient of performance at any given time. Based on experience, however, it can be assumed that its decrease over the annual reference period should not exceed 5 % on average. In this case, $P_i$ = 95 % was assumed for all technological lines.

Designation of the quality factor Q:

$$Q_i = \frac{Q_{i2}}{Q_{i1}} \cdot 100\ \% \tag{7}$$

where [9]:

$Q_{i1}$ - Zn content in feed on *i* technological line (Mg),
$Q_{i2}$ - Zn content in product *i* technological line (Mg).

$$Q_1 = \frac{13{,}290.81}{15{,}003.46} \cdot 100 = 88{,}58\ \%, \qquad Q_2 = \frac{8{,}672.405}{10{,}308.621} \cdot 100 = 84{,}13\ \%, \qquad Q_6 = \frac{13{,}290.81}{15{,}003.46} \cdot 100 = 88{,}58\ \%,$$

A summary of the obtained results is presented in **Table 2** and **Figure 5**.

**Table 2** Data of charge and product for each technological lines in the studied period (%)

| No. of lines | Availability $A_i$ | Performance $P_i$ | Quality $Q_i$ | OEE |
|---|---|---|---|---|
| Line no. 1 | 94.70 | 95 | 88.58 | 79.68 |
| Line no. 2 | 93.44 | 95 | 84.13 | 74.68 |
| Line no. 6 | 94.64 | 95 | 88.58 | 79.63 |

The value of the OEE index designated for the line no. 2 suggests that the system has the potential for improvements. The result of 74.68 % can be considered satisfactory, however it is relatively low in relation to the other two lines for which the OEE is 79.68 % for line no. 1 and 79.63 % for line no. 6. These are the results met at the global level.

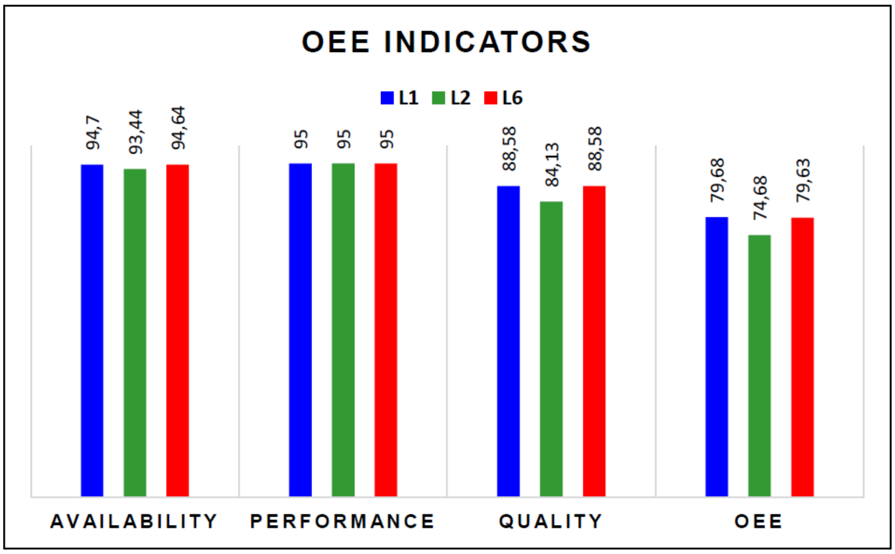


**Figure 5** Graph of OEE indicators for the tested lines (%)

The cause of this difference is the fact that for line no. 2 another feed material was used and therefore the process was different. Nonetheless the possibility to improve the process and the results should be sought.

## 4. CONCLUSION

The analysis of index values for 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. The collective results of determining the OEE, MTBF and MTTR indicators are presented in **Table 3**.

**Table 3** Summary table of results for the tested technological lines

| Factor | Unit | Technological line no. 1 | Technological line no. 2 | Technological line no. 6 |
|---|---|---|---|---|
| MTBF | h/year | 125.2 | 190.9 | 150.72 |
| MTTR | h/year | 21.25 | 10.38 | 26.11 |
| OEE | % | 79.68 | 74.68 | 79.63 |

**Table 3** shows that the MTTR, MTBF and OEE indicators are quite diverse. The lowest number of failures and downtimes occurs in the technological line no. 2. At the same time, this line is characterized by the lowest OEE index (OEE = 74.68 %). In the case of the line no. 1 and no. 6, further improvement requires reducing the failure frequency of devices ($MTTR_1$ = 21.25 h/y, $MTTR_6$ = 26.11 h/y - while line no. 2 more than two times less, $MTTR_2$ = 10.38 h/y). Nevertheless, it can be concluded that the system works correctly after the modernization. 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 the capacity and availability, what is expressed in the OEE indicator value close to the global level). In this case the index of machines availability was particulary important. 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 in order to reduce the average failure time (MTTR) and thus to increase 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 by the use of an industrial cannon from Winchester company.

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