An analysis of the failure frequency of machines in an enterprise characterised by a changeable production level

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Abstract

The article presents the results of investigations into the failure frequency of a selected strategic machine, i.e. a plastic extruder working in an enterprise manufacturing pre-insulated pipes for the needs of the heat-generating industry. The analysis has been focused on the time of failure-free work, the time of waiting for a failure to be repaired and the time of failure removal by means of MTBF, MTTR and MTR indicators.

The analysis has been conducted in the aspect of machine’s work with uneven load, which is forced by the seasonal, changeable character of the production volume. Changes in the determined indicators were examined in particular production periods and at monthly intervals during a calendar year. The research analysis and the conclusions formulated on its basis made it possible to put forward a proposal of measures aimed at improving the current situation and ensuring a better effectiveness of activities undertaken by maintenance teams, as well as their better co-operation with production departments.

Introduction

Failure frequency of machines is a significant problem in industrial enterprises. Failures cause downtimes in the production process and, in consequence, they may contribute to a decreased production, as well as financial losses and the loss of customers’ trust. Most organisations are more and more frequently and effectively minimizing downtimes caused by failures of machines and equipment. Apart from failure frequency, a very important factor influencing the correct functioning of the whole production process and technical facilities which take part in this process is availability or readiness of machines [1]. According to the definition, availability means the ability of a machine to be fit when its use is necessary.

Efficient maintenance of the high availability of machines and equipment taking part in the production process is not a simple task. This process is made difficult by an ever-increasing pressure of time and financial savings. An additional difficulty in the proper functioning of this process is also a changeable volume of production, characterised by seasonal fluctuations of machine load. An intensified load of machines can increase their failure frequency. At this time also preventive measures are more difficult. This phenomenon has been illustrated by a theoretical function of failure intensity $\lambda(t)$ presented in figure 1.

![Fig. 1. Failure intensity versus working conditions (on the basis of [2, 3])](image)

In a season characterised by increased production all the machines are usually so loaded that there is no possibility of transferring production to other, less loaded machines and, in consequence, any failures result in the production line stoppage. All these phenomena force changes in the way maintenance teams are managed [4].
Research method

The investigations were conducted in a production enterprise manufacturing pre-insulated pipes to be used in the heat-generating industry. The enterprise is characterised by a changeable (seasonal) level of production. The biggest production and, in consequence, the greatest load of machines taking part in the production process is observed in the period from April to October. At this time production is based on a three-shift system and the employment of production workers is increased.

The analysis was carried out for one of the crucial machines in the enterprise – an extruder of plastic, which in this case is PE – polypropylene. Thus manufactured pipes are used as external pipe jackets. The data used for research has been collected over the last two years and includes among others:
- date of failure;
- time of failure;
- type of failure;
- time of machine downtime due to failure;
- time of failure removal.

Failures have been divided into three groups [5]:
1. Mechanical failures – failures of mechanical and hydraulic systems which have to be removed by mechanics, e.g. failures of power transmission, charging hopper etc.
2. Electrical failures – failures related to machine power systems which have to be repaired by electricians having relevant qualifications, e.g. failures of contactors, drive motors etc.
3. Automation failures – failures of control systems etc. which must be removed by automation specialists.

The analysis was based on data collected during 89 failures, 31 of which were mechanical failures and 57 – electrical ones. At the time subjected to analysis there was only 1 automation failure, so it was not taken into consideration.

On the basis of the data, the following indices in particular months were calculated [6, 7]:
- MTBF – Mean Time Between Failure,
- MTTR – Mean Time to Repair,
- MTR – Mean Time Repair.

The analysis was also based on a very popular statistical significance test – Mann-Whitney’s test [8].

Analysis of results

The analysis of results consisted in observing the changes of the computed reliability indices (MTBF, MTTR, MTR) depending on the month in the calendar year, in general for the whole extruder and for its systems: mechanical and electrical.

Total failure frequency

Table 1 contains the results for all the failures of the examined extruder.

<table>
<thead>
<tr>
<th>Production period</th>
<th>MTBF [min]</th>
<th>MTTR [min]</th>
<th>MTR [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>High production period</td>
<td>11448</td>
<td>61.5</td>
<td>82.2</td>
</tr>
<tr>
<td>Low production period</td>
<td>16554</td>
<td>0.2</td>
<td>101.5</td>
</tr>
</tbody>
</table>

In the high production period the value of MTBF reached ca 11 500 minutes and for the low production period – ca 16 500 minutes. The MTTR index, which informs of the time after which maintenance employees start working on failure removal, was approximately 1 hour for the high production period, whereas in the low production period it reached merely 0.1 minutes, which means that the maintenance workers proceeded to remove failures almost immediately. The MTR index, which informs of the time taken by maintenance workers to remove a failure, in the high production period was approximately 80 minutes and in the low production period – ca 100 minutes.

The conducted Mann-Whitney’s test, reaching the significance level of 0.05, showed that all the values for both periods differ considerably from each other.

Figures 2–4 present the distribution of the number of failures as well as MTBF, MTTR and MTR indices depending on the month in which they occurred. The increased production months have been marked with a brighter colour.
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Fig. 3. The value of MTTR for the examined extruder

The values of MTTR, i.e. a delay between the reporting of a failure and the commencement of repair works, in the period of intensified production, i.e. from July to October, range from 25 to 260 minutes.

Fig. 4. The value of MTR for the examined extruder

The MTR index, i.e. the average time to repair, shows the slightest differences in the analysed periods. It reaches its minimum in May (ca 15 minutes) and maximum – in July and November (more than 150 minutes). In the remaining months it ranges from ca 30 to 125 minutes.

Failure frequency of the mechanical system

Another stage of research involved analysing the selected extruder’s mechanical system. The analysis was carried out for breakdowns included in the category of mechanical failures. Table 2 contains the results for the extruder’s mechanical system.

Table 2. The mechanical system’s failure frequency

<table>
<thead>
<tr>
<th>Production period</th>
<th>MTBF [min]</th>
<th>MTTR [min]</th>
<th>MTR [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>High production period</td>
<td>8713</td>
<td>81.3</td>
<td>97.1</td>
</tr>
<tr>
<td>Low production period</td>
<td>20935</td>
<td>0.2</td>
<td>107.8</td>
</tr>
</tbody>
</table>

The value of MTBF for the extruder working in the intensified production period is nearly 9000 minutes, whereas in the low production period it reaches almost 21 000 minutes, which means that the in the high production period the number of the extruder’s failures is practically doubled compared to the low production period. The time of waiting for repair works to be undertaken reached 80 minutes in the increased production period, while throughout the remaining part of the year failures were removed immediately. The time of work required to remove a failure (MTR) in both cases was similar, reaching ca 100 minutes. In the case of MTT, Mann-Whitney’s test did not show any significant differences between the high and low production season.

Figures 5–7 presents changeability of the determined indices in particular months of the calendar year. On the axis of abscissae March and May do not appear, as in these months no mechanical failures were noted.

The highest value of MTBF for mechanical failures was noted in February (over 40 000 minutes) and November (ca 25 000 minutes). The extruder’s mechanical failures occurred the most frequently in July (ca 3500 minutes) and October (ca 6500 minutes). In the remaining periods it ranged from 7500 to nearly 17 000 minutes.
In low production months the time after which maintenance employees start to repair a failure is negligible – practically work is undertaken immediately. In the high production period the MTTR index reaches its highest values in July – almost 370 minutes, as well as in September (60 min) and August (55 minutes).

The MTR index, which informs of the time within which repair works are performed, does not depend on the period of work in the enterprise. It reaches the highest values, ranging from 90 to 215 minutes, in January, April, July, September and November, whereas the lowest values are noted in February, June, August, October and December (from 20 to 56 minutes).

**Failure frequency of the electrical system**

The last analysed element is the electrical system of the extruder subjected to examination. The indices calculated for this system have been presented in table 3.

<table>
<thead>
<tr>
<th>Production period</th>
<th>MTBF [min]</th>
<th>MTTR [min]</th>
<th>MTR [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>High production period</td>
<td>13030</td>
<td>52.6</td>
<td>72.3</td>
</tr>
<tr>
<td>Low production period</td>
<td>8522</td>
<td>0.0</td>
<td>117.3</td>
</tr>
</tbody>
</table>

In the intensified work period the extruder’s electrical system has fewer failures than in the low production period, MTBF reaching 13 000 and 8500 minutes respectively (Table 1). The value of MTTR in the high production period is approximately 50 minutes, while in the remaining periods repairs are undertaken immediately. The time of failure removal expressed by MTR is lower in the high production period, reaching ca 70 minutes, whereas in the remaining months it is nearly 120 minutes. Mann-Whitney’s test showed considerable differences between the computed values for both production periods.

The distribution of indices in particular months is illustrated by charts presented in figures 8–10. On the x-axis February does not appear as no electrical failures were noted at that time.

Similarly to mechanical failures, in the low production period repairs are performed on a regular basis, without considerable delays (Fig. 9). The highest values of MTTR are noted in July, October and August, reaching 161, 120 and 84 minutes, respectively. In the remaining months the index does not exceed several minutes.

The lowest values of MTBF for the electrical system are noted in January – 3800 minutes, and in July – nearly 5500 minutes. The lowest failure frequency of the electrical system is observed in September (almost 19 000 minutes) and in April (nearly 18 000 minutes). In the remaining months the value of MTBF ranges from 5500 to 16 500 minutes.
Fig. 10. The value of MTR for the examined extruder’s electrical system

Conclusions

On the basis of the conducted research, the following can be concluded:

1. The time of the extruder’s failure-free work, expressed by means of the MTBF index, is lower in the period of intensified production (from April to October).

2. In the high production period, the time between the moment of failure reporting and the commencement of works on its removal, expressed by the MTTR index, increases.

3. Failure removal time, expressed by the MTR index, is shorter in the intensified production period than in the remaining periods.

4. Failure frequency of the extruder’s mechanical system is higher in the intensified production period than in the remaining periods.

5. MTBF for the extruder’s electrical system is lower in the intensified production period, similarly to MTR value; however, the time needed for failure removal is significantly shorter.

6. The electrical system’s failure frequency expressed by MTBF is higher than that of its mechanical system.

The above conclusions allow formulating the following recommendations for the maintenance management:

1. In the period preceding the intensified production season it is necessary to enhance preventive measures, which will prepare the machines for greater load and reduce their failure frequency at this time.

2. An analysis of increased failure frequency of the extruder’s electrical system should be carried out and improvement measures need to be undertaken.

3. The time of waiting for failure removal in the intensified production period should be reduced, especially by: improving the management of spare parts warehouse, simplifying the administrative procedures, increasing the employment in the maintenance department.

4. An analysis of failure removal time should be conducted by means of management tools, next measures aimed at improving the failure removal process should be developed and implemented.

The implementation of corrective measures should result in an increased effectiveness of activities undertaken by maintenance employees and shorten the time of waiting for repair. Owing to that, the quality of services provided by maintenance employees as well as the quality of cooperation with production departments will be improved.

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References