An important trend today is the continual improvement of product quality with the objective of increased customer satisfaction, but also leading to more effective cost reduction management. Effective quality management in a company also enables increasing production productivity thanks to the increasing amount of top-quality products made and the consequent minimalization of repairs of non-conforming workpieces. This contribution deals with one of the important tools for ensuring quality in the production process using the FMEA (Failure Mode and Effect Analysis) method used in the production of roller bearings for the automobile industry.

Keywords: PFMEA, The analyses of defects and their consequences, Bearings, Automobile industry, Quality
2 FMEA application

It is possible to divide the FMEA method into two phases. The first phase is represented by the design and development of a new product and the second phase is consequently the production process itself. The FMEA design of a product, indicated as DFMEA (Design Failure Mode and Effect Analysis), is an analysis of possible methods and the consequences of breakdown during product design and the FMEA process, while PFMEA (Process Failure Mode and Effect Analysis) is indicated as an analysis supporting the development of the production process to moderate the possible occurrence of breakdowns (Fig. 2). One of the most important elements of successfully introducing FMEA is its timeliness. Implementing a FMEA product or process in advance allows you to apply changes more easily and more cheaply due to the timely discovery of possible defects. In using the FMEA method it is necessary to carry out the following steps according to the following guidelines:

- to choose an object for analyzing a process or its parts;
- to describe the present state of a manufactured product;
- to identify all defects and to define their causes;
- to determine the significance of the defects, the risks of the occurrence and detection. [8]

The reason for applying PFMEA is the continuous improvement of products, processes, reliability and a reduction of the number of claims, by which the number of customers and their satisfaction will be increased. [11]

![Fig. 2 The relation between DFMEA and PFMEA [9]](image)

In applying FMEA it is necessary to map out the production process, to analyze the possible defects, to define the causes and to set acceptable measures for reducing risk. [13] Assessing risk during the procedure of the FMEA process is evaluated using three characteristics – the severity, occurrence and detection. Each of these criteria is evaluated according to tables with a scale from 1 to 10, whose value 10 is undesirable and represents a non-fulfillment of the safety requirements and regulations. Value 1 is desirable and represents a fulfillment of the safety requirements and regulations.

Among the evaluation parameters there is:

- Severity (S) is the value, which is connected with the most serious consequences in the case of a defect method.
- Occurrence (O) states the probability of the occurrence of a defect in a process and takes into consideration given measures to limit it.
- Detection (D) is a relative assessment, which is connected with the instrument used for detection management with the objective of achieving a low number, and it is necessary to improve the planned detection tool.

The product of these three criteria for each defect is a RPN risk number, which is a risk indicator and states the priority of measures taken. [3, 4]

In processing FMEA it is necessary to deal with each product part or assembly. It is also necessary to devote great attention to the safety connected to components or processes. Especially in practice the procedures are valid according to the method of American car producers (QS-9000: FMEA) or according to the methods of the German Automobile Association (VDA), whose principles are similar. The use of FMEA is recommended by norm ISO 9000:2000 and is continuously being more often required by customers, who then verify that the manufacturer has assessed and evaluated all risks as to process or product failure and that the product is therefore at the required quality. PFMEA is focused moreover on the effects and methods of process failure during production. [12]

The objective of FMEA is to prevent defects in time and to introduce measures to limit them. FMEA as a pre-emergence defect method is already being used at a very early stage in the product production process.

Organizations using FMEA have for example as an objective:

- to increase functional safety and the reliability of products and processes,
- to minimize the costs of production and assembly,
- to meet the required deadlines,
- to orient themselves on customer requirements,
- to create a database at companies, recording safety and measure procedures in undesirable situations, etc. [6, 15]

3 Case study - defect analysis in the process of roller bearing production

Defect analysis for roller bearing production represents the basis for establishing PFMEA at a company. The PFMEA document is a document, which contains all kinds of company know-how and that is why it is not available to the public. When visiting a production plant a customer can look into PFMEA for his own components (Fig. 3). [1]

On the basis of this it was necessary to firstly create a FMEA team, made up of the representatives of the individual departments of a company (quality representatives, process engineering, logistics and production). The task of the FMEA team was to gather all data, dealing with the
occurrence of undesired defects in the production of roller bearings for individual production processes in a given year. It was consequently necessary to work these materials out in the form of the distinct kinds and numbers of the individual defects.

Materials which were available for defect occurrence analysis:
- DFMEA,
- production drawings,
- shift progress reports (a database for processing defect occurrence for one calendar year and it contains information concerning the various problems recorded in production),
- 4D reports on dealing with internal problems (4 Discipline report – a shortened 8D report version, used for dealing with internal claims),
- inspection plans,
- customer claims (the greatest number of claims for a calendar year, for example interior diameter (ID) outside the tolerance and operations left out during production (Graph 1). Furthermore, the occurrence of missing markings, part replacement and uncut inner diameters).

The main idea of the paper is to map the value flow and disadvantages. The analysis covers the current state of individual processes within the production line. After defining the existing deficiencies, a rationalization plan was created in which a combination of lean manufacturing elements was used. The proposed solutions can be used to establish lean manufacturing principles across the production line throughout the plant. If the proposed solution cannot be put into practice, it can be used as a plan for other types of improvements. [6, 9, 16]

3.1 Evaluating the defect analysis

On the basis of processing the input materials there were evaluated defects occurring during one calendar year in the production of the individual components of roller bearings (CRB). The defect analysis was applied in the plants of the turning, hardening and grinding machines and the components were marked with:
- ID outside of specs,
- Left-out operation,
- Marking missing,
- Part modification,
- Incomplete ID grinding,
- Damaged ID,
- Functional defects,
- Missing components,
- Mixed up part,
- Other parameters.

The procedure for evaluating the defect analysis (Fig. 4) was carried out by processing all supplied materials into a form from which it was consequently possible to put together the resultant analysis. With the general summary of the occurrence of defects a visual overview of them was also created. Information was obtained as a result of this analysis, which was consequently used for creating the FMEA process.

On the basis of the analysis of available materials there was discovered the complete occurrence of individual kinds of defects for the evaluated components occurring in a product at specific plants.
As an overview there was created a resultant table of analysis, which is made up of columns under the names: material (AR, JR, RA, VT), order number, problem origin (turning plant, hardening plant, grinding plant, storage), the machine, defect, defect description, immediate measure, date, etc. The frequency of defect occurrence was worked out in the form of a graph (Graph 2).

From Graph 2 it is evident that According to the resultant analysis the greatest number of defects was caused by:

- a bad inner dimension (ID) – 10 %,
- deformation – 8 %,
- a bad outer dimension (OD) – 7 %,
- allowances – 7 %,
- visual defects – 7 %,
- missing material – 7 %.

Graph 2 The frequency of defect occurrence in production [1]
3.2 Vizual illustration of defects

For easier identification there were created figures and descriptions of the basic visual defects occurring on the individual components. Defects, which occurred during the analysis, were for example burnt materials or cracks. Unacceptable pieces of burnt material including cracks and thermally damaged surfaces caused by grinding, are shown in the figure (Fig. 5). Cracks are unacceptable defects and can cause ring cracking.

One of the defects that occurred was an unacceptable shape of straightness and the shape of the circularity. The straightness shape must be flat or slightly convex along the entire ground surface, or according to a drawing. The shape of circularity has to be smooth and circular, and must not be in the shape of a star or multi-edged. The unacceptable shape of straightness and circularity are illustrated in the figures (Fig. 6 and Fig. 7).

4 The structure of PFMEA and the regulations for use

Another procedure, necessary for gathering PFMEA, was to identify the defect results, that is the impact on the final application, or following operations, and to evaluate the occurrence of defects using the three characteristics (significance, occurrence, detection). The table contains the frequency of measurements for stating the detection (Tab. 1).

After evaluating the individual occurrence of defects the determination of the priority indicators of risk RPN followed, that is used to determine the priority of measures. The risk number of the individual possible defects formed by a specific cause is calculated as a summary of the values of severity, occurrence and detection (Tab. 2).
For the summarized processing of the PFMEA database a PFMEA form was designed, which contains basic information dealing with creation, process responsibility, the project team, processed data, the examination date, etc. The form itself contains the individual production areas, process steps, possible methods, results, defect causes and their assessment in regards to severity, occurrence and detection. By multiplying these parameters a RPN risk number is obtained. For defects with a high RPN number or severity there is consequently determined measures to minimize them. The risk number (RPN) in each failure regime is calculated so that breakdowns with high risks are identified. [4] Defects with a high RPN number in the PFMEA database are recorded in the PFMEA form (Tab. 3), including their assessment and the consequent measures.

**Tab. 3 The PFMEA form [1]**

<table>
<thead>
<tr>
<th>Plant</th>
<th>Process step / Function</th>
<th>Possible defect method</th>
<th>Possible defect consequences</th>
<th>Possible defect causes</th>
<th>Prevention management tool</th>
<th>Detection management tool</th>
<th>Detection</th>
<th>RPN</th>
<th>Recommended measure</th>
<th>Response and Completion Date</th>
<th>Results of Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grinding Plant</strong></td>
<td>AR - grinding OD</td>
<td>Visual defects (grooves, burrs, shanks)</td>
<td>Reduction</td>
<td>Bearing life reduction</td>
<td>Adjustment plan and set-up guide</td>
<td>6 Inspection 3 pieces per 5min</td>
<td>8 336</td>
<td>Technician</td>
<td>Check machine condition and training</td>
<td>7 4 8 224</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bearing failure</td>
<td>Visual standard training</td>
<td>4 Inspection 3 pieces per 5min</td>
<td>8 224</td>
<td>Foreman</td>
<td>Operator training on visual standard of lines</td>
<td>7 3 8 168</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Burnt orbit</td>
<td>Badly entered grinding parameters (speed)</td>
<td>Reduction</td>
<td>Bearing life reduction</td>
<td>Adjustment plan and set-up guide</td>
<td>4 Verification by etching at release + continuous check during shifts</td>
<td>8 256</td>
<td>Technician</td>
<td>Check machine condition and training</td>
<td>8 3 8 192</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Burnt outer diameter</td>
<td>Badly entered grinding parameters (speed)</td>
<td>Reduction</td>
<td>Bearing life reduction</td>
<td>Adjustment plan and set-up guide</td>
<td>4 Verification by etching at release + continuous check during shifts</td>
<td>8 256</td>
<td>Technician</td>
<td>Check machine condition and training</td>
<td>8 3 8 192</td>
<td></td>
</tr>
<tr>
<td><strong>Grinding plant</strong></td>
<td>JR - grinding OD</td>
<td>Preservation procedure failure</td>
<td>Reduction</td>
<td>Bearing life reduction</td>
<td>Preservation instructions</td>
<td>6 Training</td>
<td>8 336</td>
<td>Operator training on visual standard of lines</td>
<td>7 4 8 224</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corrosion</td>
<td>Ignorance of visual standard</td>
<td>Reduction</td>
<td>Bearing life reduction</td>
<td>Visual standard training</td>
<td>4 Inspection 3 pieces per 5min</td>
<td>8 224</td>
<td>Foreman</td>
<td>Operator training on visual standard of lines</td>
<td>7 3 8 168</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large radial runout</td>
<td>Poorly ground face - frontal non-perpendicularity OD/ID</td>
<td>Reduction</td>
<td>Bearing life reduction</td>
<td>Radial runout measurement during alignment</td>
<td>5 1 piece measurement during alignment</td>
<td>6 210</td>
<td>Technician</td>
<td>Face operation training</td>
<td>7 4 6 168</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual defects (grooves, burrs, shanks)</td>
<td>Badly entered grinding parameters</td>
<td>Reduction</td>
<td>Bearing life reduction</td>
<td>Adjustment plan and set-up guide</td>
<td>6 Inspection 3 pieces per 5min</td>
<td>8 336</td>
<td>Technician</td>
<td>Check machine condition and setter training</td>
<td>7 4 8 224</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bearing failure</td>
<td>Ignorance of visual standard</td>
<td>Reduction</td>
<td>Bearing life reduction</td>
<td>Visual standard training</td>
<td>4 Inspection 3 pieces per 5min</td>
<td>8 224</td>
<td>Foreman</td>
<td>Operator training on visual standard of lines</td>
<td>7 3 8 168</td>
<td></td>
</tr>
</tbody>
</table>

For correctly managing PFMEA these rules were defined:
- During a new discovery on the part of the customer (claim, notification, initiative), there will always be carried out an examination of the internal processes also in connection to new projects. In other cases it is determined to be at least 1x a year.
- In the case of determination a measure has to be followed up and its effectivity has to be evaluated and after the effect is confirmed a given defect can reach the RPN for reevaluation, prevention improvement (leading to an occurrence reduction) or increased inspection (an improvement in the detection area).
- The FMEA team firstly always has to deal with the highest RPN and defects with the highest number of severity (S), occurrence (O) and detection (D).
- Special critical character significance is evaluated at least by a value of 8.

5 Conclusion

The PFMEA method has been used for the production of bearings in the automobile industry. In the first phase of introducing the process FMEA method it was necessary to map out in detail all steps in the production process.
process. For production defect analysis there was made available internal materials with the recordings of their individual defects in the production process during one calendar year. These materials were assessed, modified with the new findings and recorded in the summarized defect database. After the database was created the PFMEA form was designed into which was recorded all methods, causes and defect measures at the individual plants, which was consequently evaluated using criteria for determining the risk numbers. After creating the PFMEA it was consequently possible to firstly measure defects with a higher RPN number. In regards to the fact that PFMEA is indicated as a „live“ document, which must be continuously renewed with new findings filled in, rules were created for the proper management of the FMEA process at a company. Experimental verification of implementing the FMEA principles at a company confirmed the topicality of the problems solved, and the importance of using one of the quality tools in the production process of the company.

References


