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FMECA analysis of thermal deburring machine EXTRUDE HONE TEM P-350

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Abstract

This study investigates FMECA analysis and its potential use in improving the reliability and maintenance of the thermal deburring machine in a manufacturing company located in Slovakia. In the beginning, an overview of the FMEA/FMECA methods and their utilization for increased reliability are discussed. As a practical solution, the deburring machine EXTRUDE HONE TEM P-350 was chosen. Functions of its systems and components, thermal deburring process, its characteristics and in practice application are described. Maintenance policy in the company and the current state of maintenance of the machine are also presented. In addition, the study includes failure analysis which evaluates the riskiest systems of the machine. One element, hydraulic unit, is a subject for the FMECA analysis which envisions the assessment of the current failure modes using risk priority number (RPN) and proposals of prevention and detection action reducing the level of RPN. The final section focuses on influencing and improving maintenance and summarizing the potential benefits of FMECA Analysis for company and machine operation.

Introduction

Manufacturing companies are under increased pressure to continuously improve productivity and product quality. Production Departments often exceed the production limits of their machines, which consequently leads to an increase in failure rate. To overcome this, production requires fully capable operability of machines with a minimum of downtime. However, maintenance departments are often unable to provide due to the high extent of failures and their impacts on the machinery operation and quality of products.

Any production equipment and machinery are subject to failures; causes can include normal wear, misuse or inadequate maintenance, external causes, wrong design or manufacturing mistakes, etc. The duty of the maintenance is to restore the equipment after a failure, by corrective (operational) maintenance. However, it is more important to avoid failure in the first place or at least minimize its effects. This can be achieved by detecting the deterioration using predictive maintenance (or condition monitoring), and to make an early repair before the failure by using preventive maintenance. The best is to suppress the root cause of deterioration/failure by using so-called proactive maintenance (Rakyta et al., 2016).

The maintenance of equipment means to perform, at a reasonable cost, the necessary operations to keep it able to do the job correctly it is designed for, from quantity, quality and cost point of view, during its foreseen active life, and, if desirable, for a longer time.

There has been significant research done in the field of maintenance and areas related to maintenance

– reliability, availability, maintainability and safety. It goes back to 1960s, when the NASA Standard, released by Apollo Program Office project, was published (RA-006-013-1A, 1966). This guideline has been developed in order to "accomplish identification and ranking of potential failures critical to hardware performance and safety" and to plan design/development tests accordingly. FMECA is a "simplified reliability estimation tool" and should be accomplished before reliability prediction is carried out to provide basic information. This method finds application both in the design phase as well as in the maintenance. Both design and maintenance are aimed at the reliable and safe operation of machines and equipment. The maintenance should be done in an effective manner, where many improvements and methods have been developed in the last few decades. This reliability research can be found in different industries, including production manufacturing (Gupta & Mishra, 2017), forestry machines (Ťavoda, Kováč & Łukaszczyk, 2018), food processing industry (Ostadi & Masouleh, 2019), maritime (Chybowski & Matuszak, 2004; Adamkiewicz & Fydrych, 2013), railway vehicles (Kašiar et al., 2016; Famfulik et al., 2020), road vehicles (Galliková, Poprocký & Volna, 2016).

Another aspect of safety that is closely connected with maintenance and operation is a risk. Let us mention some research work in this area, e.g. (Pačaiová & Nagyová, 2015) or (Harpster & Rama, 2018). Furthermore, a general methodology using FMECA is RCM (Reliability centered maintenance) and using simulation models in it (Hussain & Jan 2019).

As previously mentioned, the reliability and maintenance of any machine and equipment are based on its design (Blatnický, Dižo & Blatnická, 2018). Operational research, maintenance planning, operation and logistics optimisation can also contribute to maintenance effectiveness (Šaderová, 2016; Paprocka, 2018). Moreover, the maintenance process optimization may also contribute to waste reduction (Tannady et al., 2019)

Modern maintenance systems, detection methods, diagnostic devices and tools of reliable maintenance are able to determine the machine risk (Janak et al., 2016). Predicted intervals of failure and analytical outputs are able to modify machine maintenance to meet company production parameters (Straka et al., 2018).

Today's industry has to be highly productive and efficient. High machines availability and production quality is a must, in particular in the automotive industry where just-in-time production systems are generally used. Maintenance personnel are in the first line to guarantee these requirements. Collaborating with universities is one possible way to find solutions in maintenance improvements. Such concrete example of collaboration is described in the paper where a particular machine, EXTRUDE HONE TEM P-350, used for thermal deburring was selected to find methods for its higher production reliability. The process covers the failure mode, effects and criticality analysis of the thermal deburring machine. The analysis of the machine – its functional and operational properties, analysis of the current state of maintenance and machine failure rate in the years 2015–2017 have been completed. The output of the analysis is the processing of the data for the creation of FMEA forms and the proposal of preventive and detection actions in order to reduce the risk priority number of failure modes, thus increasing reliability and availability of the machine.

Thermal deburring machine EXTRUDE HONE TEM P-350

EXTRUDE HONE TEM P-350 (Figure 1) is a highly efficient thermal deburring machine for removing surface and subsurface imperfections of workpieces by a single operation. The unit uses an unconventional method of thermal deburring, in which the workpiece is exposed to very high temperature up to 3350°C for a short period, lasting just a few milliseconds. During the thermal deburring process, there is no mechanical damage to the workpiece material. The main principle of the process is the oxidation of all workpiece imperfections

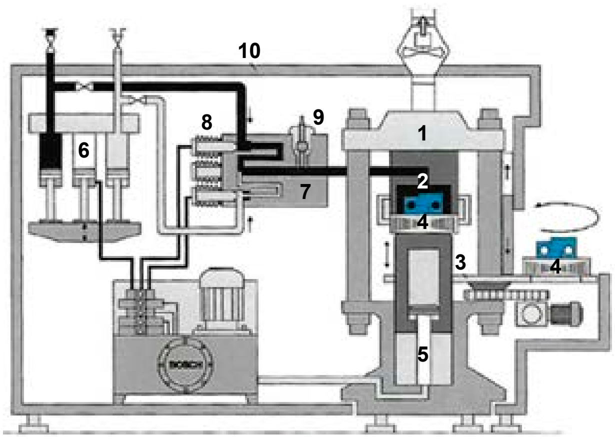


Figure 1. Design of the EXTRUDE HONE TEM P-350; 1 – Machine frame; 2 – Deburring Chamber; 3 – Index table; 4 – Closing plate; 5 – Closing hydraulic system; 6 – Gas metering system; 7 – Mixing block; 8 – Gas valves; 9 – Spark plug; 10 – Soundproof cabin; 11 – Index table rotating mechanism

– ostrich, shavings, edges, contaminants, excess material, etc.

The thermal deburring machine is designed to meet the needs of medium to large production amounts, while also being able to render even the most complicated shape workpieces. There are two basic modifications of machines with different chamber sizes, both of them have a clamping force of 3.5 MN:

- ϕ 250 × 300 mm,
- ϕ 320 × 300 mm.

At the company, the machine is used for the thermal deburring of hydraulic units designed for:

- High-pressure hydraulic generators,
- Hydraulic motors,
- Centrifugal axial hydraulic generators,
- Proportional PVG switchgear.

The thermal deburring machine can be installed in operation in two ways. These methods include:

- Manually operated machine – machine control, workpiece loading and unloading is provided by the operator of the machine;
- Integration into an automated production site – synchronization with the automated production line; workpiece loading and unloading is provided by the robotic manipulator.

Machine description

The cylindrical bell-shaped deburring chamber is built into the frame of the machine. A rotating index table in which five closing plates are stored is mounted on the front panel of the machine. The closing plates serve as supporting elements for the workpieces, respectively as supporting elements for workpiece clamps if the manufacture requires their using. The closing plates are moved by the index table rotating mechanism.

During the thermal deburring process, the closing plate is pressed against the deburring chamber by means of a hydraulic locking system and gas-tightly closed and insured in the right position. The required amount of gas to achieve an efficient deburring effect is measured through a gas metering system where the combustible gas and oxygen are metered hydraulically into the deburring chamber. In a mixing block installed in the inlet portion of the deburring chamber, the gases are evenly mixed, and after closing the hydraulically operated gas valves, the combustible gas mixture are ignited by the spark plug. Flammable gases used in the thermal deburring process are, in particular:

- Natural gas,
- Methane,
- Hydrogen.

The whole deburring machine is covered by a soundproof cabin.

Types of maintenance applied to the thermal deburring machine

Maintenance policy in the company is currently based on the principle of full outsourcing of maintenance. The outsourcing company has full responsibility for the maintenance of all workplaces and related equipment.

The thermal deburring machine works with an explosive mixture of natural gas and oxygen, which places the machine in the category of critical equipment of the company. In the event of a malfunction, it can endanger not only the production process but also the health and lives of operating personnel working nearby. In this regard, it is necessary to ensure the strict adherence to safety regulations and protocols and to properly perform all service, inspection, control and exchange operations, according to the predetermined procedures, in order to ensure the safety and health protection of the thermal deburring workplace.

The investigated machine EXTRUDE HONE TEM P-350 has applied several types of maintenance and service systems:

- Breakdown (corrective) maintenance,
- Preventive scheduled maintenance,
- Autonomous maintenance,
- Inspections of the machine and selected machine systems,
- Regular TPM events.

Analysis of failure modes

Analysis of failure modes of the thermal deburring machine was completed on the basis of the maintenance contract data provided by the outsourced maintenance company. The data contained records of all maintenance orders requested by the owner of the machine during the years 2015 to 2017.

A maintenance order can be characterized as a requirement for maintenance activities to be performed by an outsourced maintenance company:

- In the event of a fault condition of the machine that limits or stops operation on the machine.
- In the absence of spare capacity, spare parts, operating tools and other commodities belonging to a machine intended for the autonomous maintenance of the machine.

- In case of reaching power or time parameter of the machine, when it is necessary to perform a regular check or maintenance of the machine to a certain extent.
- In case of performing legally prescribed inspections of the machine and its components.
- In case of necessary verification of the protection and safety features of the machine and the workplace.

Evaluation of failure analysis

The output of data processing of maintenance orders for thermal deburring machine EXTRUDE HONE TEM P-350 is:

- Analysis of the number of maintenance orders.
- Analysis of maintenance frequency of individual machine systems.
- Pareto analysis 80/20 – determination of the most critical systems of the machine with consideration of the weight of the failure criticality.

Analysis of the number of maintenance orders

Based on the chart of analysis of the number of orders (Figure 2), it can be determined that the number of maintenance orders over the years gradually increased by approximately 20 orders each year.

The growing number of "Operative" orders is evident as the operational reliability of the machine is gradually decreasing, as well as the operational and performance levels due to the wear and tear of individual system components.

According to the increasing number of failures, there is a clear increase in the proportion of planned maintenance activities. However, this may not be a necessary consequence of the increasing number of failure. Significant increases in the proportion of "Prevention" orders resulting in the identification of machine shortcomings and corrective actions leading to their removal also lead to a higher number of "Scheduled" orders. The result shows that the increase in "Prevention" orders has significantly slowed down the growth trend of "Operative" orders. If the current maintenance model of the machine will count on increasing preventive activities, activities listed in the Machine Maintenance Plan will be followed, and the FMECA analysis of the machine will be integrated into the machine maintenance, gradually failures are expected to increasing in the coming year.

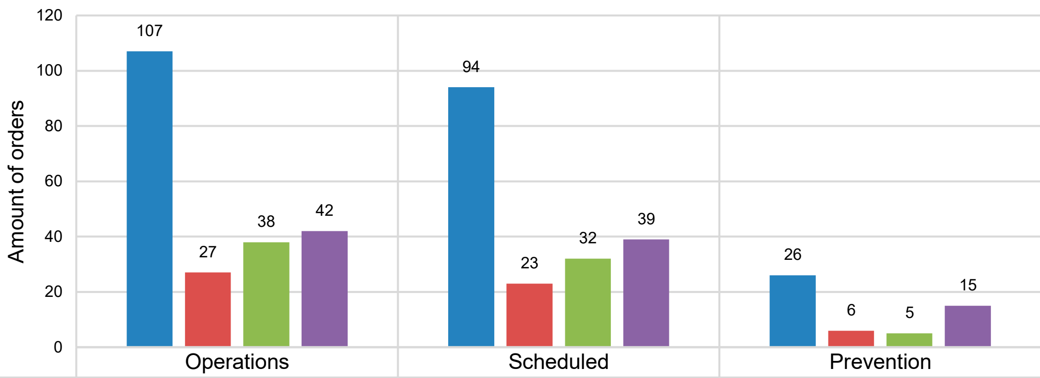
Analysis of maintenance frequency of individual machine systems

The main purpose of the analysis was to determine the maintenance frequency of the systems of the machine. Due to the number of orders individual machine systems, the mechanical systems can be divided into three classes (Table 1).

Table 1. Maintenance frequency class of machine systems

Maintenance frequency class	Amount of orders
Frequent	≥ 25
Medium	10–25
Low	≤ 10

The chart (Figure 3) shows that the most frequently maintained elements over the monitored period include:



	Operations	Scheduled	Prevention
Overal	107	94	26
2015	27	23	6
2016	38	32	5
2017	42	39	15

Figure 2. Chart of analysis of the number of maintenance orders

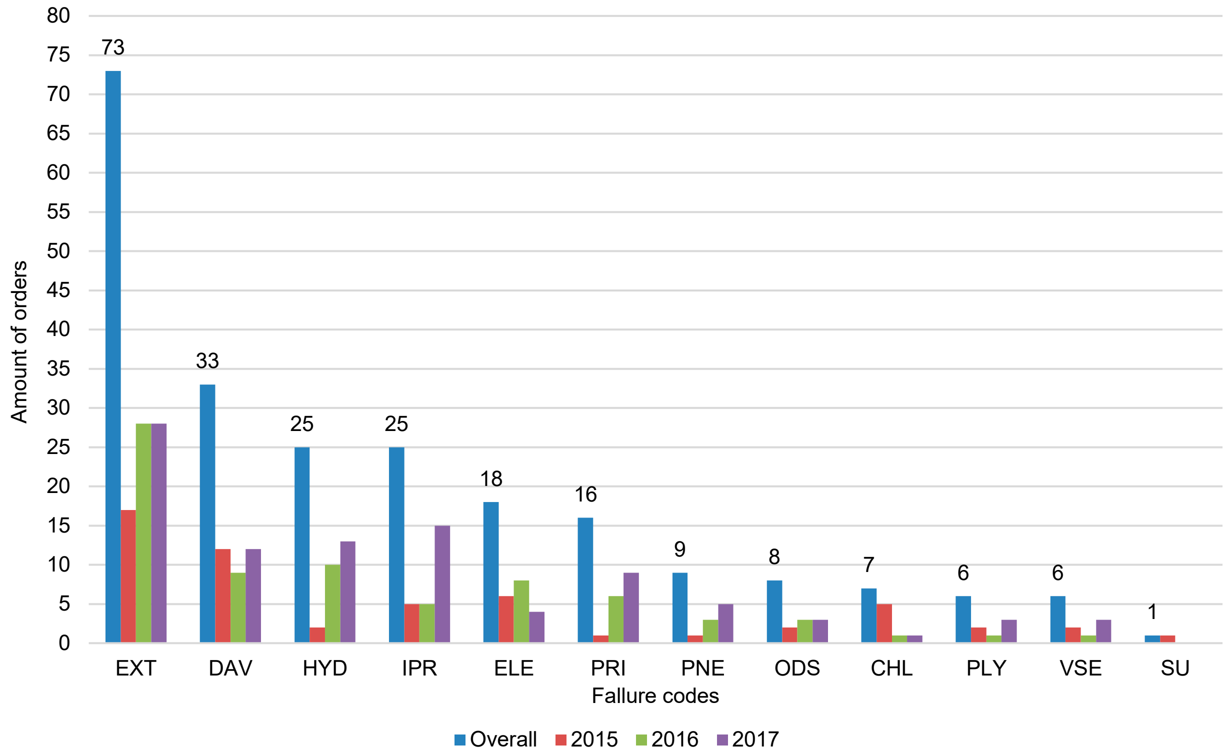


Figure 3. Chart of analysis of maintenance frequency of individual machine systems

- Machine mechanics – including basic thermal deburring parts (mixing block, deburring chamber, index rotary table);
- Gas metering system – ensuring a ratio of gases mixture and precise delivery to the mixing block (dispensing hydraulic cylinders, mixing block);
- Hydraulics – providing the drive of all hydraulic circuits and their respective components (hydraulic cylinders, valves, distribution units, etc.).

Additionally, a high number of orders has been requested with orders marked "IPR" which cannot be understood as failure modes of the machine. Since their purpose is to verify the technical condition of the machine and to prevent malfunctions and in the absence of their implementation, the machine would have a higher failure rate. They are a necessary part of the analysis of the maintenance frequency of the individual machine systems.

Systems with medium maintenance frequency are:

- Electrical accessories – ensuring the supply and distribution of electricity and control of the equipment (electrical network elements, safety machines, etc.);
- Preparation – supporting elements of the workpieces (cracks and debris of the material, incorrect position on the closing plates).

Systems with the least maintenance frequency are:

- Suction – ensuring control of the placement of the preparations on the closing plates and cleaning the closing plate (suction and control group, sensors, pneumatic cylinders);
- Cooling unit – providing hear removal from heat-stressed components (gaskets, hoses, regulators, valves);
- Gas unit – ensuring optimal supply and control of natural gas leakage (gas leak detectors and sensors, dosing cylinder, thermocouples, etc.).

A special case orders with a code name "VSE" or "SU" which are the requirements of an external order – for example, "welding of preparations". They do not represent failure modes or systems of the machine, but instead, the absence of their execution could case an increased failure of the machine.

Pareto analysis 80/20 of the most critical machine systems

The main result of this analysis of failure modes is to identify the most critical systems of the EXTRUDE HONE TEM P-350 machine. In the analysis, only "Operations" orders were considered, which represent actual faults of the machine. The critical system weight values were assigned to

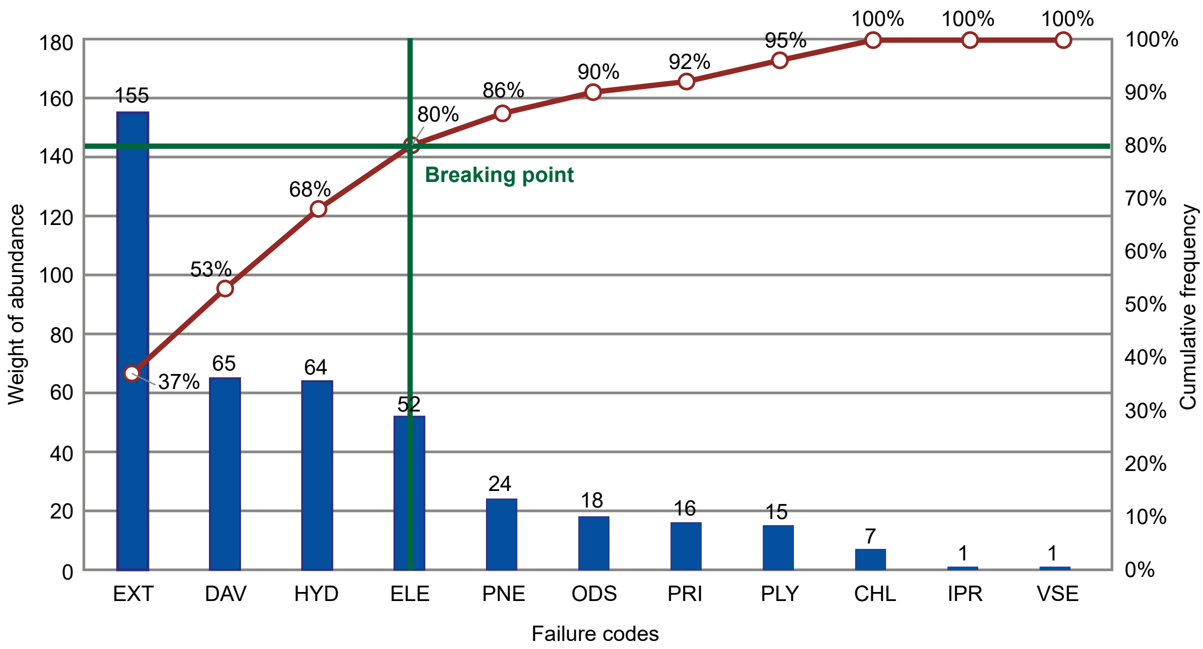


Figure 4. Pareto analysis 80/20

each machine system, which directly describes the impact of a system failure on TEM process, the risk of machine components and on the life and health of operators of the machine and personnel operating at the workplace.

Pareto analysis (Figure 4) with the counting of the weight of failure criticality of individual machine systems revealed the most critical systems of the thermal deburring machine:

- Machine mechanics,
- Hydraulics,
- Gas metering system,
- Electrical accessories.

Failures of these systems pose the most significant risk to the reliable operation of the machine and cause the most of the machine outages. The consequences of the failures of these systems lead to the interruption of the TEM process and may result in more extensive damage to the machine or may directly endanger the safety of the machine operators.

FMECA analysis

FMECA (Failure Mode, Effects and Criticality Analysis) is one of the methods of a priori reliability. The FMECA analysis is an extension of FMEA (Failure Mode and Effects Analysis) to evaluate failure criteria. It contains a systematic set of activities that are performed to:

- Identify and evaluate a possible product/process failure and the effects of this failure,
- Identify measures that could reduce the likelihood of a potential failure,
- Determine the criticality of a potential failure,
- Document the process of potential failure analysis.

Basic principles of FMECA Analysis

FMECA has defined five basic principles that form the basis for its elaboration:

1. Creation of system structure – overview of system elements and their parameters, interconnection between elements, system location with respect to the machine.
2. Functional structure of the system – defining the functions from the lowest to the highest functional level that can secure each element.
3. Definition of failure mode – list of all possible and potential modes of system failures (characteristics of the events leading to the failure of the element).
4. Definition of the criticality of failure mode – calculation of RPN.
5. System optimization – design of corrective and preventive maintenance and fault detection measures and evaluation of their effectiveness.

Risk Priority Number (RPN)

Part of the FMECA Analysis is to assess the risk of individual machine failures. Each failure is determined by maintaining the current state of maintenance and fault detection, an RPN that can take values from 1 (absolute best) to 1000 (absolute worst). The initial value of the RPN is compared to the RPN proposed by the after the design of the preventive and detection actions. The objective of the FMECA Analysis is to reduce the RPN to the lowest possible value from a technical and economic point of view (Pačaiová & Nagyová, 2015):

$$RPN = S \times O \times D \quad (1)$$

S (Severity) – evaluation of the effects of the failure.
O (Occurrence) – evaluation of the probability of occurrence of a failure.
D (Detection) – evaluation of the probability of detecting the occurrence of a failure.

Each parameter can take values from 1 (absolute best) to 10 (absolute worst). Other value ranges can be used, e.g. 1–5.

Failure modes and optimization

Two basic types of actions that reduce RPN can be selected when processing FMEA forms:
- Preventive actions,
- Detection actions.

On the hydraulic unit, 27 failure modes of the machine were found, which interrupted the main operation – TEM process. Every failure mode is assigned a corresponding RPN value based on the current maintenance status (RPN column). The primary purpose of drafts of actions is reducing current RPN values under the value of 100, which is respected in the company as the worst-case value of RPN for safe and reliable operation of the machine.

Proposals for preventive actions (P column) are designed to reduce the probability of occurrence of failure mode and are most often oriented towards:
- Replacement of system components;
- Checking and setting the system element parameters;
- Modification (usually shortening) of the maintenance intervals (operating hours, cycles, kilometers, etc.);
- Refilling the operation media.

Most of the preventive actions applied to failure modes may reduce the amount of RPN in the range of 30–50%.

Proposals for detection actions (D column) serve to increase the probability of detecting the initial symptoms of a failure mode or existing failure modes. They include all methods for detecting the technical condition of the equipment and its components:
- Checks for functionality, wear, damage of elements,
- Control of leakage of operating media,
- Diagnostic measurement of elements,
- Installation of sensors on the system elements,
- Built-in signaling elements (warning lights, detectors, acoustic siren).

Detection actions markedly reduce the amount of RPN, in most cases, around 40–80%. The best results of reducing the amount of RPN are achieved by a combination of both types of actions (PD column). In many cases, the implementation of proposed actions will reduce the risk of system failure modes by more than 75%. Excellent results are ensured not only by increasing the proportion of prevention but above all, by implementing more effective tools to detect failures and tighten up technical checks. This leads to a reduction in failure rate, better ability to record premature failure symptoms and increased operability of machine. Example of failure modes of the hydraulic unit with RPN rating – original RPN values and after preventive, detection and combined actions are shown in Table 2.

Most of the proposed actions were derived from the maintenance plan of the machine:
- Shortening of check intervals;
- Proposals for verification of functionality, cleaning and replacement of distribution elements;
- Installation of new sensors and detectors of technical condition and their connection with the control panel of the machine;
- Checks and refilling of operating media.

Table 2. Failure modes of the hydraulic unit with RPN rating

No.	Element	Failure mode	RPN	P	D	PD
1	Operating pump	No hydraulic pressure was generated within the specified range (10–290 bar)	120	60	40	20
2	Control pump	Malfunction of pumping of hydraulic oil	160	–	–	40
3	Electric motor	Does not reach the required power (22 kW)	90	60	30	20
4	Clutch	Does not transmit the required torque	60	30	20	10
5	Reservoir	Excessive pollution by the sludge – low level of oil	200	–	80	–

The output of the proposed actions is to adjust the individual levels of maintenance of the machine:
- New activities for autonomous maintenance,
- New activities for preventive and predictive maintenance,
- Modification of maintenance plan of the machine,
- Requirements for expanded services as part of inspections of the machine.

Conclusions

The primary purpose of this project was the creation of FMECA analysis of thermal deburring machine EXTRUDE HONE TEM P-350 operated by the company. Results of FMECA analysis will be used for audit needs, machine maintenance adjustments and improvement of overall equipment effectiveness (OEE).

If the proposed maintenance measures are implemented into the maintenance program of the machine, the following benefits are possible: to expect a gradual reduction of the machines failure rate, provide wider knowledge of an operator about the machine, improve efficient maintenance interventions and reduced downtime.

The result of all these activities is an improved TEM process, which can increase machine productivity, and to improve the safety of plant operation and protection and health of operators.

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