D. VYKYDAL, J. PLURA, P. HALFAROVÁ, P. KLAPUT

ISSN 0543-5846
METABK 54(4) 675-678 (2015)
UDC – UDK 338.58:669.015:621-426:368.025.6=111

ADVANCED APPROACHES TO FAILURE MODE AND EFFECT ANALYSIS (FMEA)APPLICATIONS

Received – Primljeno: 2014-07-10
Accepted – Prihvaćeno: 2015-02-30
Preliminary Note – Prethodno priopćenje

The present paper explores advanced approaches to the FMEA method (Failure Mode and Effect Analysis) which take into account the costs associated with occurrence of failures during the manufacture of a product. Different approaches are demonstrated using an example FMEA application to production of drawn wire. Their purpose is to determine risk levels, while taking account of the above-mentioned costs. Finally, the resulting priority levels are compared for developing actions mitigating the risks.

Key words: costs, products, wire, risks

INTRODUCTION

The prosperity of any organization depends on the quality of its products. It is generally recognized that the final quality of products is largely the result of the pre-production phase, in which the quality planning process takes place. Quality planning is a set of activities, through which quality objectives are defined together with the tools and procedures to achieve those objectives. The purpose of these activities is to identify customer requirements and develop a product design which fully meets such requirements. An integral part of quality planning is the design of a process by which the product can be realized.

At the pre-production phase, a number of quality planning methods and tools can be used. Customer requirements are identified and translated into subsequent product design and development using QFD [1]. Statistical Process Control (SPC) is a feedback-oriented system aimed at achieving and maintaining a stable process. During pre-production, it is used for analysing process variations and assuring the process stability in statistical terms. Verification of the statistical stability is a precondition for the assessment of process capability. Before any data collection, it is necessary to perform a measurement system analysis which verifies the suitability of the particular measurement system. An important step before the final product and process design is approved and released is the review and optimization of the design. The objective of this step is to minimize the risk of product failures during production and during its use. For this purpose, the FMEA is used. This method and some non-traditional ways of its application are the topic of this paper.

D. Vykydal, J. Plura, P. Halfarova, P. Klaput, VŠB – Technical University of Ostrava, Faculty of Metallurgy and Materials Engineering, Ostrava, Czech Republic

FMEA

FMEA relies on a team-based analysis of risks of potential failures. The use of the FMEA is required by the automotive industry. FMEA is mainly used for two basic applications: as Design FMEA and Process FMEA. Design FMEA makes it possible to minimize risks of possible failures, which can originate during designed product use. Process FMEA makes it possible to minimize risks of possible failures, which can originate during designed process realization.

The procedure of FMEA application includes analysis of potential failure modes, identification of their possible effects and causes and analysis of preventive actions used and actions for failures detection. The risk of possible failures is assessed using the risk priority number (RPN), which is calculated on the basis of assessment of failure severity, probability of occurrence and probability of detection.

The severity of a failure mode is assessed on the basis of its effects. The occurrence is given by the probability of the failure mode to occur and the detection is in the case of process FMEA determined by the ability to detect the failure mode or by the efficiency of existing inspection procedures. The point scores for the severity, occurrence and detection of each failure mode with a certain cause are multiplied to obtain the RPN. Preventive actions are developed and implemented for failure modes with high risk levels, as indicated by the RPN value, to reduce their risk. The design of preventive actions is connected with defining the responsibilities and deadlines for implementation of individual actions. At the last stage, which is the risk evaluation after implementation of the actions, the criteria (severity, occurrence, detection) are re-evaluated and the RPN is calculated again. The purpose of this stage is to evaluate the efficiency of the actions, which should be reflected in reduced RPN values [2,3].

Advanced Applications of FMEA

The above-described sequence represents the traditional and generally used approach to FMEA and RPN calculation. It is straightforward but suffers from several drawbacks. One of the serious drawbacks is the largely subjective way of assigning numerical values to the individual criteria of severity, occurrence and detection. In an effort to overcome this, mathematical modelling, in particular fuzzy logic, is used. In fuzzy logic, propositions have truth values. Fuzzy logic is thus distinguished from propositional logic, which only uses two logical values, true and false, normally expressed as 1 and 0. Fuzzy logic uses all values from the $<0; 1>$ range, i.e. an infinite number of values. Instead of point scores for severity, occurrence and detectability, this FMEA variant uses text descriptions. The uncertainty of the evaluator in determining the levels of the criteria is thus reduced [4,5]. Another drawback is the often criticized oversimplification due to the use of a limited number of criteria and lacking criteria weights. Combining the FMEA with multicriteria decision-making methods (e.g. AHP – Analytical Hierarchy Process, ANP – Analytical Network process and others) offers a partial solution to this problem. In addition, a point limit can be defined for classifying failures into acceptable ones and those which must be dealt with [6,7]. The last drawback is that today's approach to the use of FMEA does not include quantification of costs related to the occurrence of identified failures. Yet, this criterion may be of key importance to strategic decisions on accepting or rejecting the preventive actions proposed. Therefore, the traditional FMEA approach has been modified into a cost-based FMEA which takes into account the costs associated with potential failure of the product [8,9]. Nevertheless, these advanced techniques share a single basis derived from the traditional approach to FMEA. They differ in the method of determining the risk of failure through different procedures for calculating the RPN. Using a case study as an example, this paper presents a newly-proposed method of conducting cost FMEA and compares various approaches to the calculation of the risk priority number. This case study involves the production of a steel drawn spring wire.

COST-BASED FMEA OF WIRE DRAWING PROCESS

The cost-based FMEA sequence is almost identical to the traditional approach. This means that the first step is to identify potential failure modes of the product, their possible effects and causes. In the next step, the RPN is calculated and preventive actions are proposed. The difference is in the RPN calculation. The method is described in detail in a paper by Vykydal et al. [8]. A number of defects in the drawn wire can be identified. These defects can be classified into five groups: shape defects, internal defects, surface defects, defects related to surface quality and structure-related defects. A total of 15 potential defects were identified in the spring wire manufacturing route. The wire is made in a continuous wire rod rolling mill by a process comprising cleaning, preparation and soaking of billets and rolling, cooling and conditioning of wire. The potential defects are listed in Table 1. The values of severity, occurrence and detection were then determined for individual defects. According to the traditional FMEA approach, the RPN was calculated as the product of these criteria. Table 1 shows that defects with the highest risk according to the RPN are the following: cuts, rolled-in scale, out-of-specification diameter and shape defects. In the paper [8], this result was compared with results of the RPN_{C1}

Table 1 **Different approaches to risk assessment of possible defects in the manufacture of drawn wire**

Sub-process	Defect	S	O	P_O	D	P_D	RPN	**RPN** / %	**RPN_{SO}** / %	**RPN_{C1}** / %	**RPN_{C2}** / %	**RPN_{C3}** / %
Billet cleaning	Dimensional deviations upon grinding	1	4	0,002	4	0,85	16	3,15	1,96	0,19	1,98	3,93
	Edge burrs	4	2	0,0002	3	0,9	24	4,72	3,92	0,26	0,49	0,26
	Burnt surface	7	2	0,0002	2	0,95	28	5,51	6,86	0,57	0,41	0,33
Preparation and soaking of billets in continuous wire rod rolling mill	Decarburization	8	2	0,0002	2	0,95	32	6,30	7,84	4,71	2,99	2,37
	Burning billets in furnace	6	2	0,0002	2	0,95	24	4,72	5,88	8,65	7,32	5,81
Wire rolling	Out-of-specification diameter	7	2	0,0002	3	0,9	42	8,27	6,86	6,95	7,56	4,00
	Shape defects	7	2	0,0002	3	0,9	42	8,27	6,86	10,17	11,07	5,85
	Flash	8	2	0,0002	2	0,95	32	6,30	7,84	11,51	7,31	5,79
	Rolled-in material	8	2	0,0002	2	0,95	32	6,30	7,84	11,51	7,31	5,79
	Cut	8	3	0,001	3	0,9	72	14,2	11,76	17,53	16,69	29,41
	Rolled-in scale	8	2	0,0002	3	0,9	48	9,45	7,84	3,44	3,27	1,73
Cooling	Out-of-specification microstructure	7	2	0,0002	2	0,95	28	5,51	6,86	5,89	4,27	3,39
	Hardening microstructure	7	2	0,0002	2	0,95	28	5,51	6,86	5,91	4,29	3,40
	Inadequate scale	6	3	0,001	2	0,95	36	7,09	8,82	10,59	8,96	23,69
Wire finishing	Scratching	2	2	0,0002	6	0,75	24	4,72	1,96	2,11	16,08	4,25

calculation. The latter takes into account costs related to the occurrence of the identified failures:

$$RPN_{C1} = S \cdot O \cdot (P_D \cdot C_I + P_{DC} \cdot C_E) \qquad (1)$$

where:

S - severity of the defect (from 1 to 10),

O - occurrence of the defect (from 1 to 10),

P_D - probability of detection of the defect (value between 0 and 1),

P_{DC} - probability of the defect to pass to the customer (expressed as $1 - P_D$),

C_I - costs related to the occurrence of the particular defect before delivery to customer,

C_E - costs associated with the failure after delivery to customer.

This comparison showed that the risk priority number which accounts for costs associated with the potential failure may differ from the one calculated by the traditional procedure. The organization thus obtains a more comprehensive view of individual failures and associated risks. Using this approach, the organization can examine the particular failure mode from the perspective of its effect on the product use, the production process and the undesirable costs. Further exploration of the proposed method showed that it should be updated. The original principle was that RPN_{C1} represented the estimated cost of occurrence of the failure. However, such a statement is inaccurate. The risk determined in such a way is equivalent to the risk priority number which expresses the severity of a failure mode in two ways. According to the traditional approach, the severity is given by the impact of the failure on the customer and, if relevant, on other stages of production, and by the costs associated with the potential occurrence of the failure. As a result, this single relationship included two measures of severity but no reflection of detection of the failure. Therefore, the updated expression is recommended:

$$RPN_{C2} = O \cdot D \cdot (P_D \cdot C_I + P_{DC} \cdot C_E) \qquad (2)$$

where:

D - detection of the failure (from 1 to 10).

It was also found that suitable tools for this case study are updated tables for evaluation of the probability of occurrence and for the ability to detect the failure (Table 1). This issue is explored by a number of publications cited by Hu-Chen Liu et al. [10]. The estimated costs which must be expended on rectifying a failure which either was detected on the manufacturer's site or occurred on the customer's site are associated with another approach to determining the failure risk. It is equivalent to the traditional risk management approaches where the risk can only be determined as the product of two criteria: the severity and occurrence (refer to Table 1 - RPN_{SO}) [11]. Based on this assumption, the estimated cost or the corresponding risk priority number is calculated as follows:

$$RPN_{C3} = P_O \cdot (P_D \cdot C_I + P_{DC} \cdot C_E) \qquad (3)$$

where:

P_O - probability of occurrence of the defect (value between 0 and 1),

Comparison of the results of individual risk priority numbers expressed as a percentage of the total sum of the risk priority numbers for all possible defects is given in Table 1. Percentage expression allows to compare the priorities for various potential defects using different approaches for risk assessment and can be the basis for determining the most risky defects using Pareto analysis. From comparison of the individual values it is evident that the use of different forms of RPN expression may lead to different conclusions. For example, when comparing the percentage values for the risk of scratching expressed as RPN and RPN_{C2}, significant differences are found. When using *RPN*, the defect with the second smallest risk is selected, whereas the use of RPN_{C2} leads to the defect with the second highest risk. This is caused by the low team rating of defect severity and by the high costs resulting from the defect occurrence. Only in cases where the entire costs are linearly dependent on the severity point assessment, the failure priorities can be same for both approaches. Differences are also apparent when comparing the priorities of potential defects based on the percentage of risk priority numbers using RPN_{SO} and RPN_{C3}. The differences are caused by values of defect occurrence probability, which are not linearly dependent on the occurrence score. In addition, there is the influence of the non-linear relationship between costs estimation and severity assessment. Similarly, it is possible to compare other methods of risk assessment and choose the method that is suitable for the given organization or combine these approaches.

CONCLUSION

Application of the FMEA in metalworking is not exceptional. The FMEA case study focusing on the production of spring wire in a continuous wire rod rolling mill is an example. This paper presents a non-traditional approach to the application of FMEA. It evaluates the risks of potential failures of drawn wire through the associated costs. It also shows that it is possible and even desirable to employ advanced approaches to the FMEA in metalworking. They allow an organization to evaluate the potential failures and their economic impact on the customer, on the production process and on the organization itself in a much more comprehensive fashion. As a result, they can have a fundamental impact on strategic decision-making with regard to product design optimization procedures and minimization of risks of failures.

Acknowledgement

This paper was prepared under the specific research project No. SP2014/56 conducted at the Faculty of Metallurgy and Materials Engineering, VŠB-TU Ostrava with the support of Ministry of Education of the Czech Republic.

REFERENCES

[1] D. Vykydal, J. Plura, P. Halfarová, R. Fabík, P. Klaput, Use of quality planning methods in optimizing welding wire quality characteristics, Metalurgija 52 (2013) 4, 529-532.

[2] Potential Failure Mode and Effect Analysis (FMEA). 4th Edition, Reference manual. Automotive Industry Action Group, 2008, 151 p.

[3] M. Kolich, Using Failure Mode and Effects Analysis to design a comfortable automotive driver seat, Applied Ergonomics 45 (2014), 1087-1096.
DOI: 10.1016/j.apergo.2014.01.007

[4] A. G. Asl, F. Ahmadzedeh, Risk prioritization based on health, safety and environmental factors by using fuzzy FMEA, International Journal of Mining, Metallurgy & Mechanical engineering 1 (2013), 233-237.

[5] S. Mandal, J. Maiti, Risk analysis using FMEA: Fuzzy similarity value and possibility theory based approach, Expert Systems with Applications 41 (2014), 3527-3537

[6] F. Zammori, R. Gabbrielli, ANP/RPN: A multi criteria Evaluation of the risk priority number, Quality and Reliability Engineering International 28 (2012), 85-104.

[7] Z. Jia, L. Zhiyu, Risk management of international project based on AHP and FMEA, Applied Mechanics and Materials, 357-360.

[8] D. Vykydal, R. Fabík, M. Kelblerová, Cost-oriented FMEA of hot rolled wire production, METAL 2011: 20th Anniversary International Conference on Metallurgy and Materials, Brno Czech Republic, Tanger (2011), 1310-1317.

[9] A. von Ahsen, Cost-oriented failure mode and effect analysis, International Journal of Quality & Reliability Management 25 (2008), 466-476.

[10] H. Liu, L. Liu, N. Liu, Risk evaluation approaches in failure mode and effects analysis: A literature review, Expert Systems with Applications, 40 (2013), 828-838.
DOI: 10.1016/j.eswa.2012.08.010

[11] J. Bijańska, K. Wodarski, Risk management in the planning of development projects in the industrial enterprises, Metalurgija 53 (2014) 2, 276-278.

Note: The responsible translator for English language is Jaroslav Drnek, Czech Republic