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Method of improve the level of product quality

Dominika Siwiec[1], Andrzej Pacana[1]

[1] Rzeszow University of Technology, The Faculty of Mechanical Engineering and Aeronautics al. Powstańców Warszawy 8, 35-959 Rzeszów, Poland,
Corresponding author e-mail: e-mail: app@prz.edu.pl

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Abstract
Meeting customers' requirements and achieved the right level of product quality is key action of enterprises. It is being done by controlling the product, using for example non-destructive testing (NDT). But the NDT not indicating what is the root of incompatibility. Additionally, previous research does not include the decision methods, which would be related the identify the causes of the problem as part of improving the product quality. Therefore, the aim is supporting the process of improving the product quality level in the context of precisely identify the incompatibility and the root of their occurrence with including the solve decision problem. In this aim, it was assumed that using after the NDT research in connection way: brainstorming, cause and effect diagram, AHP method (Fuzzy Analytic Hierarchy Process) and the 5Why method, will be allowed on effective identify the root of the problem. The method test was carried out for the porosity on a welded mechanical seal made of steel 410, which was identified by the fluorescence method (FPI) in Podkarpacie enterprise. The analysis has shown the effectiveness of using after NDT the combined methods as part of identifying the incompatibility and precisely identifying the root of its occurrence in context of solving the decision problem. The proposed method can be used to improving the quality of other products, for example from the aviation and automotive industry, as part of meeting customer requirements. Originality is the combined NDT research with quality management techniques and supported the process of improving the quality level of the product by implementing in this sequence the fuzzy multicriteria decision method.

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1. Introduction

Identifying the root of the problem is particularly important as part of continuous improvement of the level of products and in the same meeting the needs of customers and interested parties (Ulewicz et al. 2013; Siwiec and Pacana, 2020, Knop, 2020). In the context of achieving the level of quality products the main action is using the NDT research (Pacana, Siwiec and Bednarova, 2019; Zielińska and Rucka, 2018), which are one of the most preferred in control of the quality product. It results from effectiveness in identify the incompatibility of the product without destructive it (as opposed to destructive testing). However, NDT research is not showing what is the cause of incompatibility. Then, it is necessary to make the next actions, by helped which these causes will be properly identified. In this aim, it will be effective to use quality management techniques after NDT research (Ulewicz, 2014; Sygut and Krynke, 2017), which are supporting analysis causes of the problem. As has shown by the authors of articles (Doshi et al., 2012; Peniwati, 2007) this process should be realized as part of a solve decision problem, which is referred to as making decisions about the cause of the problem. However, the analyzes far included only use mentioned NDT research (Pacana, Siwiec and Bednarova, 2019; Zielińska and Rucka, 2018) in a combined way with quality management techniques (Dziuba, Jarossova and Gołębiecka, 2014; Liliana, 2016).

After the literature review, it was shown that hitherto the process of analysis of causes of problems was not supported by decision methods which are recommended for this (Doshi et al., 2012; Peniwati, 2007). Primarily, quality management techniques were used for it, mainly the Ishikawa diagram (cause and effect diagram) (Liliana, 2016; Pacana et al., 2019; Wong, 2011, Ostasz, 2020), the 5Why method (Dziuba, Jarossova and Gołębiecka, 2014; Pacana, Siwiec and Bednarova, 2019), the Pareto-Lorenz diagram (Ulewicz, 2014; Sika et al., 2020), brainstorming and multiply voting (Pacana, Siwiec and Bednarova, 2020). For example, in an article (Sika et al., 2020), the Pareto-Lorenz method was used after NDT

research, in order to analyze incompatibilities of casts. Then, the author of an article (Ulewicz, 2014) used the Pareto-Lorenz method and Ishikawa diagram with NDT research, in order to determine the degree of incompatibility of manufactured products. Other examples are articles, i.e. (Muhammed et al., 2016; Pacana et al., 2019; Setyandi, Tjahyono and Haryadi, 2019; Siwiec and Pacana, 2020), in which the Ishikawa diagram was used after NDT research, also in order to analyze incompatibilities of products. In turn, in articles (Dziuba, Jarossova and Gołębiecka, 2014; Pacana, Siwiec and Bednarova, 2019; Siwiec and Pacana, 2020), the 5Why method (except the Ishikawa diagram) was used in order to determine causes of incompatibilities of products. Where, the 5Why method was used to identify the root of incompatibility. In a turn of the context of the mentioned decision problem, in aim to identify the priority of causes, the Pareto analysis with the Ishikawa diagram was proposed (Doshi et al., 2020). Or the number of causes on the Ishikawa diagram was estimated as part of identify if this number is enough to precisely the main cause of the problem (Bilsel and Lin, 2012; Gazda 2013).

After the literature review, it was concluded that NDT research and quality management techniques were combined in order to analyze the causes of incompatibilities products, e.g. (Ulewicz, 2014; Muhammed et al., 2016; Pacana et al., 2019; Setyandi, Tjahyono and Haryadi, 2019; Siwiec and Pacana, 2020). Also, it was tried to introduce elements of techniques to solve decision problems, e.g. (Bilsel and Lin, 2012; Doshi et al., 2020). But, the decision problem was not solved by using methods preferred to solve decision problem, for example, popular the FAHP method (Fuzzy Analytic Hierarchy Process) (Chang, 1996; Siwiec, Bednarova and Pacana, 2020). Therefore, it was considered that previous analyzes were not one, coherent method, which will allow improved the analyze of causes problems as part of combined the quality management techniques and decision method. It was considered it for a gap. Therefore, it was concluded that it will be effective to combine the process of identify the incompatibility by NDT with the process of identify the causes of this incompatibility as part of solving the decision problem.

The aim is supporting the process of improving the product quality level in the context of precisely identify the incompatibility and the root of their occurrence with including the solve decision problem. In this aim, a hypothesis was accepted, that using after NDT research in a combined way: brainstorming, cause and effect diagram, FAHP method and 5Why method will be allowed to effectively identify the root of the problem. In order to verify the accepted hypothesis the test of the proposed method was done. In the article, this test was done for the problem with incompatibility identified in Podkarpacie enterprise.

In this enterprise, on the need of the external client, was analyzed the mechanical seal by fluorescence method (FPI). On this product, the porosity was identified. According to the management of NDT research, the mechanical seal was not still stabilized in terms of quality. It probably resulted from a lack of precise the root cause of the problem. Initially, it was considered that porosity was resulting from pollution. Therefore, it was considered that adequate is supporting the process of product quality in the context of precisely identify the incompatibility and root of its occurrence.

2. Experimental

The proposed method was combined techniques, i.e.: brainstorming, cause and effect diagram, FAHP method and 5Why method. This method was implemented after NDT research. Using the brainstorming was conditioned by the possibility to effectively identify the potential causes of the problem (Pacana et al., 2019). In turn, the choice of the cause and effect diagram was resulted from the possibility to group all causes according to categories (for example 5M+E), and then show these causes in a visual way (Pacana et al., 2019; Pacana, Siwiec and Bednarova, 2019). While, using the FAHP method was resulting from adequate this method to solve the decision problem, at the same time possibilities to reducing the inconsistent grades (Chang, 1996; Siwiec, Bednarova and Pacana, 2020). It was assumed that the categories of the diagram, which contain the main cause will be specified in a precise way by the FAHP method. Wherein, by the FAHP method from all potential causes of this category, the main cause will be selected. To precise the root cause of the problem, it was justified in using the adequate to this the 5Why method (Dziuba, Jarossova and Gołębiecka, 2014; Pacana, Siwiec and Bednarova, 2019). This method was shown in six steps.

The first step of the method is determining the purpose of the analysis according to the SMART method, which procedure is shown for example in the article (Lawlor and Hornyak, 2012). The goal should be related to the identified incompatibility that was detected after the product quality control with non-destructive testing (NDT). Additionally, the aim should refer to the concept of the proposed method (i.n. identifying the root of the problem).

In a turn of the choice of method of NDT to analyze the quality of product is addicted to the material of product and requirements of clients. An example of the choice of the NDT because of the required surface of the product material is shown in Table 1.

Table 1. Requirements of the surface to NDT research (Wymagania powierzchni, 2020)

NDT method	Requirements of surface
Vizual (VT)	outer surface of a composite product; it is enough one, clean place the surface
Penetrative (PT)	open discontinuity free of pollution the surface; a problem in testing the porosity surface
Magnetic Particle (MT)	free of pollution and smooth surface; also to galvanic coatings; only to ferromagnetic materials
Radiographic (RT)	access to outer and internal surface
Ultrasonic (UT)	access to outer and internal surface; rough surface makes it difficult or impossible to research
Eddy current (ET)	free of pollution and smooth surface; mainly magnetic and nonmagnetic materials

After identifying the problem (an incompatibility of product) by NDT research it is possible to make the second step of the method.In the second step of the method, the potential causes have an influence on the occurrence problem are identified. In this aim the team of experts are completed, who are identifying the potential causes as part of brainstorming. Then, these causes are grouped and visualized on the causes and effects diagram. Preparing the diagram is made according to the 5M+E rule, i.e. man, method, machine, material, management and environment. It is possible to choose other categories, and it depends on the entity using the method.

The third step is the calculation of the weights of the categories of cause and effect diagram. This process relies on the precise identity (by reducing the ambiguity in expert assessments) category of the diagram, which has the main cause. In this aim, the FAHP method is using which is adequate for this (Kusumawardani and Agintiara, 2015).

Initially, the team of experts in preferred by Saaty scale from 1 to 5 awards grades to all categories of the diagram, where 1 - lowest grade, 5 - highest grade. Also, it is possible to use other Saaty scales, for example, 1-7 or 1-9, and the choice depends on the entity using the method (Pacana, Siwiec and Bednarova, 2020). Then, all grades are modification on triangular fuzzy numbers according to Table 2.

Table 2. Classical and fuzzy Saaty scale (Kusumawardani and Agintiara, 2015)

Grade in classical Saaty scale	Triangular fuzzy number	Triangular fuzzy reciprocal number
1	(1,1,1)	(1,1,1)
2	(1,2,3)	(1/3,1/2,1)
3	(2,3,4)	(1/4,1/3,1/2)
4	(3,4,5)	(1/5,1/4,1/3)
5	(4,5,6)	(1/6,1/5,1/4)
6	(5,6,7)	(1/7,1/6,1/5)
7	(6,7,8)	(1/8,1/7,1/6)
8	(7,8,9)	(1/9,1/8,1/7)
9	(8,9,9)	(1/9,1/9,1/8)

Then, a combined fuzzy decision matrix and comparison matrix are created according to the authors of the articles (Chang, 1996; Tsai et al., 2020; Łuczak, 2012). Next, the relative fuzzy weight values are calculated (1) (Chang, 1996; Tsai et al., 2020; Łuczak, 2012):

$$W_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}} \; where \; i,j = 1 \sim n \qquad (1)$$

where:
a_{ij} – Tringular Fuzzy Number located at row i and column j in the pariwise comparision matrix;
W_i – the fuzzy weight of row i.

Later, the degree of possibility for fuzzy numbers (2) and the least degree of possibility for fuzzy numbers (3), weight vector (4) and normalized non-fuzzy weight vector (5) (Łuczak, 2012; Tsai et al., 2020; Sofyalioğlu and Öztürk, 2012):

$$V\left(\widetilde{W_i} \geq \widetilde{W_j}\right) = \mu_{\widetilde{W_i}}(d) = \begin{cases} 1, & for \quad m_{ij} \geq m_{ji} \\ 0, & for \quad l_{ji} \geq u_{ij} \\ \dfrac{(l_{ji} - u_{ij})}{(m_{ij} - u_{ij}) - (m_{ji} - l_{ji})} & for\ others. \end{cases} \qquad (2)$$

$$V\left(\widetilde{W_i} \geq \widetilde{W_j} | j = 1, \dots, n; i \neq j\right) = \min_{\substack{j \in (1,\dots,n) \\ j \neq i}} V\left(\widetilde{W_i} \geq \widetilde{W_j}\right) = \mu_{W_i}(d) = \mu_{W_j}(d); i = 1, 2, .. \qquad (3)$$

$$W' = \left(min_1 V\left(\widetilde{W_i} \geq \widetilde{W_j}\right), \dots, min_n V\left(\widetilde{W_i} \geq \widetilde{W_j}\right)\right) \qquad (4)$$

$$W'_N = \left(\frac{\mu_{\widetilde{W}_i}(d)}{\sum minV}, \frac{\dots}{\dots}, \frac{\mu_{\widetilde{W}_n}(d)}{\sum minV}\right)^T = \left(w_j, \dots, w_n\right), \text{where i} = 1, 2, \dots \text{n; j} = 1, 2, \dots, \text{n} \qquad (5)$$

Based on the results of weights it is possible to make a ranking of categories weights of the cause and effect diagram. The category with the maximum weight is classified as a category containing the main cause of the problem.

The fourth stage of the method is to identify in a precise way the main cause of the problem. This process relies on determining the weight for all potential causes belong to the chosen category of the diagram, and then on choose the main cause (with the maximum weight). This process is realised by using the FAHP method and is made in the same way as is presented in the third stage.

The fifth stage is using the 5Why method to identify the root cause of the problem (showing what is the cause of occurrence of the problem). Therefore, to the problem and selected the main cause (stage 2) the question "Why?" is asked, to which an answer should be given (Dziuba, Jarossova and Gołębiecka, 2014; Pacana, Siwiec and Bednarova, 2019). The question must ask until the moment of identifying the root of the problem.

An algorithm of the proposed method is shown in Figure 1.

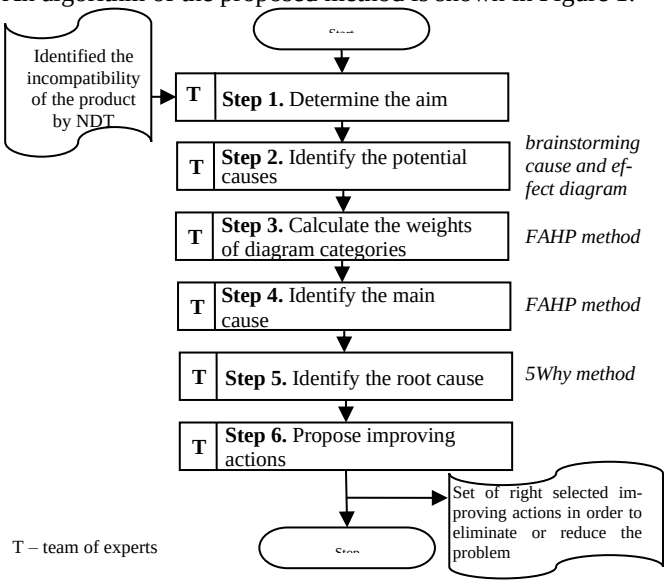

Fig. 1. An algorithm of improving the level of product quality

The sixth step of the method is to determine the improving actions, thanks for which it will be possible to reduce or eliminate the occurrence of the problem in the future.

3. Results and discussion

An analysis was made for the problem of incompatibility of the product in enterprise localized in Podkarpacie. The problem was to the relatively common porosity on the mechanical seal from 410 steel. This incompatibility was identified by non-destructive testing (fluorescent method - FPI). The characterize of the mechanical seal is shown in the subject literature (for example: Uszczelnienie mechaniczne, 2020). An example of porosity on this product is shown in Figure 2.

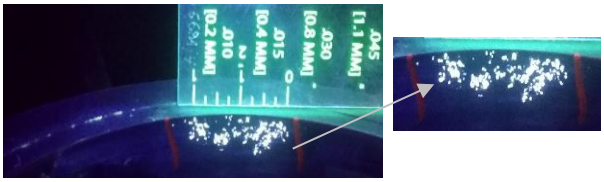

Fig. 2. Porosity on mechanical seal identified by FPI method

The production process of the mechanical seal was not stabilized in terms of quality, thus, the requirements of customers and interested parties were not met. Also, the root of incompatibility was not unequivocally determined yet (initially it was considered that it is pollution). For this reason, it was legitimate for using the proposed method.

The aim was to precise the root of porosity on the mechanical seal. In order to identify the potential causes of the porosity the cause and effect diagram was made, in which during the brainstorming to six categories were assigned the potential causes (Figure 3).

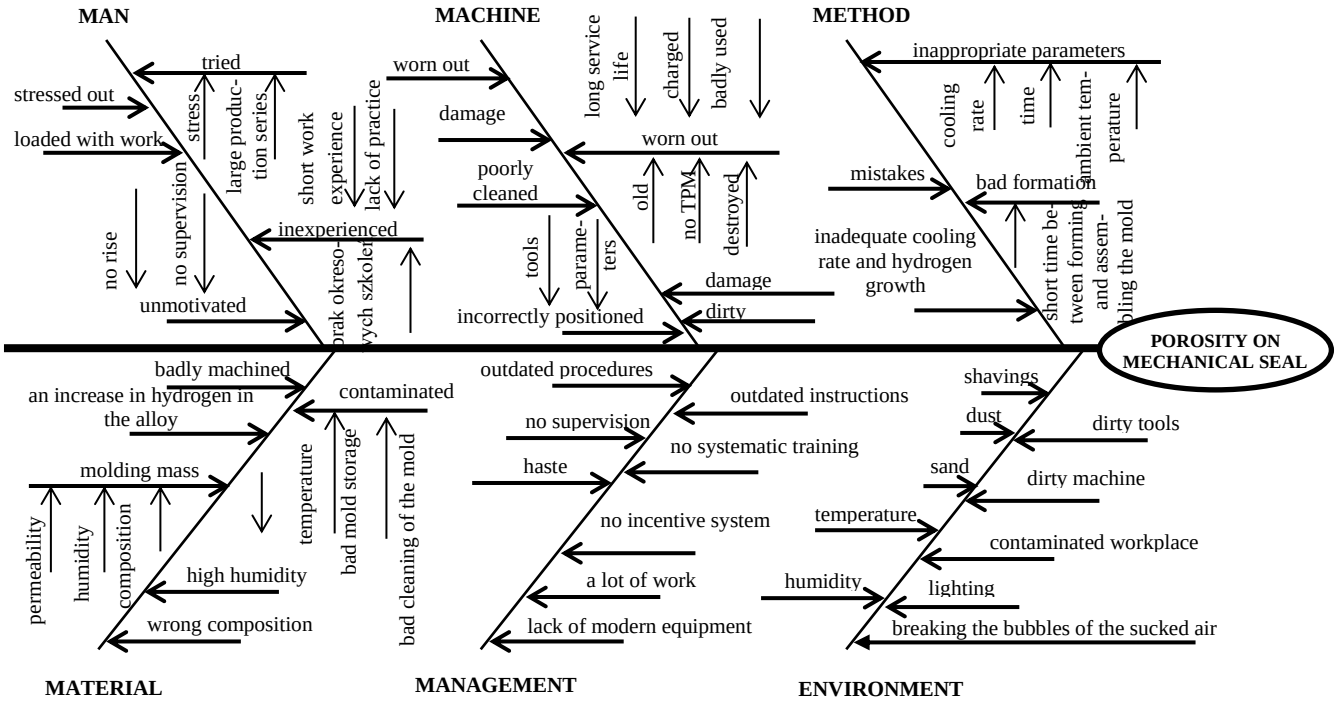

Fig. 3. The cause and effect diagram for porosity on mechanical seal

Subsequently, the team of experts gave the grades on a scale of 1-5 for each diagram category, which were modified on the triangular fuzzy number. Based on grades of categories the FAHP method was carried out, from which the results are shown in Table 3.

Table 3. Results of the analysis of the category of a cause-and-effect diagram by the FAHP method.

Categories of diagram	Combined marix	Fragment of the pairwise comparison matrix			Relative fuzzy weight value	Normalized non-fuzzy weight vector	Ranking
	l_{ij}; m_{ij}, u_{ij}	Man	Machine	Method	W_i	W_n'	
Man	1; 2,45; 4	1; 1; 1	0,33; 1,73; 1,33	0,17; 0,55; 1,33	0,02; 0,15; 1,18	0,20	2
Machine	1; 1,41; 3	0,25; 0,58; 3	1;1;1	0,17; 0,32; 1	0,02; 0,09; 1,06	0,19	3
Method	3; 4,47; 6	0,75; 1,83; 6	1; 3,16; 2	1; 1; 1	0,04; 0,24; 2,04	0,00	4
Material	1; 3,16; 6	0,25; 1,29; 6	0,33; 2,24; 2	0,17; 0,71; 2	0,01; 0,19; 2,11	0,21	1
Management	1; 2,45; 4	0,25; 1; 4	0,33; 1,73; 1,33	0,17; 0,55; 1,33	0,01; 0,15; 1,41	0,20	2
Environment	1; 2,45; 4	0,25; 1; 4	0,33; 1,73; 1,33	0,17; 0,55; 1,33	0,01; 0,18; 1,41	0,20	2

An analysis was shown, that the material was the category of the diagram, which was included the main cause of the problem (weight 0,21). Therefore, the potential causes which were noted for this category were analysed according to the procedure FAHP method. These causes were: inappropriate parameters (P1), bad formation (P2), inadequate cooling rate and hydrogen growth (P3). The results of the calculation are shown in Table 4.

Table 4. Results of the potential causes analysis by FAHP method.

Potential causes	Combined marix	Pairwise comparison matrix			Relative fuzzy weight value	Normalized non-fuzzy weight vector	Ranking
	l_{ij}; m_{ij}, u_{ij}	P1	P2	P3	W_i	W_n'	
P1	4; 5; 6	1; 1; 1	1,33; 2;50; 2,0	0,80; 1,25; 2,0	0,27; 0,45; 0,71	0,76	1
P2	1; 2; 3	0,17; 0,40; 0,75	1; 1; 1	0,20; 0,50; 1,0	0,12; 0,18; 0,39	0,24	2
P3	3; 4; 5	0,50; 0,80; 1,25	1;0 2,0; 1,67	1;1;1	0,21; 0,36; 0,56	0,00	3

After using the FAHP method to analyze the potential causes of the material category, it was shown that the main cause was inappropriate parameters (P1). This cause was included in the 5Why method in order to identify the root of the porosity (Figure 4).

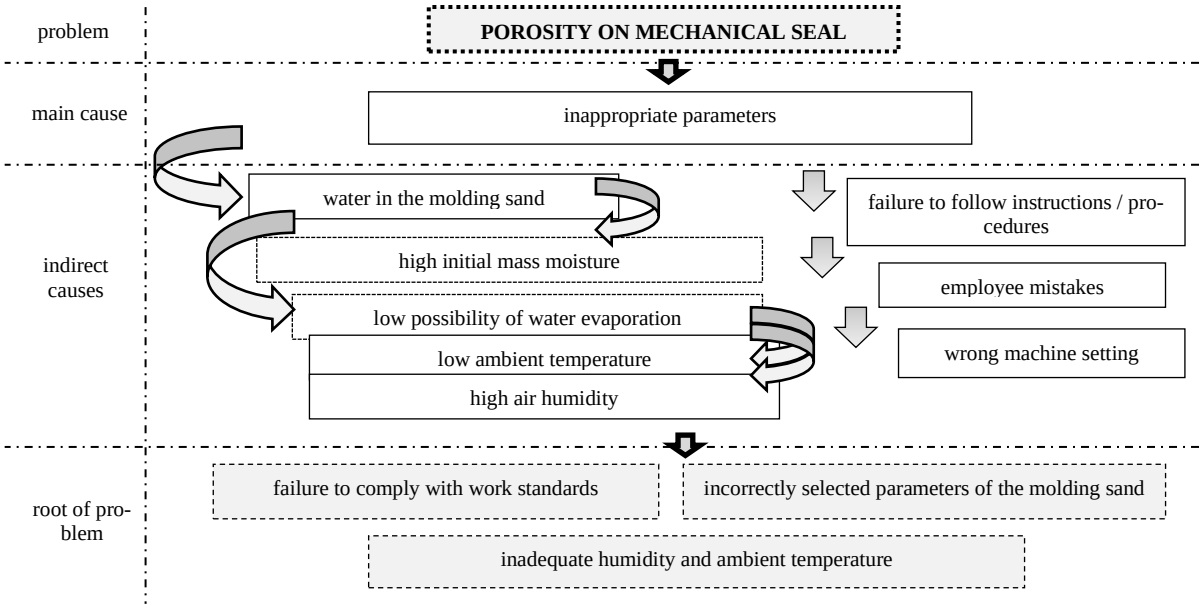

Fig. 4. Analysis of the porosity problem on the mechanical seal using the 5Why method

After analyzed the problem with porosity on mechanical seal using the 5Why method, it was concluded that the root of the problem were: failure to comply with work standards, incorrectly selected parameters of the molding sand and inadequate humidity and ambient temperature.

As part of improving actions would be effective to make retraining of employees, and also actualize the procedures and instructions. It would also be important to select the parameters of the molding sand again, and thus to use appropriate techniques to change the humidity and temperature of the environment. Due to these measures, it would be possible to reduce or completely eliminate the formation of a porosity cluster.

4. Summary and conclusion

Product quality improvement takes place as part of meeting the requirements of customers and interested parties. In this context, the main actions in enterprises are the quality controls in order to identify the eventuality of incompatibilities. They are performed, for example, by non-destructive testing (NDT). But these controls not allow on identify the root of incompatibility. Then, it is necessary to use other methods to allow it. In view of it, that research so far not included improving the level of product quality in the context of combined NDT research, quality management techniques and decision methods, it was considered it for a gap. Therefore, the aim was supporting the process of improving the level of a quality product in the context of precisely identify the incompatibility and the root of its occurrence with including the solve decision problem. For this purpose, following the NDT tests, the methods were used in a combined manner, i.e.: brainstorming, cause-and-effect diagram, FAHP (Fuzzy Analytic Hierarchy Process) method and 5Why method. The test of the method was made for the relatively common porosity on the mechanical seal from 410 steel, which was identified in the Podkarpacie

enterprise. The proposed method was realized by brainstorming, thanks to which the potential causes of incompatibility were identified. Then, using the cause and effect diagram these causes were grouped and visualized. Next, the team of experts was made assessment the categories of the diagram, deciding which categories include the main cause. This process was made by the FAHP method, thanks to which inconsistency of assessments was reduced. Also, using the FAHP method, it was assessed which of the reasons indicated for the selected diagram category is the main cause. In turn, in order to precisely the root of the problem the 5Why method was used. In the cause of porosity on the mechanical seal, it was shown that material was a category that had the main cause. Then, as the main cause was considered the inappropriate parameters. After used the 5Why method the root causes were identified, i.e.: failure to comply with work standards, incorrectly selected parameters of the molding sand and inadequate humidity and ambient temperature.

It was concluded, that the proposed method allows for the precise identify the root of incompatibility. Therefore, this method can be used for improving the level of quality products (for example from the aviation or automotive industry), as part of meeting customer needs. Originality is the combined NDT research with quality management techniques and supported the process of improving the quality level of the product by implementing in this sequence the fuzzy multicriteria decision method. As a result, the gap regarding the lack of jointly occurring decision-making methods, quality management methods and NDT tests as part of product quality improvement was filled.

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提高产品质量水平的方法

關鍵詞

产品质量水平 非破坏性测试 机械工业 模糊层次分析法 产品不相容

摘要

满足客户要求并达到适当的产品质量水平是企业的关键行动。它是通过控制产品来完成的，例如使用无损检测（NDT。但是 NDT 并未指出不兼容的根源。此外，以前的研究不包括决策方法，该决策方法与确定问题的原因相关，这是提高产品质量的一部分。因此，目的是在包括解决决策问题在内的精确识别不兼容及其发生根源的背景下，支持提高产品质量水平的过程。在此目标中，假设在进行无损检测之后以联系方式使用：集思广益，因果图，AHP 方法（模糊分析层次过程）和 5Why 方法，可有效识别问题的根源-lem。在 Podkarpacie 企业中用荧光法（FPI）鉴定了由钢 410 制成的焊接机械密封上的孔隙率的方法测试。分析显示了在无损检测之后使用组合方法作为识别不兼容并在解决决策问题的背景下精确识别其发生根源的一部分的有效性。所提出的方法可用于提高其他产品的质量，例如满足航空和汽车行业的其他产品，以满足客户需求。创意是将无损检测研究与质量管理技术相结合的方法，通过按顺序执行模糊多准则决策方法来支持提高产品质量水平的过程。