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Andrzej Pacana[1]
Dominika Siwiec

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INTEGRATED TECHNIQUE SEARCHING CAUSES OF QUALITY INCOMPATIBILITIES

Abstract: *Achieving the expectation quality products level is possible among others, by using adequate management techniques, which allow or identify incompatibilities, its sources, and above all, the reasons for its occurrence and ways of its elimination. Applying in this aim singe technique is common, but it was turned out that a lack is integrated connection between selected techniques. The purpose of the study is to propose a technique consisting of cyclical use: brainstorming (BM), relationship diagram, cause and effect diagram, multiple voting, and the AHP method.The technique was verified in the nondestructive testing process. The analysis was performed for often occurring incompatibilities in mechanical sealers for 410 steel. The identified incompatibilities of the analyzed mechanical sealers were the most frequent porosity, which was identified by fluorescent method (FPI). The effectiveness of the proposed technique was shown. The main advantage of its use was to improve the process of decision-making referred to incompatibility causes. It is possible to effectively use this method to analyze another type of incompatibility and products in production and service enterprises.*

Keywords: *Production Engineering, Mechanical Engineering, Incompatibility of Proudct, Decision Making, Quality Management Tools, AHP, Causes And Effect Diagram; Improving Quality Of Products*

1. Introduction

As part of the actions from production engineering, it is necessary to meet the needs of quality products level (Pacana & Siwiec, 2022).In this aim realized are controls and analysis of quality products, whose task is, inter alia, detection incompatibilities and source occurrence (Ulewicz, 2003; Pacana et al., 2019; Malindžák, et al. 2017; Gazda, et al. 2013). In the case of identifying the product incompatibilities, the popular practice, e.g. in controls of products from the aviation or automotive industry, are non-destructive testing (NDT) (Zientek, 2016). Their effectiveness in comparison to other methods, as, e.g., destructive testing (NDT), ensures the detect incompatibility of the product without its destructive (Zielińska & Rucka, 2018). However, NDT research does not indicate what is the cause of this incompatibility.Therefore, it was considered advisable is to integrate NDT research with other techniques that allow it. These techniques include, for example, quality management techniques (Meyer, 2003),

[1] Corresponding author: Andrzej Pacana
Email: app@prz.edu.pl

which, when used in a properly selected sequential manner, ensure the identity and causes of problem occurrence (Ostasz et al., 2022; Pacana & Siwiec, 2021; Pacana et al., 2019). Additionally, as shown in the literature, e.g. (Doshi et al., 2012; Peniwati, 2007), solving the problem with incompatibility of the product is a decision problem. In the research context, decision making refers to the choice of incompatibility cause, among others, at the stage of identifying them on the Ishikawa diagram. The literature review has shown that as part of NDT research, possibilities to increase its sensitivity were analyzed (Tumbulletl et al. 2017), application to different kind of products (Markus et al., 2018; Mevissen & Meo, 2019; Rucka et al., 2018) or impact of factors as, e.g.: sensitivity, dye, or signal on the quality of NDT research (Piao et al., 2019; Lu et al., 2019).

In turn, by quality management techniques, the incompatibilities of products were analyzed (Ulewicz, 2003; Pacana, Siwiec & Bednarova, 2020), and in this, the potential causes of problems were identified, e.g., by using the Ishikawa diagram (Liliana, 2016; Stefanovic et al., 2014; Siwiec & Pacana, 2021; Wong, 2011) and sources causes of problems were identified, e.g., by using the 5Why method (Dziuba et al., 2014; Lu et al., 2020; Pacana et al., 2021). To identify the causes of problems, teamwork techniques were used, e.g., brainstorming and multiply voting (Kohn & Smith, 2011; Pacana et al., 2020; Putman & Paulus, 2008; Siweic et al., 2019). Moreover, it was proposed to use the Pareto analysis after the Ishikawa diagram to determine the priority of these causes (Doshi et al., 2012), and it was analyzed whether the number of all causes in the Ishikawa diagram is sufficient to determine the source cause of the problem (Bilsel & Lin, 2012).However, there are no works that would include the decision-making process regarding the cause of the problem in the proposed actions, by using decision-making methods adequate for this, e.g., the AHP method (Analytic Hierarchy Process) (Siwiec et al., 2019; Siwiec & Pacana, 2021; Saaty, 2008; Saaty, 2007).

Therefore, the aim was to propose an integrated technique that improves the process of identifying incompatibility in the product. For this purpose, it was assumed:

Hypothesis: Used in a combined way after NDT research: brainstorming, relationship diagram, cause and effect diagram, multiply voting technique, and the AHP method will be effective as part of identifying the problem and precisely to indicate the source causes of occurrence of this problem and adequate remedial actions.

The test of the proposed technique was made to solve the relatively frequent problem that occurred in one of the enterprises from the south of Poland. This problem was porosity in the mechanical seal welded from 410 steel. This incompatibility was identified by NDT research.

The originality of the study is that the proposed techniques are “universal” because all the methods selected in the proposed techniques have universal (general) applications to different types of products. Mostly, those are physical products, but also services. Furthermore, the methodologies of these methods applied in the proposed sequence have universal applications. These methods can be used to verify all products and each type of incompatibility. Despite this, in previous studies, these methods were not combined in a single model to complexly verify the quality of the product.

2. Method

The proposed technique was to integrate: brainstorming, relationship diagram, cause and effects diagram, multiply voting technique, and AHP method. The originality of the proposed technique is, among others, combined traditional quality management techniques with the AHP method (Analytic Hierarchy Process) (Ulewicz et al., 2021; Pacana et al., 2020; Siwiec & Pacana, 2021).

The decision of combining these techniques with the AHP method was conditioned by a necessity of making the decision about the choice of the source cause of the problem. The AHP method is considered an effective method to solve decision problems (Pacana et al., 2020; Saaty, 2007), and the proposed combination of these techniques has not occurred. Due to the fact that individual techniques are commonly known (Ulewicz, 2003; Podvezko, 2009; Pacana et al., 2019; Saaty, 2008; Skorupka & Duchaczek, 2010; Siwiec et al., 2019), it was considered justified to present only the structure of the integrated technique. The algorithm of the proposed method is shown in Figure 1.

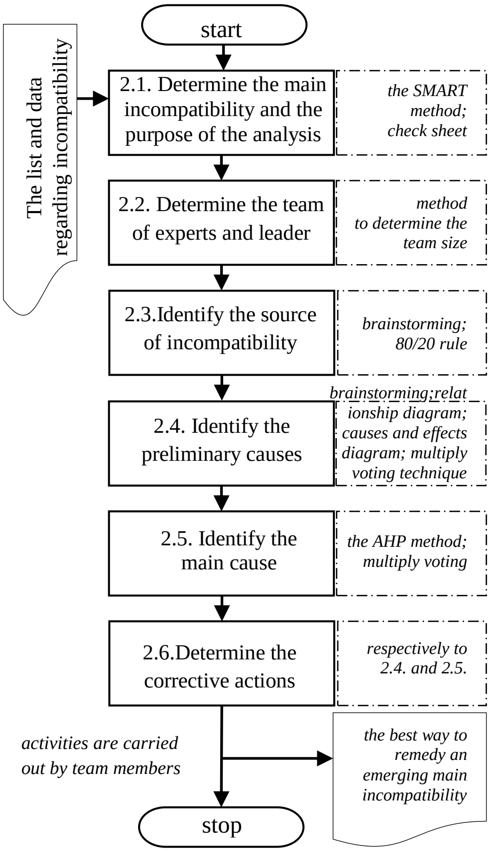

Figure 1. Block diagram of the proposed, integrated technique of indicating the source of incompatibility

The originality of this method is the possibility for decision-making to improve the process referring to causes of incompatibility. It is possible to effectively use this method to analyze another type of incompatibility, because the proposed combinations of techniques are universal. Additionally, this method can be combined with any quality control of products.

The proposed technique supporting the process of identifying causes of incompatibility is proposed to be used in 6 stages.

2.1. Determine the main incompatibility and the purpose of the analysis

As the first stage, it was assumed to determine the purposed of the analysis, which should include the general concept of application of proposed technique (supporting process of identifying the source of problem). The aim should be to be concerned with one of the identified incompatibilities. Most often, it is the main incompatibility characterized by the highest number of occurrences, the highest cost, or effects. The aim should be determined by the entity applying the proposed technique.To right determine the aim, it is necessary to use the SMART method, which is described, e.g. in (Lawlor & Hornyak, 2012). The determination of the aim refers to necessarily obtaining information about incompatibility. This information should be included for example, kind (name, type) of incompatibility, the kind (name, type) of a product on which the incompatibility was detected, and the number of identified incompatibilities of the selected type, e.g. annually (Lawlor & Hornyak, 2012). This information can be obtained from the catalog of incompatibilities or the check sheet which are run by enterprises.

2.2. Determine the team of experts and the leader

In a second stage, the team of experts is selected, which will be responsible for carrying out the identification process to identify the source and causes of incompatibility. The selection of experts should include their knowledge and competence in the context of the problem. The process of selecting the team of experts is shown in the subject literature, e.g. (Kurpaszewkicz & Zółtowski, 2002).

As part of the proposed method, the leader of the team is determined, who will be responsible for coordinate the work of the team in the process of identifying the source of incompatibility. It is recommended that the leader of the team is the person who has experience in teamwork because in this way the probability of achieving the aim is increasing.

2.3. Identify the source of incompatibility.

As the third stage, it was assumed that the source of incompatibility, so identify the place in which incompatibility has occurred. This stage is realized as part of the brainstorming performed by the selected team. All sources are identified, or, in the case of a very large number, the 20/80 rule is applied (Aithal, 2017; Pacana, 2020).

2.4. Identify the preliminarycauses

Subsequently, the preliminary causes of incompatibility are identified. This stage means searching for the answer to the question: What happened that incompatibility has occurred?It is performed for each source (place of occurrence of the incompatibility) selected in step 2.3. In this aim, the are used: brainstorming (BM), relationship diagram and cause and effects diagram. The choice of these techniques has resulted from the possibility of their application to identify as many possible causes (Luca, 2016; Pacana et al., 2019). Additionally, the choice of diagrams was conditioned on the possibility to present the problem (and its causes) in a visual way (Ulewicz, 2003; Pacana et al., 2019; Siwiec & Pacana, 2021).

Initially, in a previously selected team by helped brainstorming (BM) the preliminary causes of incompatibility are identified for the assumed source. According to the BM method, the leader notes all identified causes in a place visible to all team members, e.g., on a sheet of paper or on a blackboard. This stage is taken up to about 30 minutes, and it ended with the most often a large list of potential (preliminary) causes of incompatibility, from which the leader can delete unrealistic submissions.

The relationship diagram is used to group all identified preliminary causes of incompatibility. Initially, it is necessary to identify categories (theme groups) according to which these causes will be grouped. These categories are determined at the discretion of the team. It is proposed to use the basic categories from the Ishikawa diagram, i.e., man, method, machine, material, management and environment (Pacana et al., 2019; Pacana et al., 2020) orenvironment, system, suppliers, and personnel. The team groups the source causes into specific categories and visualizes them in an organized way according to the categories to whom they were assigned. In this aim, it is recommended to use the causes and effects diagram (so-called fish bones) (Meyer, 2003). The developed cause and effects diagram is placed in a place visible to all team members (e.g., on a blackboard or a sheet of paper) (Bilsel & Lin, 2012; Ulewicz, 2003; Pacana et al., 2019). This visualization is to help better understand the problem before taking the next actions.

2.5. Identify the main cause

The fifth stage of the technique is to identify the main cause of occurrence of the incompatibility in the analyzed source. Usually, this process is realized as a second step of BM. In the proposed technique in this place, the use of the AHP method (Analytic Hierarchy Process) (Pacana et al., 2020; Saaty, 2007; Siwiec & Pacana, 2021), which supported the multiply voting method. The purpose to implement the AHP method was to objectivization of decisions in the field of identification the main cause of occurrence of incompatibility by comparison of pair. The AHP method in comparison to other heuristic techniques, which were used as part of the proposed method (e.g., multiply voting) allows not only to make a numerical measure of the importance of causes (Skorupka & Dichaczek, 2010), but also to assess the causes in a homogeneous and repeatable way. By the AHP method, the integration of deducted thinking and systematic approach to solve complex problems is achieved. Thanks to the AHP it is possible to make simultaneous assessment causes expressed in a measurable and immeasurable way, while simultaneously taking into account the priorities of the causes (i.e. impact the cause on the occurrence the incompatibility) as part of make the best expert choice, which is supported by the result of the calculation process (Skorupka & Dichaczek, 2010). Taking into account the advantages of the AHP method, it was decited to use its proposed technique as a substitute for popular methods, e.g., multiply voting or Suzuki method (ABCD) (Aithal, 2017).

The process of identification main cause by the AHP method starts from choice maximum 9 preliminary causes (which have the greatest impact on occurrence, the incompatibility) of all causes indicated in the cause and effect diagram. The choice is done by the team by using in this aim multiply voting, and advisable preliminary the the cause are marked on cause and effects diagram. It is necessary to remember that the number of causes cannot be large than 9, which is result from the assumptions of the AHP method, where simultaneous comparison in pairs is effective for 7 ± 2 causes (Mu & Pereyra-Rojas, 2017; Pacana et al., 2020; Skorupka & Duchaszek, 2010; Steinberger et al., 2006). Selected causes from the preliminary causes are called potential causes.

Then the team of experts, as part of multiply voting assessment all the selected causes (so-called potential causes) on the scale preferred for the AHP method, from 1 to 7. It is possible to use other scales, e.g., 1-5 or 1-9 (Pacana et al., 2020; Saaty, 2007). Based on the results of voting, the list of all selected to analyze the causes is created (maximum 9 potential causes) and their assessments on selected Saaty scale.Then it is necessary to make the calculation by using the AHP method according to the subject literature (Horvathova et al., 2019; Pacana et al., 2020; Saaty, 2007; Siwiec & Pacana, 2021; Piantanakulchai & Saengkhao, 2003; Skorupka & Duchaczek, 2010). The maximum value achieved after calculation by the AHP method means that this cause is the main cause of the analyzed incompatibility in the analyzed source.

2.6. Determine the correctiveactions

When the source and main cause of occurrence of the incompatibility were identified, it is possible to determine the remedial methods (corrective actions). In this aim, it is necessary to determine the aim combined with the main cause and repeat the method using again the brainstorming in search of the solution problem with an emerging source cause, and also the relationship diagram and causes and effects diagram (analogical to step 2.4.). Then it is necessary to make the AHP method (analogically as is shown in stage 2.5.). It should keep in mind that in this time it is realized in the context of searching the answer to the question of how to solve the problem.As a result, the maximum value from the AHP method is the best way to remedy an emerging main incompatibility.

After determining the source of incompatibility, the main cause of incompatibility, and the way to prevent the main incompatibility, an analogical action regarding subsequent incompatibilities or the source of its occurrence.

All the methods selected in the proposed techniques have universal (general) applications to different types of products. Furthermore, the methodologies of these methods applied in proposed sequence have universal applications. These methods can be used to verify all products and each type of incompatibility.

3. Data to verify of method

The verification of the integrated technique was done for incompatibility with a welded mechanical seal applied in the aviation industry, which was made of 410 steel (CPWS5613). The mechanical seal is a new generation product that seals the contact surface between rotating and stationary parts. This product may constitute a vacuum seal among others. This product does not experience the problems found in gland packing. In addition, it is not destructive to shafts and sleeves. Applying the mechanical seal allows the leak and reduces the need for regular conservation, which results from self-adjusting springs as the discs wear. The production of these seals is technologically complex, and therefore of this are problems with stabilizing the production process. This is indicated by the relatively frequent incompatibilities identified, e.g., through NDT testing.In the company in which the verify of the integrated technique was made, it was observed that porosity was the most recurring incompatibility. Because the source cause of the problem (initially pointing to impurities) additional actions were taken to reduce its occurrence but not were taken. Therefore, it was proposed to analyze this problem in mechanical seals by using proposed techniques that support the process of identifying the source of product incompatibility and also the choice of appropriate remedial actions. As part of analyzing the quality of the seal, the fluorescent method (FPI) was used, where the choice of the FPI to analyze the mechanical seal was conditioned primarily by the kind of material (410 steel) (Das et al., 2000; Markus et al., 2018) and the requirements of the external client who ordered the inspection. The FPI method is effective in identifying the incompatibilities, and moreover it is low cost compared to other NDT research (Das et al., 2000). In this method, fluorescent dyes are used, which under UV light shown on incompatibility. The process of using the FPI method to identify the incompatibility is shown in the subject literature, e.g. (Pacana et al., 2019).

4. Results and disssusion

According to the method cited, in the first stage, based on selected data, the main incompatibility was determined. On the basis of information about the size of the incompatibility that was collected by the datasheet, it was shown that porosity is the main cause.

In this stage, the aim of using the proposed integrated technique was also determined. This objective was to accurately identify the source of incompatibility (porosity) and determine corrective actions for mechanical seal testing. The example of the porosity of the mechanical seal is shown in Figure 2.

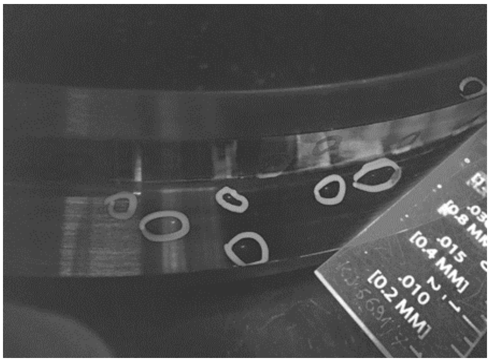

Figure 2. The porosity on the mechanical seal

As part of the the second stage of integrated technique to analyze the problem of mechanical porosity seal, the expert team and leader were selected.

In the third and fourth stages, among the team, brainstorming was carried out to identify the sources and causes of porosity in the mechanical seal. The identified causes were grouped by a relationship diagram. The results of the work as part of these two stages are shown as cause and effects diagram (Figure 3).

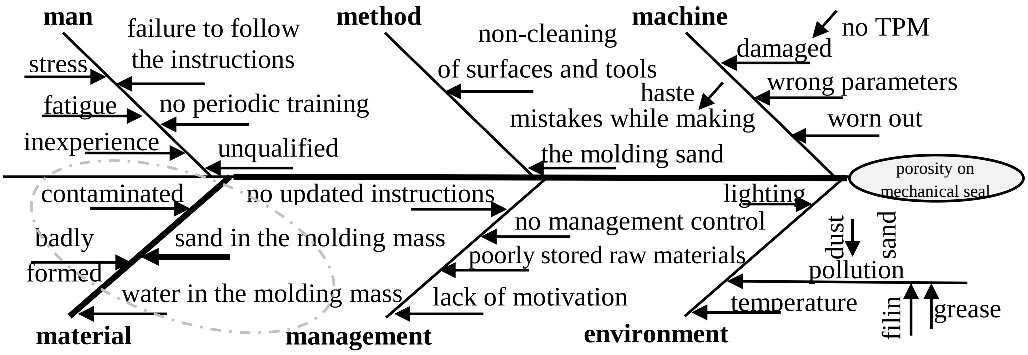

Figure 3. The causes and effects diagram for the problem of porosity on the mechanical seal

Then, in the fifth stage, the AHP method was used in order to identify the main cause of porosity. As part of multiple voting, the team experts have pointed out the four causes and made their assessment on a scale from 1 to 7. The results are shown in Table 1.

Table 1. The results from multiple voting for causes preliminary causes

No.	Preliminary causes	Rating
P1	contaminated	5
P2	badly formed	6
P3	water in the molding mass	4
P4	sand in the molding mass	7

In need of analyzing, the causes were marked conventionally P1 P4. Following the process of the AHP method, the calculation was made, and the result is shown in Table 2.

Table 2. The results from the calculation by the AHP method

No.	P1	P2	P3	P4	∑	weight and ranking	
P1	0,2	0,2	0,2	0,2	0,9	0,23	3
P2	0,3	0,3	0,3	0,3	1,1	0,27	2
P3	0,2	0,2	0,2	0,2	0,7	0,18	4
P4	0,3	0,3	0,3	0,3	1,3	0,32	1

The results were consistent according to the principle of the constancy of preferences for the AHP method (where r = 0,9).The results are shown in Table 3.

Table 3. The results as part of check the right of the calculation process

Sij	P1	P2	P3	P4	$\prod_{j=1}^{k} S_{ij}$	P1	P2	P3	P4	$\sum_{i=1}^{k}\left[\prod_{j=1}^{k} S_{ij}\right]^{\frac{1}{k}}$	w_i	Check
weight	0,2	0,3	0,2	0,3								
P1	1	5/6	5/4	5/7	P1	0,2	0,2	0,2	0,2	0,9	4	Λmax
P2	6/5	1	6/4	6/7	P2	0,3	0,3	0,3	0,3	1,1	4	=4
P3	4/5	4/6	1	4/7	P3	0,2	0,2	0,2	0,2	0,7	4	CI=0
P4	7/5	7/6	7/4	1	P4	0,3	0,3	0,3	0,3	1,3	4	CR=0

The main cause of the problem was concluded to be the cause marked as P4, so the sand in the molding mass. This cause has achieved the highest weight among other preliminary causes, which was analyzed by the AHP method, that is, w_i = 0,32.

Next, as part of the sixth stage, it was assumed to determine why the porosity with the main cause of sand in the molding mass has occurred in the mechanical seal. The method was repeated using brainstorming, relationship diagram, and a causes and effects diagram. The results of this process are shown in Figure 4.

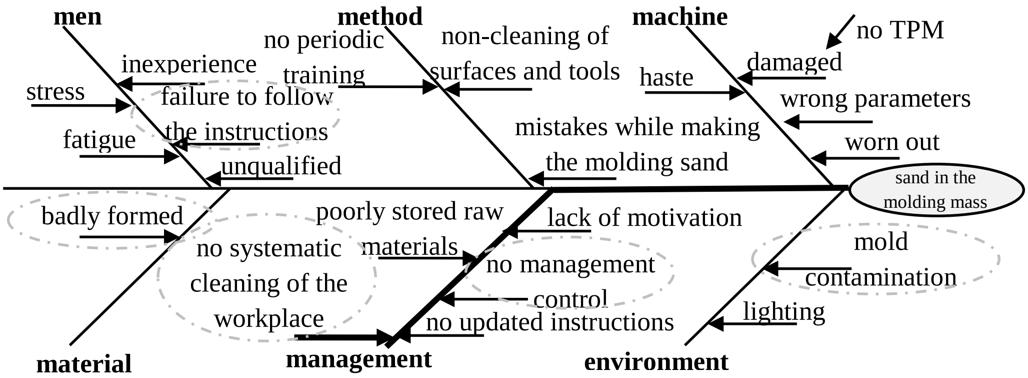

Figure 4. The causes and effects diagram for problem sand in the molding mass

Then, as part of the multiple voting, the team of experts has pointed out five preliminary causes and made their assessments. (Table 4).

Due to the long names of the causes, they were traditionally marked for the purposes of the analysis P1÷P5. Following the AHP method, calculations were performed, the results of which are presented in Table 5.

Table 4. The results from multiple voting

No.	preliminary causes	Rating
P1	Failure to follow the instructions	2
P2	Badly formed	3
P3	No systematic cleaning of the workplace	7
P4	No management control	4
P5	Mold contamination	6

Table 5. The calculation results by the AHP method

No.	P1	P2	P3	P4	∑	weight and ranking	
P1	0,1	0,1	0,1	0,1	0,5	0,09	5
P2	0,1	0,1	0,1	0,1	0,7	0,14	4
P3	0,3	0,3	0,3	0,3	1,6	0,32	1
P4	0,2	0,2	0,2	0,2	0,9	0,18	3
P5	0,3	0,3	0,3	0,3	1,4	0,27	2

The results were consistent according to the principle of constancy of preferences for the AHP method (where r = 1,12) (Pacana, Siwiec & Bednarova, 2020; Siwiec & Pacana, 2021).Therefore, it was possible to conclude that porosity has occurred because of no systematic cleaning of the workplace (i.e. P3=0,32).

Therefore, the best way to eliminate or reduce the occurrence of porosity in the mechanical seal is systematic in cleaning the workplace.

5. Discussion

The achievement of a quality level of products refers to the use of appropriate techniques, which allow the identification of the incompatibility and the source of its occurrence (Pacana & Siwiec, 2021; Zielińska & Rucka, 2018; Zientek, 2016). A gap has been shown which refers to the possibility of using techniques in a combined way, to simultaneously identify the incompatibility (e.g. by NDT), the causes of its occurrence (e.g. by quality management techniques) (Ostasz, Siwiec & Pacana, 2022; Pacana & Siwiec, 2022; Ulewicz et al., 2021), and at the same time show precisely way the source of occurrence of the incompatibility in the context of solve decision problem (e.g. by the AHP method) (Siwiec & Pacana, 2021; Pacana, Siwiec & Bednarova, 2020; Liliana, 2016). Therefore, the objective was to propose an integrated technique supporting the process of identifying product incompatibility and showing adequate corrective actions. As part of solving the decision problem, this technique allows the search for sources of incompatibility, causes of its occurrence, and the identification of the best corrective actions referring to the precise indication of the source of the problem. In this purpose, it was combined: brainstorming relationship diagram, cause and effect diagram, multiple voting techniques, and the AHP method. After test of the method, it was assumed that used in a combined way after NDT research: brainstorming, relationship diagram, cause and effects diagram, multiply voting technique, and the AHP method will be effective as part of identifying the problem and precisely to indicate the source causes of occurrence of this problem and adequate remedial actions.

The advantages of the proposed technique are:

- improving the process of decision making about causes incompatibility, by the integrated AHP method with traditional quality management techniques;
- complex analysis of all possibility causes of product incompatibility precise; identification of source of incompatibility causes;
- making decisions supported by the calculation process;
- the possibility of improving the product by reducing or eliminating incompatibility in a precise and standardized way.

In effect of this, the possibility of making a bad decision about the source cause or corrective actions was reduced, and it allows one to take adequate actions to minimize or eliminate the problem. For this reason, the proposed integrated technique is a new proposition that supports the process of identifying the source of incompatibility and improvement actions.

The disadvantages of the proposed technique are as follows:

- the need to use the proposed technique each time for various incompatibilities;
- The team needs to have a team of experts which are competent to solve a given problem.

Future research will be concentrated on computer software for this technique. Therefore, this technique can be practiced to analyze not only in the NDT area but also other types of problem in production and service enterprises.

6. Conclusion

The proposed technique was verified in one of the companies in Poland, where products were controlled by non-destructive fluorescent (FPI) tests, including those from the aerospace and mechanical industries. For example, the mechanical seal. However, as was noticed, previous actions that correct the problem of incompatibility were not efficient enough to prevent relatively frequent incompatibilities. The most common incompatibility that occurred in the mechanical seal of 410 steel was porosity. It was considered that, despite the identification of this incompatibility in NDT research (by the fluorescent method), the source of its occurrence was not identified in a clear way. Therefore, it was not possible to make adequate improvements. Therefore, an objective was to propose an integrated technique supporting the process of identifying the source, causes, and improvement actions in relation to the incompatibility of the seal.

To analyze the problem of porosity in a mechanical seal, the team of experts was selected, among whom brainstorming was made to identify the preliminary causes of porosity on the mechanical seal. The identified causes were grouped by the relationship diagram. The grouped causes are shown on the causes and effect diagram. In the next stage, after the multiple voting, the four preliminary causes (i.e. contaminated, badly formed water in the molding mass, and sand in the molding mass) were selected. After doing an analysis, to determine why the source cause of porosity had the place, it was shown that there was no systematic cleaning of the workplace. Therefore, by implementing the sixth stage of the technique, it was considered that the best way to eliminate or reduce porosity in the mechanical seal is systematic cleaning the work-place.

This technique could be used to improve the process of decision-making about causes of incompatibility. Also, it is effective to use for complex analysis of all possible causes of product incompatibility in a precise way. Furthermore, it allows to identify source of incompatibility causes for any products. Therefore, by this technique, it is possible to improve the product by reducing or eliminating incompatibility in a precise and standardized way.

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Andrzej Pacana
Rzeszow University of Technology,
Rzeszow,
Poland
app@prz.edu.pl
ORCID 0000-0003-1121-6352

Dominika Siwiec
Rzeszow University of Technology,
Rzeszow,
Poland
d.siwiec@prz.edu.pl
ORCID 0000-0002-6663-6621