

# Analysis of the Possibility of Used of the Quality Management Techniques with Non-Destructive Testing

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**Abstract:** The quality of products is, in particular, analyzed in product case from the aerospace industry in order to achieve the desired quality and safety levels. The aim of the study is to propose the use of selected quality management techniques in the quality control process made by non-destructive testing. The subject of the research were two products made of steel 410, in which incompatibilities were detected relatively frequently. It was a four-hole flange bearing housing and a gasdynamic sealant. The products mentioned were subjected (according to the quality procedure) to non-destructive testing with two methods: a fluorescent and a magnetic-powder. In order to identify the source cause of incompatibilities the implementation of selected quality management techniques was proposed. These techniques were: 5W2H method, Ishikawa method and 5Why method. Although these methods are simple, they were not used in the enterprise so far. So it was an order to use them, to check their adequacy. By supplementing the non-destructive research with the proposed sequence of selected quality management techniques, it was shown that it is possible to identify the source cause. In addition, by indicating the source cause it is possible to propose improvement actions adequate to the problem. So it will improve the quality of the next products. The proposed solution using the 5W2H method, Ishikawa diagram and 5Why method is complete and easy in practice technique for qualitative analysis to identify the root cause of incompatibility. After using these not complicated methods, it will be effective to use in the appropriate sequence more advanced methods, such as 8D, Six Sigma and DMAIC.

**Keywords:** non-destructive testing; root cause analysis; quality control; quality management; quality management techniques

## 1 INTRODUCTION

In aviation industry the products are subjected to specific quality controls in order to achieve the desired level of quality and safety. The types of researches to which the metal products are subjected are destructive and non-destructive testing [1, 2]. In destructive testing (DT) in order to make an assessment of the mechanical properties, the sample collected for testing is destroyed. Thus, the destructive tests are mainly used for complex objects, for which it is not possible to make research with other methods. To diagnose the product the non-destructive tests are more often used (NDT), which allow making a quality analysis of the product without destroying it [3]. In comparison to destructive tests, the non-destructive tests are less expensive. The literature of the subject gives many examples of non-destructive testing and their use. With using the ultrasonic method, the quality research of single adhesive joints in plate constructions was carried out, for example: alloys after the technological process [4], PCB plates with metal core [5], steel bridges [6], the inside of metallic sample, gas turbines, quality of pipes from plastic reinforced with carbon fibre (CFRP) of different geometries. This method was improved in order to increase the signal-to-noise ratio of defect (SNR) [7] and distinguish transitional signals and noises, or monitor the corrosion of steel. The research of the dependence of parameters was made, e.g., temperature and velocity of ultrasound propagated, propagation of ultrasound waves, creep degradation in welded steel joint [8]. By means of eddy currents, the depth of incompatibilities and quality of metal products or coating were measured [9, 10], mechanical properties [11], the parameters used in research were analyzed e.g. signal [12], speed, sensitivity [13, 14], step frequency. The quality analysis of products was made by using the methods like penetration and magnetic-powder, where the penetration method was used to identify the incompatibilities on the surface, and the magnetic-powder method was used to identify the incompatibilities on the surface and under the surface. Improvements were made to

increase the effectiveness of these methods, and, among others the effect of fluorescent dye sensitivity on effectiveness of the research was examined, as well as the influence of the temperature and external magnetic field on the magnetic field sensor, the influence of initial magnetization on the magnetic memory signal, also the multi-layered structure of a magnetic focusing sensor was made, which allows detection of a greater non-compliance. Other applications of non-destructive testing, as well as literature review of the subject are discussed in the paper by Hristoforou E. [15]. The analysis of literature of the subject shows numerous items devoted to the issue of non-destructive testing. It was noted that non-destructive testing found the applications in case of complex problems about mechanical products [16], and also that non-destructive testing was used e.g.: to analyse the quality of products to identify the incompatibilities, to analyse dependencies between material and parameters, to analyse the change of product shape; and some research was done to improve the way of non-destructive testing. In the subject literature, no activities were undertaken to extend the research to additional qualitative analyses. It was concluded that after identifying the incompatibilities with the use of the non-destructive testing no actions were taken thanks to which it would be possible to identify the cause of incompatibilities.

In order to perform effective qualitative analyses, only non-destructive testing is insufficient. By using the commonly used tools considered as useful for non-destructive testing, it is only possible to detect incompatibilities of products, because they only provide preliminary information on incompatibilities [17], and for the enterprises, whose priority is to achieve the highest quality of products, only the identification of the incompatibilities is insufficient. Thus, after performing the non-destructive testing after which incompatibilities were identified, it is necessary to conduct further analyses in order to identify the source of these incompatibilities, which is an effective way to completely eliminate them or

significantly minimize their creation. The presented research and the comparison research focus on results and conclusions and do not focus on finding the source of the identified incompatibilities. This issue is left open. Therefore, it seems useful to use non-destructive testing with selected techniques of quality management. The aim of this integration of non-destructive testing and techniques of quality management would be achieved as a part of the continuous improvement of increasingly higher quality products. Due to the variety of quality management techniques, it seems correct because of the character of the problem to use only the selected techniques and to use them in the right order, e.g. the 5W2H method, Ishikawa diagram and 5Why method. In the paper, the integration of the listed techniques with the process of non-destructive testing was proposed. Although these methods are simple they were not used in the enterprise so far. So it was an order to use them to check their adequacy. The proposed solution with the used 5W2H method, Ishikawa diagram and 5Why method is complete and easy to practice technique to make quality analyses to identify the source cause of incompatibilities. The used technique in the process of non-destructive testing is the way for effective quality management. It can be used to solve other quality problems, and also in other enterprises as a part of improving the production processes. After using these not complicated methods, it will be effective to use more advanced methods such as 8D, Six Sigma and DMAIC in the appropriate sequence.

## 2 THE SELECTION OF NON-DESTRUCTIVE TESTING METHOD

The use of non-destructive testing sometimes does not bring the expected results, and it could be a result of inadequate selection of the method to analyze the problem or material [2, 17]. One of the basic non-destructive tests includes visual, ultrasound, magnetic-powder, radiographic, eddy current and penetration tests [18]. The characteristics of basic non-destructive tests are presented in Tab. 1.

In the enterprise in which the analysis was made, the non-destructive tests were conducted using the fluorescent and magnetic-powder method, due to the possibility of making effective, uncomplicated quality analyses of products at relatively low costs of services (compared to other non-destructive testing methods). It was concluded that it will be effective for the enterprise to demonstrate that it is possible to implement the sequence of technique in these two methods, so in tests by the fluorescent and magnetic – powder methods. The choice of the method for the analysis of the product was conditioned: type of material from which the products were made, as well as the order from external customers. Because the magnetic-powder method is applicable only to the ferromagnetic material, the gasodynamic sealant, which was ferromagnetic, was analyzed. In turn, the fluorescent flange method was used to analyze the four-hole bearing housing.

**Table 1** The characteristics of selected non-destructive tests [6]

Method	Surface	Main advantages and disadvantages
Visual (VT)	analysis from the inside of the complex products; one access place could be enough; clean surface;	comprehensive; these the optical tools is necessary; uncertainty;
Penetration (PT)	open discontinuity on the surface and free from impurities; difficult research of porous surfaces;	only discontinuity on the surface; not for porous surfaces; simple; dirty; all discontinuities on the surface are detected in one operation;
Magnetic-Powder (MT)	smooth and clean surface; possible application to parts with thin galvanic coatings;	only to ferromagnetic materials; identification only of surface and subsurface discontinuity; demagnetization is necessary after the test;
Radiographic (RT)	the access to a product from external and internal side is necessary;	large surface can be tested despite the high costs; the depth of discontinuity is not measured; the direction of linear discontinuity is important; it is considered the best detection method of internal incompatibilities;
Ultrasound (UT)	the access to product from external or internal side is necessary; rough surface makes it difficult or impossible to study;	high cost in the analysis of a product of a big construction; effective to identify the internal flat discontinuities;
Eddy Current (ET)	relatively smooth and clean surface;	For discontinuities coming to or near the surface; to detect thickness changes of protective covers; for comparing materials; used for magnetic and non-magnetic materials;

## 3 MATERIALS AND METHODS

The use of non-destructive testing has found application in the aviation industry [19], which is considered to be the leader among the sectors using the mechanical products because in the aviation industry the attention is paid to the continuous improvement of the quality of the products used. In the analyzed production and service company located in the Podkarpackie Voivodeship, the non-destructive testing was practiced to control the quality of products from the aviation industry. One of the inspected mechanical products was the four-hole flange bearing housing and the gasodynamic sealant, and these products were used in the aviation industry. It was considered important to make an analysis involving these products and propose the implementation of quality management techniques in the process of improving non-destructive testing. After detecting incompatibilities by non-destructive testing in the enterprise, the decision was made on the causes of incompatibilities without further analysis. Also, no action was taken in order to improve the quality analyses, including analyses to identify the root cause of the problems. In addition, two products were deliberately selected for analysis due to the fact that it was possible to subject them to two different non-destructive

testing methods (fluorescent method - the four-hole flange bearing housing, magnetic-powder method, applicable only to ferromagnetic materials - a gasodynamic sealant, which was a ferromagnetic material).

The subject of the research was a four-hole flange bearing housing and a gasodynamic sealant, which were made of 410 steel, which was the nickel alloy AMS5383. Alloy AMS5383 is characterized by heat resistance and corrosion resistance. It consists of: 52,5Ni-19Cr-3,0Mo-5,1Cb (Nb)-0,90Ti-0,60Al-18Fe, melted in the process of homogenization and heat treatment [20].

The four-hole flange bearing housing is an easy to use and replaceable bearing assembly, thanks to which it is possible to correctly mount the bearing in the machine and ensure its correct operation. In turn, the gasodynamic sealant is a type of mechanical sealer (frontal) where a gas film is used to seal the rotating shaft, which is formed between the slip ring of the sealer. The gasodynamic sealant is used in devices with a rotating shaft, in which it is not possible to use the traditional mechanical contact sealer. This product is classified as the latest generation of mechanical sealants, and is also used in the aerospace industry. These products have influence on the work safety and effectiveness of ongoing processes.

First, the non-destructive testing by magnetic-powder method was made on the gasodynamic sealant. The research was done with the magnetic flaw detector MAG 50, which was supplied with alternating 3-phase erect current. The purity of the product after the washing operation as well as any magnetic residuals was checked. The direction of the current flow and the force lines of the magnetic field on 17 kJ were set on the magnetic flaw detector MAG 50. The copper pin was fixed in the product, and was then clasped in the defectoscope contacts. The surface of the product was poured with the magnetic suspension of Chemetall - MPI Diluent (HF). At 1600 A, three magnetic pulses were switched on for a minimum of 0,5 s, where the first two were made during the pouring of the product with a slurry, and the third after finishing pouring the product with the slurry. The actions were repeated three times, every 120 s. During the control in the magnetic time, the value of the contact field was measured, and was equal to  $\geq 2,4$  kA/m and was compatible with the internal instruction. The product was demagnetized after the inspection and the results were recorded.

Next, non-destructive testing with fluorescent method was subjected to a four-hole flange bearing housing. The test was started from cooling the product to a max. temperature of 40 °C. Then the product was degreased (the product was immersed in the HM-406 penetrant for 30 minutes). Then the product was immersed for 10 seconds in a bath pre-rising before the process of final cleaning. The control of the product with HM-406 penetrant was made according to the instruction. The sensitivity of the penetrant was checked with the use of the master plate TAM 146040. The product was cleaned under UV lamp using a water spray with a max. temperature of 10°C - 38 °C (max. pressure 0,275 MPa). Direct spraying on the product was made at a min. distance of 300 mm at lighting. The four-hole flange bearing housing was dried in a chamber dryer (max. temperature 70 °C). On the surface of the product a dry developer ZP-4B in the form of a powder mist was applied at the air pressure of max. 0,172 MPa and a time of 10 minutes. After a minimum 10 minutes the excess developer was removed using the compressed air (the max. pressure 0,034 MPa). The control of the four-

hole flange bearing housing was made in the control cabin under the UV lamp (the minimum intensity of radiation on the surface 1200  $\mu\text{W}/\text{cm}^2$ , the max. light intensity on the surface in cabin 20 lx [21]. After the inspection, the product was washed in an aqueous solution to remove the developer and residue of other materials used during the inspection.

After the non-destructive testing for the four-hole flange bearing housing and gasodynamic sealant with the use of the selected methods, the incompatibilities were identified as linear indication (Fig. 2).

In order to identify the root causes of these incompatibilities which were detected by using the non-destructive testing, it was proposed to implement quality management techniques. These techniques were: 5W2H method, Ishikawa diagram and 5Why method. Due to the fact that these techniques are complementary, in order to achieve effective results from the analysis, it was proposed to use them in a sequential manner (Fig. 1).

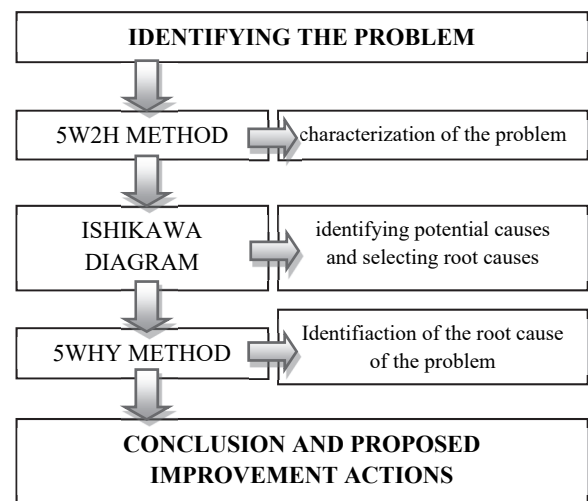


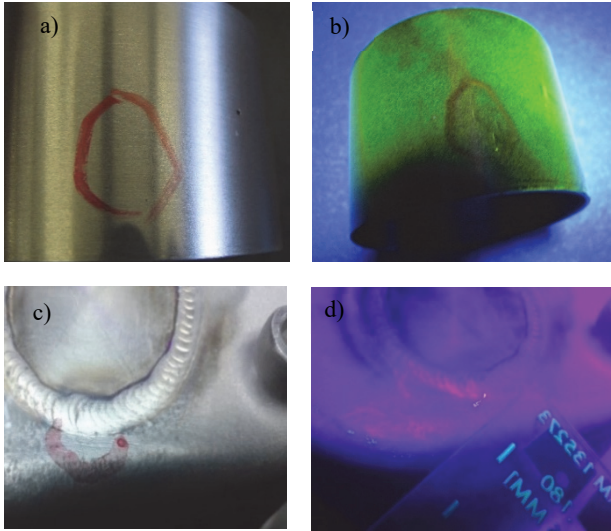
Figure 1 The sequence of quality management technique

In the first stage of analysis after the detection of non-destructions on product, the 5W2H method was used. The 5W2H method was applied twice in order to characterize the incompatibilities which were identified on the four-hole flange bearing housing and gasodynamic sealant. The method consisted in asking seven questions, thanks to which it was possible to collect the most important information on incompatibilities. Next, in order to identify the potential causes of incompatibilities the Ishikawa diagram was drawn. Because on the two products the same type of incompatibilities was identified, i.e. linear indications, only one Ishikawa diagram was made. The problem was recorded in the fish head (linear indications). Next, the basic categories of the Ishikawa diagram were selected for analysis (i.e. rule 5M + E) i.e. man, machine, method, material, management and environment, which were considered adequate to analysing incompatibilities [22-28]. Potential causes of linear indications on the products were assigned to those categories. The use of the cause and effect diagram made it possible to analyze incompatibilities and select from the potential causes the main ones, so it was possible to make the next analyses (5Why) in order to identify the source cause [29]. To identify the source cause of linear indications on products the 5Why method was used. The main reasons was asked "Why?".

After identifying the source cause, improvement actions were proposed in order to eliminate or minimize the occurrence of linear indications on the four-hole flange bearing housing and gasodynamic sealant. The questions were asked up to the moment in which the answer gives the chance to undertake a specific improvement action.

**4 ANALYSIS**

After non-destructive testing using the fluorescence method for the four-hole flange bearing housing and using the magnetic-powder method for the gasodynamic sealant, the incompatibilities were identified - which were the linear indications (Fig. 2).



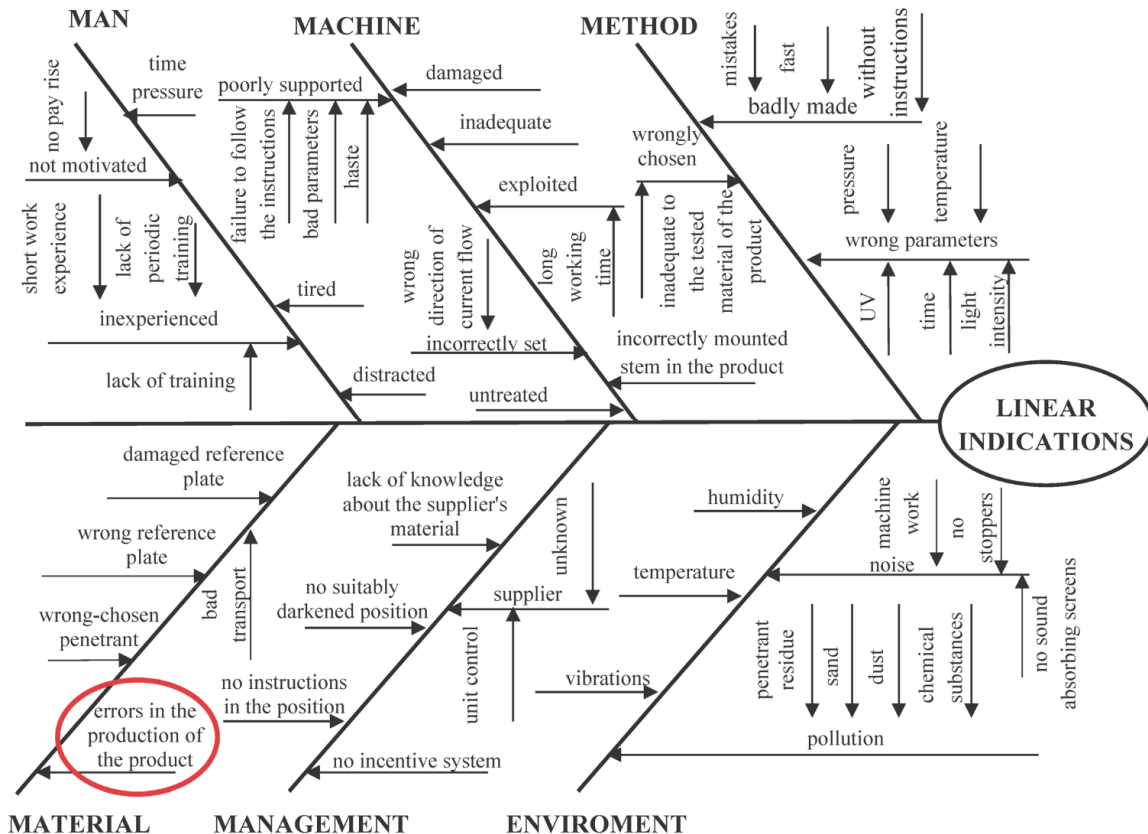
**Figure 2** The linear indications: a), b) on the gasodynamic sealant; c), d) on the bearing housing

In order to characterize the problem, the 5W2H method was performed twice – for the problem of linear indications on the flange four-hole bearing housing and for the problem of linear indications on the gasodynamic sealant (Tab. 2).

**Table 2** The 5W2H method for the problem of linear indications

5W2H METHOD for the problem of linear indications		
Question	Answer	
	bearing housing	gasodynamic sealant
Who noticed a problem	an employee examining the product using the fluorescent method	an employee examining the product using the magnetic-powder method
What was the problem?	linear indications	linear indications
Why was it a problem?	exceeding the permissible size	exceeding the permissible size
Where was the problem noticed?	on the surface of the product	on the surface of the product
When was the problem noticed?	during the fluorescence study	during the magnetic-powder test
How was the problem noticed?	fluorescent method	magnetic-powder method
How big was the problem?	1	1

Next, the Ishikawa diagram was prepared, and because on both the gasodynamic sealant and the four-hole flange bearing housing the same type of incompatibility was identified (linear indications), only one Ishikawa diagram was prepared for these problems (Fig. 3).



**Figure 3** The Ishikawa diagram for the problem of linear indications

After analysing the potential causes of problem of linear indications on the gasodynamic sealant and bearing housing, it was concluded that the main cause was errors in the production of these products. This conclusion has been drawn because the incompatibility which was on the bearing housing was near the weld. And the incompatibility which was on the gasodynamic sealant was on the center outer side of the product and was very uneven. So, it was pointed out that the main cause was errors in the production.

The analysis with the use of the 5Why method was made for the problem of linear indications on the selected products in order to identify the source cause of the problem. An example of the 5Why analysis carried out is

shown in Fig. 4. After the analysis of the problem with the use the 5Why method it was concluded that the source causes of linear indications on the gasodynamic sealant and bearing housing were inconsistencies arising during the production of products from the product supplier who ordered the inspection.

After using the quality management techniques with the non-destructive test, and identifying the source of cause, under the improvement actions the production enterprise was informed about the source of the problem. But in order to eliminate this problem, it is necessary to make improvements actions in production enterprises. And after improvement actions, it is necessary to check this effect by other methods such as for example FMEA.

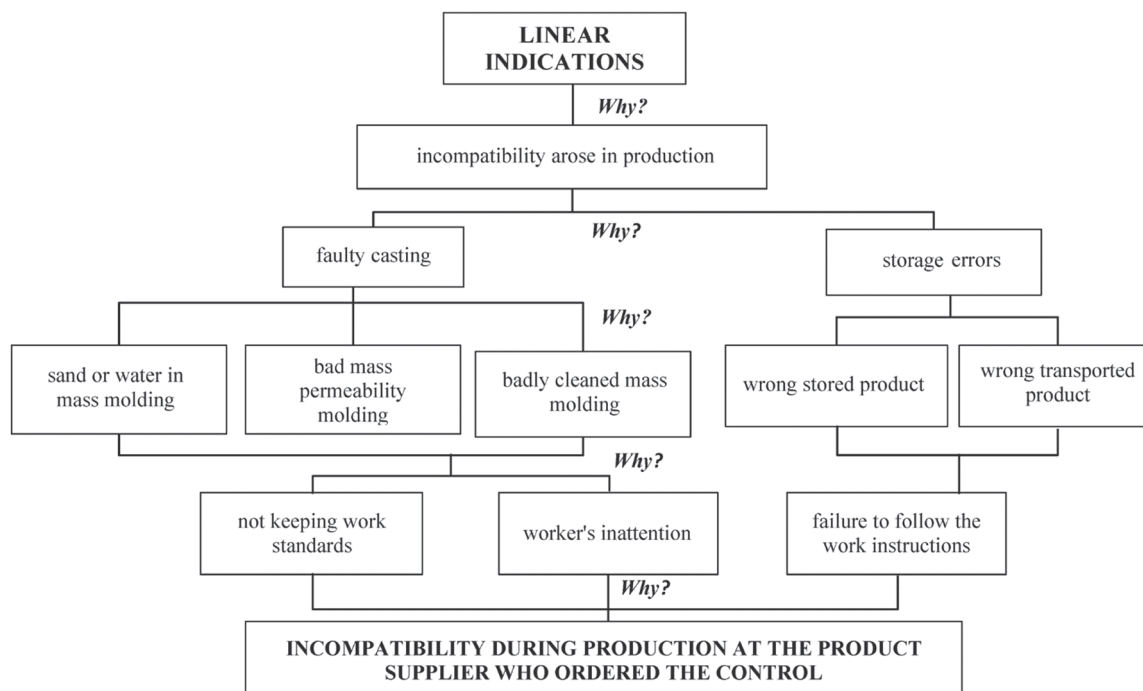


Figure 4 The 5Why method for the problem of linear indications

## 5 CONCLUSION

The non-destructive testing due to its specificity as well as low costs is often used in the quality testing of products. As part of continuous improvement of quality in well-managed enterprises, identification of incompatibilities should initiate actions aimed at finding their causes. In order to skilfully do this, you can use the selected quality management techniques. Such use of quality management techniques and non-destructive testing was proposed to increase the efficiency of identifying the root cause of the problem. These products were: the four-hole flange bearing housing and gasodynamic sealant. Due to the possibility of making effective, uncomplicated quality analyzes of products at relatively low costs of services (compared to other non-destructive testing methods) the fluorescent method and magnetic-powder method were used in the enterprise, so the integrated quality management techniques were implemented in the process of research using these methods. The choice of the method for the analysis of the product was conditioned by the type of material from which the products were made, as well as the order from

external customers. Because the magnetic-powder method has application only to the ferromagnetic material, so the gasodynamic sealant was analyzed by this method. In turn the four-hole flange bearing housing was analyzed by the fluorescent method. After performing the tests with selected methods, they identified the incompatibilities (linear indications). Next, after identifying the incompatibilities as part of the continuous improvement of quality the quality management techniques (5W2H method, Ishikawa diagram and 5Why method) were used in integrated manner. The 5W2H method was used to characterize the problem (linear indications). The analysis was made twice (using the 5W2H method), because two products were analyzed, so the analysis was made for the problem with linear indications on the gasodynamic sealant and the problem with linear indications on the bearing housing. Using this method, it was possible to gather the most important information on incompatibilities with seven questions. Next, the analysis of the problem was made by using the Ishikawa diagram. Because the same type of problem (linear indications) was identified on the gas-dynamic sealant and flange four-hole bearing housing, the analysis was performed using one Ishikawa diagram.

By this diagram the potential causes and the main causes of the problem were identified (errors in the production of the product). After identifying the main cause of the problem, it was possible to use the 5Why method, thanks to which the source cause of the linear indications was identified. The source cause was incompatibility created during the production of the product at the product supplier who ordered the inspection. On the example of two methods included in non-destructive testing, i.e. fluorescent method and magnetic-powder method, it has been concluded that it is efficient to integrate quality management techniques into qualitative analyses in order to identify the root cause of the problem. The techniques practiced sequentially present a complete and easy in practice possibility of qualitative analysis to identify the cause of the source incompatibility. It has been demonstrated that the implementation of quality management techniques in the non-destructive testing process is the way to effectively manage quality, which can also be used to solve other problems, in other enterprises as well, as part of improving production processes. After using these not complicated methods, it will be effective to use more advanced methods such as 8D, Six Sigma and DMAIC, in the appropriate sequence.

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