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Analysis of risk of nonconformities and applied quality inspection methods in the process of aluminium profiles coating based on FMEA results

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Abstract

The article presents the results of risk analysis associated with nonconformities of aluminium profiles in the process of coating and quality inspection methods used to their detection. Analysis of risk was done based on results of FMEA method. Evaluated quality inspection methods were distinguished based on the term of inspection in the ISO 9000:2005 norm. Manufacturing process of aluminium profile in micro-technological approach was presented. Triple quantification of nonconformities risk based on the FMEA method by using three different approaches was conducted. Analysis of nonconformities risks associated with the use of specific quality inspection methods was done. In the last part the analysis of causes of critical nonconformities, proposals for improvement actions reducing the risk of the critical nonconformities and applied critical quality inspection method were showed.

1. Introduction

The use of every quality inspection method in the aim of nonconformities detection binds to a specific risk. This risk is primarily due to the fact that the used quality inspection method does not detect in time the nonconformity (which should be detected). Also a chance to detect nonconformity is too small so customers will be exposed to obtain a product that does not meet their requirements. The risk associated with the use of quality inspection methods should be assessed, and such assessment should then be the starting point for actions that will allow such risks to be minimized. Quality inspection, which allows to minimize the risks associated with getting the nonconforming product to the customer should be called effective (ULEWICZ R. 2013; ULEWICZ R., NOVÝ F. 2013).

Assessment of non-conformance risk is the most often done through FMEA analysis. Guidelines for that assessment are in a reference manual developed by not-for-profit association of auto industry members called AiAG (AIAG 2008). The FMEA method is based on a detailed analysis of the selected product or process and predicting all potential nonconformities that may occur and their causes. These causes

are then prioritized in terms of their importance to the organization and, as far as possible and needed, eliminated. The main objective of using the FMEA method is to reduce the risk of manufacturing a nonconforming product and delivering it to the customer (BORKOWSKI S. 2005; MCCOLLIN CH. 1999). FMEA forces answering three key questions:

1. What nonconformities can arise?
2. What do they result from (what are their causes)?
3. What are the effects of this nonconformity for the customer? (BLIKLE A. 2014; GREBER T. 2014; HAMROL A. 2015).

In the FMEA analysis, such risk is estimated from the perspective of three elements, so-called priority numbers: occurrence (O; LPW), significance (S; LPZ), and detection (D; LPO). Final assessment of the risks associated with nonconformities in the FMEA method can be effected using various approaches. The most common indicator of risk is the index which is "the results" of the three risk components mentioned above. This indicator has different signs, with the most popular signs being: RPN, R, LPR (the last in Polish language). In the case of $RPN < 100$ (or $RPN < 120$), this means that the risk associated with the non-conformance/its cause is small enough that it does not need to be (although it

could be) corrective actions taken (WOLNIAK R., SKOTNICKA-ZASADZIEŃ B. 2011). Other than RPN the risk indicator in the FMEA method is the SOD index. It arises through the combination of S, O, and D. In this case, the SOD cut-off value is given, above which improvement actions should be undertaken (SOD = 992 - unacceptable risk). The last method of risk assessment in the FMEA method is using the risk matrices. This is a matrix prepared the most common in SxO layout. If a non-conformity is found in the so-called the red field means that its risk for customer severity (S) and probability of occurrence (O) is unacceptable - improvements are necessary (GREBER T. 2014).

The aim of the study was define the level of risk nonconformities and quality inspection methods used in relation to the process of aluminium profiles coating based on FMEA results. The level of risk was starting point to determine which the product nonconformities and quality inspection methods should be improved first. Appropriate improvement activities have been proposed.

2. Results and discussion

2.1. Manufacturing process of aluminum profile in micro-technological approach

Good knowledge of process is a basic condition for its improvement. How to know the process? It is the best to go through its successive stages (down or upstream) and then draw it. One of the methods of graphical presentation of the manufacturing process is technological micro-organizational approach (BORKOWSKI S., ULEWICZ R. 2008; DURLIK I. 1996).

The process of manufacturing of the aluminum profile in the studied company consists of the extrusion process of a raw profile held in the extrusion hall and process of painting the profile implemented in the paint shop hall. A graphic presentation of the process of manufacturing of the basic product under study was made. For this purpose, a graphical tool in the form of micro-organizational perspective was used. As part of the technological approach, detailing of the basic operations was performed indicating their specific type, for example, preliminary, proper and finishing (final) operation.

The developed technological approach for the manufacturing process of aluminum profiles is presented in Fig. 1. The operations of the manufacturing process taking place at the extrusion hall are numbered from 1 to 17, whereas operations carried out at the paint shop hall are operations from 18 to 27.

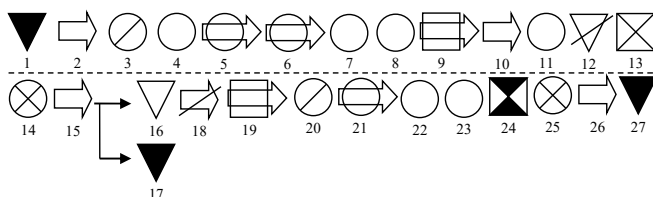


Fig 1. "Basic" manufacturing process of aluminum profile in technological micro-organizational approach

Legend:

1. Storage of 7 metres aluminum rollers (i.e. batch).
2. Transport of the batch for heating.
3. Heating of the batch (aluminum rollers) to the extrusion temperature, i.e. aluminium. 500°C and cutting into the appropriate length (i.e. billets).
4. Pressing the billet and extrusion in the shape of the profile.
5. Cutting the hot billet and its transport.
6. Air cooling the profile and its transport.
7. Stretching and straightening the profile in the aluminium.
8. Cutting the profile into commercial lengths.
9. Arrangement of the profiles in technological baskets and conformity inspection of the shape of the profiles.
10. Transport of the profiles in technological baskets with a forklift.
11. Heat treatment – aging of the profile in an oven at 180°C for 6-8 hours.
12. Cooling the profile in the open air.
13. Conformity inspection of sizes and shapes, hardness testing and organoleptic assessment.
14. Packaging the profiles to metal baskets or wooden bundles.
15. Transport by forklift to the place of storage.
16. Temporary storage of the profiles – semi-products before passing them to the next operation.
17. Storage of finished products – before passing them to client.
18. Transport of the profiles by forklift to the paint shop hall.
19. Hanging the profiles on a steel frame with a visual inspection of damage and discoloration.
20. Double chemical bath in bath tanks.
21. Transport by crane into the painting chamber together with drying.
22. Electrostatic painting.
23. Hardening the coating in an oven at 160-200°C.
24. Measurements of the product and special tests.
25. Packaging the profiles in metal baskets or wooden bundles.
26. Transport of the packed profiles by forklift to the warehouse of finished products.
27. Storage of the finished aluminum profiles prior to shipment to the customer.

2.2. Triple quantification of nonconformities risk based on the FMEA method by using different approaches

The FMEA method was used to quantification the risk associated with nonconformities of analysed product – aluminium profile. The results of FMEA analysis are shown in Table 1.

Basing on the RPN (risk priority number) indicator values, nonconformities were sorted according to their level of risk (from the largest to the smallest value). The results of sorting the RPN values are shown in Fig. 2.

Table 1. FMEA analysis for the coating process of the aluminium profile

Non-conformity marking	Name of nonconformity	Nonconformity effects	Nonconformity causes	Current state				
				Applied methods of quality inspection*	Evaluation			
					O	D	RPN	
L1	Inclusions	Wrong appearance of the paint	Dirt in the paint chamber	Organoleptic assessment	5	7	6	210
L2	Other powder inclusion				5	7	6	210
L3	Wrong thickness of lacquer	Improper resistance to mechanical damage	Wrong hung profiles while coating	Measurement	7	9	8	504
L4	Wrong hardness		Wrong chemical composition of the powder		Testing	6	7	5
L5	Wrong impact resistance	Wrong appearance of profile	Employees' inattention	Organoleptic assessment		4	6	5
L6	Mechanical damage				Improper resistance to mechanical damage	Wrong chemical composition of the powder	Testing	1
L7	Wrong plasticity	Employees' inattention	Wrong hung profiles while coating	Organoleptic assessment				1
L8	Lack of glossy				Bad temperature curing of lacquer	Wrong hung profiles while coating	Organoleptic assessment	3
L9	Abrasion marks	Wrong appearance of lacquer	Bad spraying the powder	Organoleptic assessment				4
L10	The entire surface is not covered				Wrong hung profiles while coating	Bad spraying the powder	Organoleptic assessment	2
L11	Gassing	Bad spraying the powder	Bad spraying the powder	Organoleptic assessment				1
L12	Profiles stick together				Bad spraying the powder	Bad spraying the powder	Organoleptic assessment	2
L13	Curtaining	Bad spraying the powder	Bad spraying the powder	Organoleptic assessment				1
L14	Resin				Bad spraying the powder	Bad spraying the powder	Organoleptic assessment	1
L15	Blotch	Bad spraying the powder	Bad spraying the powder	Organoleptic assessment				2
L16	Wrong drawability				Improper resistance to mechanical damage	Wrong chemical composition of the powder	Testing	2

* according to accepted method of division

The critical value for nonconformities was established based on the critical value of RPN = 120; after crossing the critical value by the nonconformity, corrective and preventive actions in respect of such a nonconformity are taken.

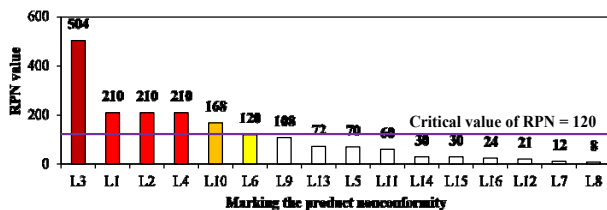


Fig 2. Criticality level of the product's nonconformities generated during the coating process of aluminum profiles based on the RPN indicator

The analysis allowed for indicating the critical nonconformities of the analysed product – these are nonconformities marked L3 (poor thickness of the paint), L1 (inclusions), L2 (another powder inclusions), L4 (poor hardness) and L10 (painting defects).

A SOD principle was used to identify critical nonconformities and to verify critical nonconformities indicated by the traditional method of identifying (based on the RPN value). The SOD principle determines the level of risk of the nonconformity on the basis of a statement in the form of a single figure of calculated values of the indicators S (severity), O (occurrence) and D (detection). The analysis allowed

for pointing out these nonconformities that, firstly, are the most important to the customer, secondly, that are the most likely and thirdly, which are particularly difficult to detect by the quality inspection methods. The higher the SOD value, the higher the criticality of nonconformities. The results of analysis are shown in Fig. 3.

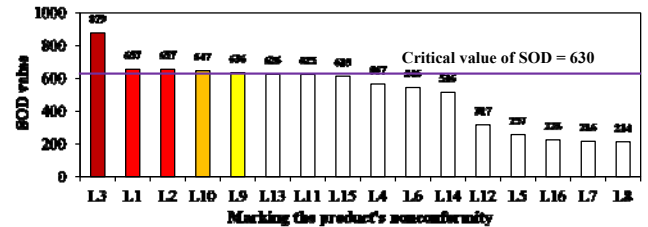


Fig 3. The level of criticality of the product nonconformities on the basis of the SOD indicator

A critical value of SOD was established at 630 level. The analysis of Fig. 3 shows that the critical nonconformities turned out to be five nonconformities marked as L3, L1, L2, L10 and L9.

A risk matrix, showing the relationship between indicators of occurrence and severity, was utilized in order to identify critical nonconformities (due to the likelihood of nonconformities occurrence and their effects for the client). By analyzing the distribution of the points representing nonconformities on the matrix (Fig. 4), nonconformities can be divided into three groups: *low risk* (below the green line), *medium risk* (between green and red line) and *high risk* (located above the red line) (EXAMINING RISK PRIORITY NUMBERS IN FMEA 2015).

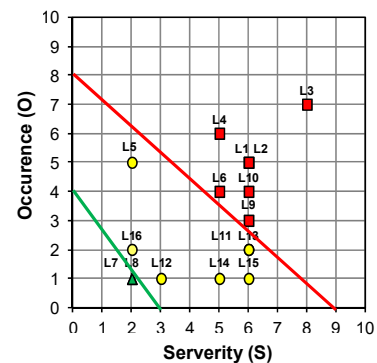


Fig 4. Risk matrix no 1

The critical nonconformities (located above the red line, marked with a red square) include nonconformities identified as L1, L2, L3, L4, L6, L9 and L10.

The form of risk matrix formally proposed, among others, by VDA 4 standard was used (GREBER T. 2014) to identify critical nonconformities, taking into account (as in the previous analysis) the relationship between the values of indicators of occurrence and severity. The character of the risk matrix allows for the classification of nonconformities in terms of their criticality to three groups, whereas critical nonconformities are the ones which „fall” in the red area of the matrix. The results of analysis are shown in Fig. 5.

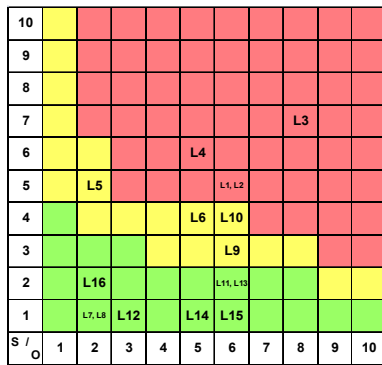


Fig 5. Risk matrix no 2

The analysis pointed to critical nonconformities which are marked L1, L2, L3 and L4.

Another risk matrix presented is based on the values of all the indicators: severity, occurrence and detection. The letters and numbers in Fig. 6a indicate whether corrective actions are required for the given nonconformity. In the case where there is a symbol:

- N = The corrective actions are not needed.
- K = Corrective actions are needed.
- # = Corrective actions are needed if the evaluation of detection (D) is equal to or greater than the one specified (in the yellow field) (EXAMINING RISK PRIORITY NUMBERS IN FMEA 2015).

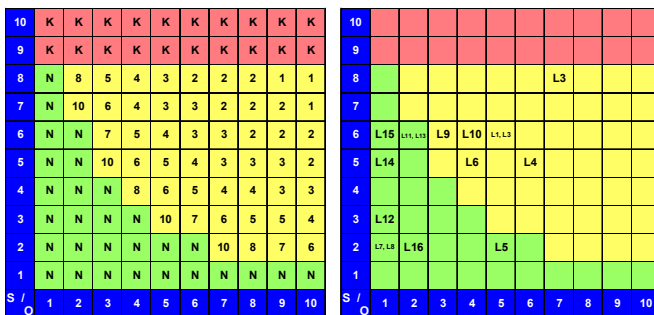


Fig 6. Risk matrix no 3: a) overall with standards, b) as the result of analysis

The analysis showed that the corrective actions are necessary to take for five nonconformities identified as L1, L2, L3 and L4. All these nonconformities were found in the yellow field (Fig. 6b), but proved to be critical due to the fact that the detection indicator, in their case, had the value higher than the one given in the standard in Fig. 6a.

The analysis results of the criticality level of nonconformity by various prioritization methods are shown in Table 2.

Table 2. Analysis of the nonconformities criticality by various methods based on the FMEA indicators

A way to determine the critical nonconformities	Used FMEA indicators in this aim	Identified critical nonconformities according to each way	The number of critical nonconformities
RPN critical value	RPN	L1, L2, L3, L4, L10	5
SOD critical value	S, O, D	L1, L2, L3, L9, L10	5
Risk matrix 1	S, O	L1, L2, L3, L4, L6, L9, L10	7
Risk matrix 2	S, O	L1, L2, L3, L4	4
Risk matrix 3	S, O, D	L1, L2, L3, L4	4
Number of repeated critical nonconformities:			3

Summing up, the analysis of criticality level of nonconformity by various methods based on the values of FMEA indicators, helped to create the final list of nonconformities, for which it must first take corrective action. In all analyzes critical nonconformities were found to be nonconformities marked as L1, L2, L3. These nonconformities should be considered a priority when taking corrective action.

2.3. Analysis of quality inspection methods risk based on the FMEA indicators

An analysis of the level of risk associated with the nonconformity occurrence, detection and severity to the customer was performed in respect to the analyzed quality inspection methods such as: *measurement* (P), *testing* (B), *organoleptic assessment* (O), also *numerical inspection* (KL) and *alternative inspection* (KA) (ISO 9000:2005; CZYŻEWSKI B. 2006; KOLMAN R. 1998; WEBBER L., WALLACE M. 2007). The values of priority numbers for the total number of nonconformities detected by these quality inspection methods were summed up (Fig. 7a). The total level of risk (based on RPN value) for nonconformities detected by the quality inspection methods was also calculated (Fig. 7b). The results of analysis are shown in Fig. 7a and 7b.

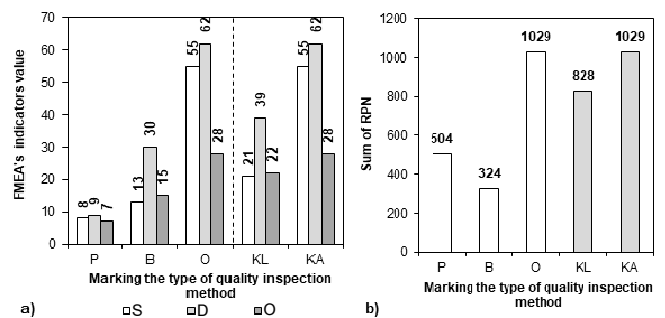


Fig 7. The cumulated level of risk associated with the occurrence (O), detection (D) and severity (S) (a) and the overall risk level (RPN) (b) in the case of nonconformities detected by the inspection methods such as P/B/O/KL/KA

From the point of view of three criteria, that is the likelihood of occurrence, the severity of nonconformity and its detection, the greatest risk occurs in the case of organoleptic assessment (O), and in the second place, testing (B). The highest level of risk is associated with detection of nonconformities by organoleptic assessment (O), followed by measurement (P) and then testing (B). To generalize, the largest total risk (measured by the RPN value) related to detected nonconformities is borne by the organoleptic assessment (O) and alternative inspection (KA).

The relationship among the total risk associated with nonconformities detected by the tested quality inspection methods and the share of the analysed quality inspection methods in the nonconformities detection as well as the share of nonconformities detected by these methods of quality inspection were analyzed. The results of analysis were presented in Fig. 8.

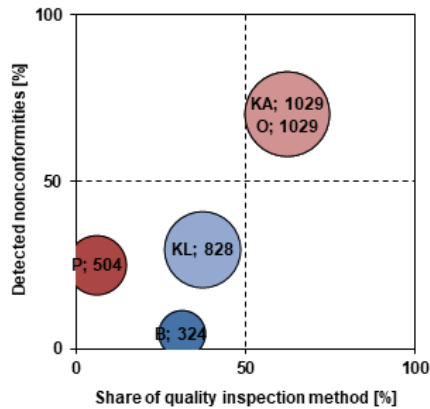


Fig. 8. Matrix diagram of the total overall risks for nonconformities detected by the quality inspection methods depending on the share of the detected nonconformities and the frequency of their occurrence

The analysis showed that the quality inspection method that occurs most often and detects most nonconformities as well as bears the greatest risk connected with the detected nonconformities is the organoleptic assessment (O) (thus, alternative inspection - KA). The total value of the RPN for nonconformities detected by the alternative inspection (KA) is 1029 and is more than 1.24 times greater than for nonconformities detected by the numerical inspection (KL). Considering the studied relationships, it can be concluded that the risk of detecting only one nonconformity by measurement (P) is greater than detecting as many as five nonconformities by testing (B). This is due to the fact that a nonconformity detected by measurement, that is poor paint thickness, is a critical nonconformity for the tested process, the most important for the customer, and has the best chance to occur in the process.

2.4. Analysis the causes of critical nonconformities and proposals for corrective actions

A critical nonconformity, on the basis of FMEA analysis, has proven to be a nonconformity designated as L3, or poor paint thickness.

Poor paint thickness occurs when the paint on the profile is either too thin or too thick. In both cases, this nonconformity is unacceptable. The nonconformity is detected by measurement in a quality inspection laboratory using paint thickness gauge (Fig. 9).



Fig. 9. Paint thickness gauge

Measuring of the thickness is performed by the quality inspection employee. The measurement is carried out on aluminum plaques. The inspector sets the measuring instrument on a plaque and reads the result. The measurement is performed five times on the marked surface and the average result of the measurement is entered into the register. The measurement should be in the range of 60 μ m to 120 μ m. If the average value of the measurements is less than 60 μ m, such a batch of products is considered nonconforming. In this case, most profiles can be repaired by re-painting. However, if the average value of measurements exceeds 120 μ m, such products can not be repaired. This does not mean, however, that they will be scrapped. These profiles can be conditionally „admitted” depending on their destination.

In the case of a too thin layer of paint, the profile can be painted again but this involves a high risk of exceeding the upper limit. This nonconformity is not visible to the naked eye but is of great importance. When the coating is too thin, it does not fulfill the protective function of the profile, which is then more exposed to weather conditions. If there is too much of the paint, when the profile works, the paint cracks and there are signs of corrosion.

Poor thickness of the paint is a nonconformity as well as the cause of many other nonconformities. This nonconformity can lead to very serious consequences if not detected. Measuring the thickness of paint is the first test that is performed on finished products. When the profile does not pass such a test, no further measurements are performed and the product is scrapped. When nonconformity is not identified and the profile goes to the client, this may lead to losing some of the properties of the paint coating, that is: resistance to mechanical damage, inadequate protection against corrosion, and the like.

Poor thickness of the paint occurs due to misalignment of guns in the paint spray chamber or because of improper suspension of the profiles on the rack. In the chamber, the spray guns are removed at each change of the used powder. They are then cleaned and reassembled. To avoid their misalignment at the next reset, structural changes should be introduced in the paint chamber.

Inclusions, inclusions of another powder (L1, L2) are nonconformities caused by contamination in the paint spray chamber or by inaccurate cleaning of the chamber from another powder, which was previously used. Inclusions are the most frequently appearing nonconformities on painted profiles because the process is not carried out under sterile conditions and is susceptible to contamination. Such nonconformities can not be removed and the profile is earmarked for scrapping. To eliminate these nonconformities, the painting process of the profiles would have to be carried out under conditions that prevent contaminants from entering the paint spray chamber. The importance of these nonconformities to the customer remains at an average level, just like their detection. Increasing efficiency in the detection of nonconformities is possible through the introduction of a computerized system of quality inspection.

3. Summary and conclusion

The article presents the results of risk analysis for nonconformities of aluminum profiles generated in the painting process and defined quality inspection method used to their detection. Risk analysis has been performed in terms of the frequency of occurrence and consequences for the client, the chance of detection and the chance of occurrence of nonconformities. As research tools the FMEA method and its indicators were used. Different methods for identifying critical nonconformities were utilized basing on chosen or all of the FMEA indicators in order to select critical nonconformities.

The analysis using the indicator RPN, SOD and three different types of risk matrices allows for indicating, in the end, three critical (the most important) nonconformities of the analysed product, that is poor thickness of the paint, inclusions and inclusions of another powder. Defined corrective action was proposed.

As part of the work, what was also analysed was the level of risk associated with the applied methods of quality inspection which was grouped according to assumption into 3 and 2 group, that is measurement, testing, organoleptic assessment (first group), numerical inspection and alternative inspection (second group). This analysis allowed for indication of the quality inspection method for which the risk (measured by the RPN value) related to nonconformities is greatest - organoleptic assessment (O) (alternative inspection - KA) and more specifically - visual inspection.

Visual inspection turned out to be a quality inspection method that, besides being the most involved in detecting nonconformities, has also the greatest responsibility for detected nonconformities. The nonconformities detected by this inspection method were the most important to the customer, theirs possibilities of occurrences were also the greatest.

Visual inspection is the inspection method, as the analysis has shown, the most encumber in detecting critical nonconformities. Visual inspection is the critical quality inspection method for the production of aluminum profiles. Hence, the action to improve the effectiveness of this quality inspection

method should never be ended, where Measurement System Analysis (MSA) procedures can be used for that purpose. Assessment of effectiveness of visual inspection by the Kappa index and set of effectiveness coefficients should be done, which will constitute the starting point for improvement the quality inspection method.

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基于FMEA结果分析铝型材涂层过程中不合格风险和应用质量检验方法

关键词

铝型材
不合格
质量检验方法
FMEA方法
风险

摘要

本文介绍了在涂层过程中与铝型材不合格相关的风险分析结果以及用于其检测的质量检验方法。基于FMEA方法的结果分析风险。基于ISO9000:2005标准中的检验条件,对质量检验方法进行了评估。介绍了微型技术方法中铝型材的制造工艺。进行了基于FMEA方法的三种不同方法的不合格风险三重量化。对与使用特定质量检验方法相关的不合格风险进行了分析。最后分析了关键不合格原因的分析,改进措施的建议,降低关键不合格风险和应用关键质量检验方法。
