ISSN: 2414-1895 DOI: 10.6919/ICJE.202203_8(3).0017

Application of PFMEA Combined with Error Proofing Technology in the Wind Turbine Blade Manufacturing

Yan Liu, Denggang Zhang, Shaoyi Yan, and Liyan Zhao

Sinoma Wind Power Blade Co., Ltd, Beijing, 100192, China

Abstract

Stable high-quality wind power blades are the key to deal with the fierce competition in the new energy industry. As a commonly used quality tool for risk management, PFMEA is widely used in various industries. The application of PFMEA plays a key role in the product manufacturing process. Based on APQP4WIND standard, this paper expounds the application of PFMEA suitable for wind power industry, and uses the positive and negative two-way method to combine customer demand input with organizational process asset output to comprehensively identify and analyze potential process risks. At the same time, combined with error proofing technology, an improvement idea to improve the effectiveness of PFMEA is proposed, which provides an effective risk prevention means for wind power blade manufacturing.

Keywords

Wind Turbine Blade; PFMEA; APQP4WIND; Error Proofing Technology.

1. Introduction

With the process of global energy low-carbon transformation, China's new energy and renewable energy are developing by leaps and bounds. The wind power industry has maintained steady and orderly development under the new national wind power generation policy, and the installation of wind power generation equipment has entered a "rush to install upsurge". As the main component of wind turbine, wind turbine blades have also accelerated the renewal and iteration of products. New high-power and long blade models are launched every year, and the longest wind turbine blade has exceeded 100m. At the same time, the production cycle of wind power blades is also gradually shortening, which puts forward higher requirements for the high standard and high quality of wind power blades, especially for offshore and export blades. Once quality defects occur, transportation and export customs declaration will be delayed, and even wind farm shutdown and batch recall maintenance will be caused. No doubt, enterprises will face huge compensation. Therefore, it is particularly important to strengthen the manufacturing control of wind power blade products and establish a perfect quality system and prevention mechanism [1]. Typical risk management tools include process failure mode and consequence analysis (PFMEA), fault tree, risk matrix, checklist, HAZOP, etc. [2 ~ 6]. Among them, PFMEA has been widely used in the automotive industry because of its preventive, systematic, semi-quantitative and other characteristics [6], and PFMEA in the wind power industry mostly draws lessons from FMEA standards of AIAG and VDA in the automotive industry [7]. However, unlike the highly automated and stable production factors in the automobile manufacturing industry, the wind power industry, as a large-scale composite component manufacturing industry, has frequent changes in production factors, especially affected by the epidemic, tight supply of core materials such as balsa, and more raw material switching frequently. The manufacturing of wind turbine blades mostly depends on manual operation, and human errors cannot be completely avoided, which will also affect factors such as machine, material, method and environment. The FMEA preventive measures are mostly limited to training and assessment methods.

As a result, FMEA risk management tools are often used in a mere formality, and often become a deliverable of PPAP, which is only output during the project or after the project, which has not played a real and effective role. Under the goal of continuously improving the high quality of wind power products, APQP4WIND organization was jointly established by many famous wind turbine manufacturers and wind power parts suppliers around the world. APQP4WIND improved the concept of APQP in the automotive industry based on the actual situation of the wind energy field, so as to distinguish the differences between the two industries and make the quality and process of wind power products more distinct [8].

This article uses the quality requirement framework defined in the "APQP4WIND Manual" and the recommended PFMEA template as the standard to establish the failure mode and risk assessment of the wind turbine blade manufacturing process. And combined with error-proofing technology to achieve the effectiveness of PFMEA preventive measures.

2. Application of PFMEA in Wind Turbine Blades based on APQP4WIND Standard

FMEA, as one of the five major tools of APQP (Advanced Product Quality Planning), plays an important role in the quality control of the automotive industry. APQP4WIND (APQP in the wind energy industry) also defines FMEA tools in the manual to improve the quality management level of the whole industry chain of the wind power industry.

2.1 PFMEA Application Scope and Timing

PFMEA is a tool used to evaluate design, manufacturing and other risks and take measures to eliminate or reduce risks before the project start. Not only projects with new designs, new technologies, and new processes require PFMEA, but new applications of existing designs or processes also require PFMEA [9]. Several application scenarios of PFMEA are shown in Table 1.

Table 1. PFMEA to be performed in the following scenarios

Usage scenarios of PFMEA	Scope of PFMEA
New design, new technology, new process	Complete design, technology or process
New application of existing design or process	Existing design or process for new environment, new site, new application
Engineering changes to existing designs or processes	PFMEA review or revision

Table 2. PFMEA in the APQP4WIND framework

APQP phase	Progress in PFMEA
Program planning and definition	Start PFMEA program
Validation of design and development	Start the PFMEA
Validation of process design and development	Complete PFMEA analysis
Product and production qualification	Complete the PFMEA action
Feedback evaluation of corrective actions	Start planning PFMEA again

In combination with the requirements of APQP4WIND, PFMEA should be carried out before the implementation of products or processes. After fully understanding the production concept, we start the preparation of PFMEA. Process design can be improved if analysis of the PFMEA can be

ISSN: 2414-1895 DOI: 10.6919/ICJE.202203_8(3).0017

completed before final process decisions. If the action of PFMEA is completed before PPAP, it is convenient to control product quality. If existing designs and processes are changed, planning and revision of the PFMEA is restarted [9-11]. The progress of PFMEA in the APQP4WIND work framework is shown in Table 2.

After it is determined to start PFMEA, a team needs to be formed. The team should be composed of different experts in process, equipment, quality, manufacturing, R&D, IE, etc., this is to avoid the problem that PFMEA is completed by the project leader or engineer alone in order to cope with the PPAP delivery task.

2.2 The Overall Analysis Idea of PFMEA

The main implementation steps of PFMEA can be completed in accordance with the steps of structural analysis, failure analysis, risk assessment, measure optimization, and documentation of results, as shown in Figure 1.

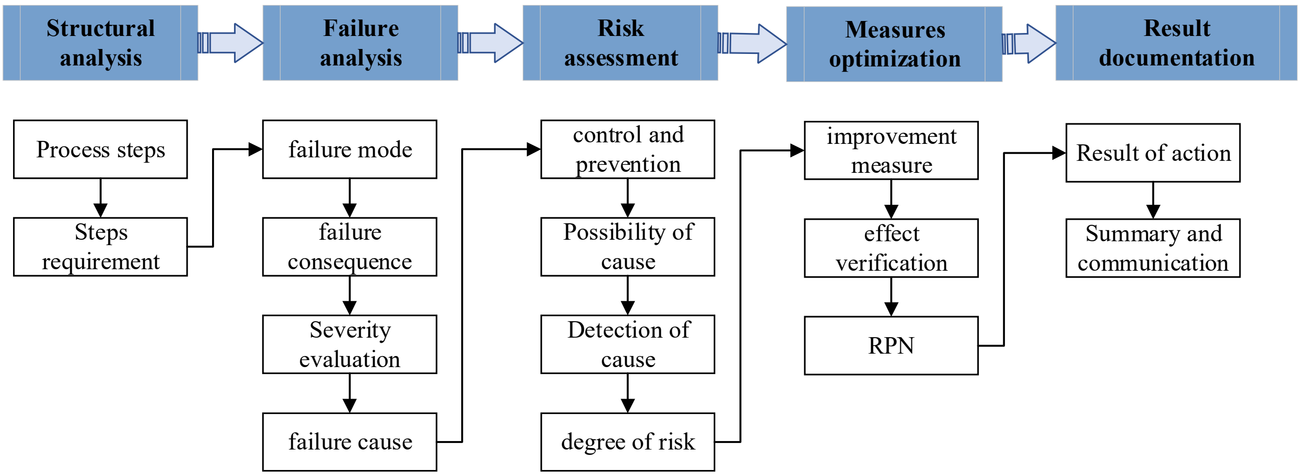

Figure 1. The main steps of PFMEA preparation

The PFMEA risk assessment parameters are composed of severity (S), frequency (O), detection degree (D). The scoring criteria of the APQP4WIND manual adopts the scoring method of the risk sequence number RPN, RPN = S*O*D, according to the score of the RPN to determine the priority control level of risk, the larger the score of the RPN, the greater the risk [12]. The severity is determined by the design characteristics of the product, and can only be changed through product design change. Therefore, the improvement in process design is mainly considered from two aspects: reducing the occurrence frequency and improving the detection degree, so as to reduce the corresponding RPN score.

Before starting PFMEA, it is necessary to complete the corresponding process flow chart, and confirm the process steps and each requirement of PFMEA according to the process flow chart. Only when the requirements are well identified can we ensure that there is no missing failure analysis. Using process flow diagram to analyze requirements and risks is often the result of positive analysis according to customer requirements. In addition to analyzing whether the product characteristics meet the requirements, the rich organizational process assets are formed in the manufacturing process of wind power blades can also be used as the reverse basis for PFMEA risk analysis [13]. Analyzing PFMEA from both customer requirements and organizational process assets is the use of positive and negative bidirectional methods to analyze PFMEA. Customer demand is used as technical input, and organizational process assets are used as long-term accumulated experience output. Input and output affect each other when analyzing PFMEA, as shown in Figure 2. When analyzing the causes of failure from the forward and reverse aspects, the factors of "human, machine, material, method and environment" will be considered comprehensively.

ISSN: 2414-1895
DOI: 10.6919/ICJE.202203_8(3).0017

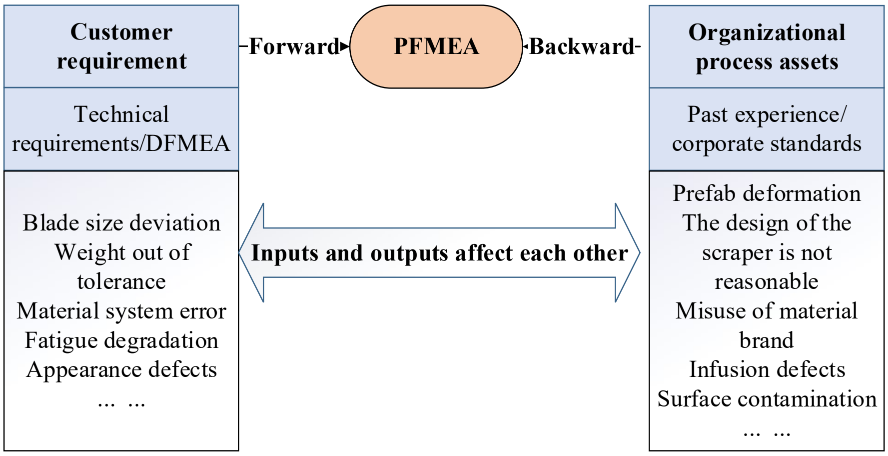

Figure 2. Two ways of PFMEA analysis method

2.3 Application of Error Prevention Technology Combined with PFMEA

The wind power industry is different from automobile assembly, although many automation equipment is introduced in the manufacturing process of wind power blades, most processes still rely on operators, and the proficiency and experience of operation have become an influencing factor for the stability of quality. The continuous resignation of old employees and the entry of new employees have gradually reduced the proportion of experienced operation employees on the company's production line. At the same time, the production pace is gradually shortening, and the long-term accumulated experience and lessons can not be quickly mastered by new employees, so that the way of quality control relying on the skill level of personnel needs to be changed rapidly. The company needs to consider how to eliminate potential risks before quality defects occur, rather than simply attributing the failure reason to the unskilled, unclear and non-conforming operation of the operating staff. The preventive control measures are only for assessment and training.

PFMEA is a very effective tool for analyzing potential risks in the process, but PFMEA itself is not a problem-solving tool. When using PFMEA tools, it is often combined with error-proofing technology, which is using facilities, devices and other technologies that can predict or prevent human errors [14], so as to effectively reduce the frequency of failures, improve detectability, and make human factors controllable.

Error-proofing technology can be designed according to product characteristics, and distinguish qualified and unqualified products through differences in product characteristics. The product characteristics of wind turbine blades include weight, size, color, position, resistance, etc. [13].

For example, in the shell laying process, it is required that the PS spar cap and SS spar cap must be placed in the corresponding positions of shell, the conventional control method is to add a QR code to the spar cap for quick identification. If the QR code is wrong, the spar cap will not be able to be quickly identified and it will lead to 100% online rework when the wrong spar cap is used, and the replacement of the right spar cap will increase labor costs. The reason for this problem is that the QR code was pre-printed, and the employee took the wrong or did not recognize the QR code. If a QR code printing device is added on the side of the spar cap mold, the QR code can be printed as it is used, which can avoid the problem of incorrect using the QR code.

The level of error-proofing technology includes not doing, human detection, equipment detection, prevention, etc. The more significant the prevention effect is, the higher the error-proofing technology level is [15].

Error-proofing requirements, priorities, and cost inputs come from the PFMEA evaluation system. High-risk items identified by PFMEA analysis cannot be controlled and prevented simply by relying on personnel training and assessment. In order to reduce the risk value of RPN, error-proofing techniques can be adopted. When error proofing is set and verified to be effective, PFMEA can be reevaluated.

3. PFMEA Application Example

The design of wind power blade is a "sandwich" structure. The PS and SS shell is bonded together through bonding glue. The bonding process is the key process in the blade manufacturing process. This paper uses a case in the bonding process to illustrate the application and optimization of PFMEA.

3.1 Risk Identification

According to the two-way PFMEA analysis method, first interpret the requirements of the customer's technical specifications, in which the blade bonding glue thickness needs to meet the requirements of 0.5 mm to 8 mm, and the bonding glue is continuous and without defects such as air bubbles and cavities.

According to the experience of the bonding process, it is identified that the risk of voids in bonding paste is relatively high, mainly due to insufficient bonding glue thickness, insufficient bonding glue width and uneven bonding glue interface.

The theoretical bonding glue type can be verified by the blade bonding simulation analysis and the process verification. The bonding glue scrapers can be made according to the theoretical glue type in different positions. During operation, employees need to select the right scraper according to the position and correctly install it in gelatinizing equipment to obtain the correct sizing type [7]. However, it has happened that an operator installed the bonding glue scraper in the wrong direction, and the bonding glue type was wrong, resulting in the defect of voids in bonding paste.

3.2 Conventional Analysis

Through the review and analysis of this quality defect, it can be concluded that the installation direction of the scraper is wrong due to the identification error and operation error of the operator. The common preventive and control measures are as follows: First, train operators to improve their ability to identify scrapers; second, improve employees' quality awareness; third, evaluate the employees who do not follow the requirements. In the short-term, the impression can be deepened by the above methods, but with the passage of time and personnel changes, the above problems will recur.

3.3 PFMEA Optimization Ideas

PFMEA analysis of bonding process is carried out. The requirement of bonding process is the bonding glue shape at different positions meets the process requirements. The failure mode (FM) is the shape of the scraper does not meet the process requirements, the impact on this process is 100% online rework, and the impact on the customer is the defect of voids in bonding paste, which affects the blade fatigue performance. The failure cause (FC) is analyzed such as human, machine, material, method and environment, and it is found that the employee uses the wrong scraper or the scraper is installed incorrectly. The conventional control method is training, according to the severity (S), occurrence frequency (O) and the detection degree (D) calculates the RPN value, RPN = s * o * d = 140, indicates that the risk is high. The RPN value cannot be reduced through conventional training control methods. The PFMEA analysis is shown in Table 3.

The reduction of RPN value is mainly to reduce the score of frequency and detection degree. Combining the error-proofing technology to formulate control measures, by adding matching points between the scraper and the bonding glue box, the scraper can be installed successfully only when it is in the correct direction and position, ensuring the correct selection and installation of the scraper and avoiding quality problems. After reanalysis of PFMEA, the occurrence frequency and detection degree were reduced to 2 and 3 points, respectively, and the RPN value was reduced from 140 to 42, and the risk was significantly reduced, as shown in Table 4.

Volume 8 Issue 3, 2022
DOI: 10.6919/ICJE.202203_8(3).0017

Table 3. Routine analysis of PFMEA

Requirement	FM	FE	S	FC	PC	O	DC	D	RN	RPN
The shape of glue in different positions meets the technological requirements	The shape of glue does not meet the process requirements	The process: 100% online rework; Customer: Lack of glue	7	People: use the wrong scraper or the scraper is installed incorrectly	Train staff on scraper requirements	4	Visual inspection; Ruler inspection	5	28	140

Table 4. Optimized analysis of PFMEA

Requirement	FM	FE	S	FC	PC	O	DC	D	RN	RPN
The shape of glue in different positions meets the technological requirements	The shape of glue does not meet the process requirements	The process: 100% online rework; Customer: Lack of glue	7	People: use the wrong scraper or the scraper is installed incorrectly	Train staff on scraper requirements; adding matching points between the scraper and the bonding glue box	2	Visual inspection; Ruler inspection	3	14	42

4. Conclusion

In the manufacturing process of wind turbine blades, using PFMEA to analyze the process design risk can identify the occurrence of potential defects in advance and improve the product quality. Based on APQP4WIND standard, this paper introduces the working ideas of PFMEA which is more suitable for the field of wind power. At the same time, the implementation plan of PFMEA and error-proofing technology is briefly described through cases, which changed the thinking mode of quality control in the manufacturing industry that only relies on learning lessons and personnel training, reduce or avoid risks from the source, so as to ensure the quality improvement of wind power blades and rapid product delivery, it lays a foundation for realizing zero defect manufacturing.

References

[1] Junyuan Zhang, Junxiao Lu, Jiawei Pan, Yongshi Tan, Xi Cheng, Yao Li. Implications of the development and evolution of global wind power industry for China-An empirical analysis is based on public policy [J]. Energy Reports, 2022(8): 205-219.

[2] Jialiang Zhang, Jichuan Kang, Liping Sun, Xu Bai. Risk assessment of floating offshore wind turbines based on fuzzy fault tree analysis [J]. Ocean Engineering, 2017(129) :382-388.

[3] Arash Shahin. Proposing an Integrated Framework of Seven Basic and New Quality Management Tools and Techniques: A Roadmap [J]. Research Journal of International Studies, 2010(17):183-195.

[4] Bendixen, L. M., & O'Neill, J. K. Chemical plant risk assessment using HAZOP and fault tree methods [J]. Plant/Operations Progress, 1984(3), 179–184.

[5] Botao Xu, Zhikai Fang, Yugang Liu, Tao Guo, Zhengyi Xiao, Bin Zhang, Weibing Dai. Hazard Analysis and Error Proofing in Spacecraft General Assembly [J]. Advances in Engineering Research, 2017(86): 199-202.

[6] Gunjan Joshi, Himanshu Joshi. FMEA and Alternatives v/s Enhanced Risk Assessment Mechanism [J]. 2014(93):33-37.

[7] Liyan Zhao, Yan Liu, Youmu Xu, Yue Jiang. Discussion on the application of PFMEA in the bonding process of off-shore blade [J]. Composites Science and Engineering, 2019(4):58-61.

[8] Zachary A. Marx. CSR Reporting in the EU under Directive 2014/95/EU: A Case Study of Danish Influence on EU CSR Policy [D]. Climate Change Law, 2017.

[9] H. Arabian Hoseynabadi, H. Oraee, P.J. Tavner. Failure Modes and Effects Analysis (FMEA) for wind turbines [J]. Electrical Power and Energy Systems, 2010 (32) 817-824.

[10] A study into the use of the process failure mode and effects analysis (PFMEA) in the automotive industry in the UK [J]. Journal of Materials Processing Technology, 2003(139): 348–356.

[11] CIOBANU Doina Valentina, DUMITRASCU Adela-Eliza, TUDOSOIU Catalin, BORZ Stelian Alexandru. Advanced Quality Planning of Manufacturing Products-APQP [J]. Applied Mechanics and Materials, 2013 (371): 777-781.

[12] He Li, H. Diaz, C. Guedes Soares. A developed failure mode and effect analysis for floating offshore wind turbine support structures [J]. Renewable Energy, 2021(164): 133-145.

[13] Lawrence P. Chao, Kosuke Ishii. Design Process Error-Proofing: Strategies for Reducing Quality Loss in Product Development [J]. International Mechanical Engineering Congress and Exposition, 2005(79453): 255-263.

[14] Foivos Psarommatis, Gökan May, Paul-Arthur Dreyfus, Dimitris Kiritsis. Zero defect manufacturing: state-of-the-art review, shortcomings and future directions in research. International Journal of Production Research, 58(1): 1-17.

[15] Lawrence P. Chao, Kosuke Ishii. Design Process Error Proofing: Failure Modes and Effects Analysis of the Design Process [J]. Journal of Mechanical Design, 2007(129): 491-501.