Improving product quality based on QFD and FMEA Theory -- Taking electrofusion joints as an example

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Abstract. A case study is reported which combines Quality Function Deployment (QFD) and Failure Mode and Effects Analysis (FMEA) to improve the quality of electro-fusion fittings. QFD is a useful tool for managing cross-functional design teams and exploring customer needs. FMEA is a qualitative method to determine the critical failure modes for a product, a process or manufacturing equipment during the design stage. FMEA involves investigation and assessment of all causes and effects of all possible failure modes from the earliest product development phase. In this study, QFD was used to identify the critical technical attributes which affect the customer satisfaction the most. FMEA was adopted to identify potential failure models and causes of critical manufacturing processes. Vague and abstract customer requirements (CRs) were obtained through customer visits and interviews and grouped by the Affinity Diagram. Analytic Hierarchy Process (AHP) questionnaire was used to rank the importance of CRs. CRs were then transferred to specific technical attributes (TAs) by House of Quality (HoQ). Manufacturing processes of electro-fusion fittings were analyzed by FMEA and relative solutions were given to failure models with high Risk Priority Number (RPN) indices. By the integration of FMEA into QFD, the product qualification ratio of electro-fusion fittings has increased by 12% based on the improvement of the technical design and manufacturing processes.

1 Introduction

Electro-fusion (EF) is a method of joining polyethylene (PE) pipes and other plastic pipes or composite pipes. Special fittings with a build-in electric heating coil are used to weld the joint, which is called electro-fusion fitting. In order to remove contaminants such as dust, mud and water, the pipe ends are cleaned and then inserted into the both sides of the EF fitting. An interface between the pipes and the fitting is not necessary and may in fact have adverse effects on the jointing process. It is typical to have an initial air gap between the pipes and the fitting. After the EF fitting is connected to a welding machine, a current is passed through the coil wire and heat is generated in the wire by Joule effect. Surrounding plastic material of the fitting and pipes subsequently heats up, deforms and melts, and the air gap closes due to thermal expansion of the material, causing fusion of the molten plastic. Once the current is switched off, the fused assembly is allowed to cool down and solidify, forming a very strong homogeneous joint along the circumference of each pipe in contact with the fitting (Wood et al., 1998).

Usclat (1985) showed that the quality of the joint depends on several key factors such as material properties, design parameters for fittings, wiring method and the operator's experience. Bowman (1991) suggested that the energy input should be carefully controlled. Shi et al. (2012) conducted a comprehensive study on defects and failure modes of electro-fusion joints and classified defects into four categories: poor fusion interface, over welding, voids and structural deformity. Three main failure modes of EF joints exist by conducting peeling tests and sustained hydraulic pressure mode under inner pressure, which are cracking through the fusion interface, cracking through the fitting, and cracking through the copper wire interface. The electro-fusion joining technology has been well established and widely used in Europe for over 30 years. In China, electro-fusion fitting manufacturing has expanded with the development of PE pipes and it is considered as supporting facilities for PE pipes. Currently there are more than ten big EF fitting manufacturing companies in the Chinese market. The company selected for this study adopts Germany EF fitting manufacturing equipment to produce high-quality products. However, the quality of the products is not stable as expected and they have received many complaints, such as material-spraying, water leakage and inconvenient connection. In addition, as the product size is relatively small, it causes installation problems and welding quality problems. Therefore, it is important to solve these problems to improve the quality of EF fittings and to satisfy customers. In this work, QFD and FMEA are combined to cope with problems occurring in different product development processes of EF fittings.

2 Literature review

QFD has been used as a successful design methodology to improve the quality of products for more than 40 years. American Supplier Institute (1991) defined QFD as 'A system for translating consumer requirements into appropriate company requirements at each stage from research and product development to engineering and manufacturing to marketing/sales and distribution'. QFD helps designers to utilize the voice of customers (VOC), or customer requirements, to determine which engineering elements or product specifications are the most essential. This prioritization helps designers to know which part of the product or process is the most beneficial to focus on during design, resulting in products that better meet customer requirements and generate increased commercial success (Lamers et al., 2007). It can be used to improve the quality of existing products or develop new products. It has been widely used in various industries, including electronic, software, automotive and material industries etc. (Akao, 1997).

The well-known quality tool FMEA has evolved gradually since its inception in aerospace industry in mid-1960s (Sevcik, 1981). FMEA is a disciplined approach used to identify potential failures of a product or service and then to determine the frequency and impact of the failure. FMEA is an important method for preventive quality and reliability assurance. It involves investigation and assessment of all causes and effects of all possible failure modes of a product, from the earliest development phase. In this study, FMEA was adopted to analyze the equipment failure mode during production processes. There are three indices that help to define the priority of failures: occurrence (O), severity (S) and detection difficulty (D). Occurrence is the frequency of the failure. Severity is the seriousness of the failure. Detection difficulty is the hardness to detect the failure before it reaches the customer. Risk Priority Number (RPN) is used to evaluate the risk level of a product's failure mode, and is determined by multiplication of the three failure mode indices:

$$\mathrm{RPN} = O \times S \times D \quad (1)$$

Chen and Ko (2009) incorporated FMEA into QFD process by considering the design risk. By performing FMEA on design requirements, fuzzy risk rating of part characteristics is obtained and used as constraints. Ginn et al. (1998) argued that QFD is the guardian to the voice of customers, while FMEA is the guardian to the voice of engineers. QFD and FMEA are tackling the same issue of customer satisfaction, but from different perspectives. Tanik (2010) presented an integrated application of FMEA-QFD on a food package industry. FMEA analysis was inserted into the initial QFD process and helped the sales team for channeling these efforts in a right direction. The author also indicated that with the help of FMEA customer satisfaction is guaranteed by eliminating potential errors through the order handling process. Ginn (1996) introduced two schools of thought from Ford Motor Company with regards to the effective deployment of QFD and FMEA together. The first approach is applying QFD Phase 1 or Phase 2 followed by a full FMEA process. The second approach is arguably the ideal long-term solution, applying four-phase QFD with full support of an FMEA process. Based on the two thoughts, Ginn et al. (1998) proposed a new model to push FMEA upstream and QFD downstream along the product development circle. Chen and Ko (2009) developed a fuzzy linear programming model to consider quality elements and parts/components risk analysis during the stage of new product development. Almannai et al. (2008) developed a joint QFD and FMEA model to choose the best alternative. Both QFD and FMEA were used to support the manufacturing decision-making process. This model combines the two quality tools in a systematic way and forms a good decision tool because QFD has the ability to identify the most suitable alternatives and FMEA has the ability to identify the associated risks with that alternative in design and implementation phases. Liu (2009) developed an extended fuzzy QFD approach based on a-cut operations. The proposed method consists of two main phases: the establishment of product planning phase and the establishment of part deployment phase. FMEA was used in the second phase, i.e., part deployment phase. Fuzzy FMEA was used to identify high risk failure modes for parts characteristics with high importance.

In this study, a combined QFD-FMEA methodology was performed to improve the quality of electro-fusion fittings, where QFD was used to identify critical technical attributes while FMEA was used to identify the critical failure modes during manufacturing processes with high RPN indices. Solutions and suggestions were provided based on the combined QFD-FMEA analysis. Main research methods and steps are illustrated in Figure 1.

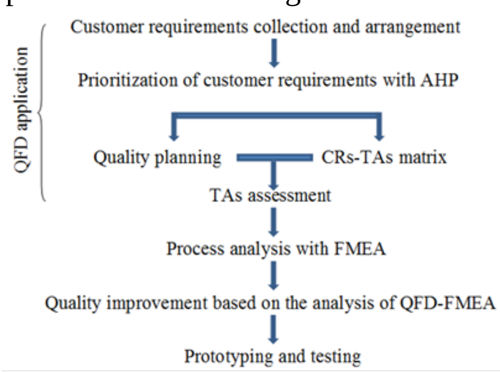

Figure 1 Research routine

3 Methodologies

3.1 QFD application

3.1.1 Collection and grouping of customer requirements (CRs)

CRs were collected through direct customer visits and communication with end users of electro-fusion fittings. Affinity Diagram was adopted to group disordered CRs, as shown in Table 1.

Table 1. Customer requirements arrangement for electro-fusion fittings

1st level	2nd level	3rd level
Good quality	Good reliability	Suitable matching tightness
		Accurate positioning
		Good warning ability for welding quality
		Good pressure resistance
		Long service life
	Easy operation	Safe operation
		Convenient operation
		Strong environmental adaptability
	Superior performance	Good dust proof effect
		Short welding time
		Good ductility
	Good looking	Good appearance

3.1.2 Prioritization of customer requirements

AHP with a 9-scale was adopted to prioritize the CRs for electro-fusion fittings. The AHP consists of three main operations: hierarchy construction, priority analysis and consistency verification (Ho, 2008). This hierarchy, as shown in Table 1, can be obtained through applying Affinity Diagram. Then AHP-based questionnaire was designed to collect customers' preferences among different CRs. Please refer to Kahraman et al. (2003) for more information on AHP-based questionnaire. AHP matrix was generalized based on the questionnaire data in Table 2. Importance rating for each customer requirement was calculated and listed in the last column of the AHP matrix. Satty (1977) proposed a consistency index $CI = (\lambda_{max} - n)/(n-1)$, where n and λmax are dimension of the matrix and the maximal eigenvalue, respectively. A matrix is consistent when the consistent ratio is less than 0.1 (Abdul-Rahman et al., 1999). Consistent ratio is the ratio of CI and RI, where CI and RI are the consistency index and the random index, respectively. In this case, the largest eigenvalue for the AHP matrix calculated by MATLAB is 13.2093. CI = (13.2093−1)/ (12−1) = 0.1099, CR = 0.1099/1.54 = 0.071. Therefore CR is less than 0.1, which indicates that the AHP matrix is consistent.

3.1.3 Market competitive assessment and quality planning

A QFD team consisting of members from R&D, production and marketing division was established. Two competitive companies which also produce electro-fusion fittings were selected as benchmarking representatives and their products were compared and analyzed. Customer satisfaction rate regarding each customer requirement was determined and a target level was set, as shown in Table 3. Improvement ratio was obtained by Target level / Current level. Sales point denotes the attractiveness of each customer requirement in the market and carried three values of 1, 1.25 and 1.5, respectively. Absolute importance was obtained by Importance rating × Improvement ratio × Sales point. Relative importance is the percentage of the absolute importance value in the sum of all absolute importance values. The relative importance value reflects the voice of customer, benchmarking with similar products and market attractiveness.

Table 2. AHP matrix

	Good appearance	Suitable matching tightness	Short welding time	Safe operation	Easy operation	Good pressure resistanc	Long service life	Good dust proof effect	Good warning ability	Good ductility	Strong environmental	Accurate positioning	Importance rating
Good appearance	1	1/4	1/2	1/9	1/2	1/5	1/7	1/3	1/7	1	1/2	1/5	0.02
Suitable matching	4	1	3	1/4	2	1/4	1/3	5	2	4	2	2	0.1
Short welding time	2	1/3	1	1/3	1	1/5	1/3	2	1/6	1/3	1/5	1/3	0.03
Safe operation	9	4	3	1	5	1	5	3	4	4	3	4	0.22
Easy operation	2	1/2	1	1/5	1	1/5	1/5	1/3	1/2	3	1/2	1/2	0.04
Good pressure resistance	5	4	5	1	5	1	2	7	2	5	3	2	0.18
Long service life	7	3	3	1/5	5	1/2	1	3	2	3	2	2	0.12
Good dust proof effect	3	1/5	1/2	1/3	3	1/7	1/3	1	1/2	1	1/2	1/2	0.04
Good warning ability for welding quality	7	1/2	6	1/4	2	1/2	1/2	2	1	2	1	1	0.08
Good ductility	1	1/4	3	1/4	1/3	1/5	1/3	1	1/2	1	1/2	1/2	0.03
Strong environmental adaptability	2	1/2	5	1/3	2	1/3	1/2	2	1	2	1	1	0.07
Accurate positioning	5	1/2	3	1/4	2	1/2	1/2	2	1	2	1	1	0.07

Table 3. Quality planning table

Customer requirements	Importance rating	Current company	Competitor 1	Competitor 2	Target level	Improvement ratio	Sales point	Absolute importance	Relative importanc
Good appearance	0.02	5	4	5	5	1	1.5	0.03	0.02
Suitable matching	0.10	3	4	4	4	1.3333	1	0.13	0.09
Short welding time	0.03	3	3	4	4	1.3333	1	0.04	0.03
Safe operation	0.22	3	4	4	4	1.3333	1	0.30	0.20
Easy operation	0.04	4	4	4	4	1	1	0.04	0.02
Good pressure resistance	0.18	3	3	5	5	1.6667	1.25	0.38	0.25
Long service life	0.12	4	3	4	4	1	1.25	0.16	0.10
Good dust proof effect	0.04	4	4	4	4	1	1	0.04	0.03
Good warning ability for welding quality	0.08	3	3	4	4	1.3333	1	0.10	0.07
Good ductility	0.03	4	4	4	4	1	1	0.03	0.02
Strong environmental adaptability	0.07	3	3	4	5	1.6667	1.25	0.14	0.09
Accurate positioning	0.07	3	4	4	5	1.6667	1	0.11	0.07

3.1.4 CRs-TAs relationship matrix

Based on the collected CRs and industry standards, 13 technical attributes of electro-fusion fittings are identified, including out-of-roundness of electro-fusion socket, socket diameter, socket depth, welding section length, observation hole depth, wiring depth, wiring pitch, position type, product structure, external dimensions, raw material, design power and welding time. Relationship matrix between CRs and TAs was developed and numerical values of 1, 3 and 5 were input into Table 4 to indicate weakly related, moderately related and strongly related relationships, respectively. Blank cells indicate no relationship.

Table 4. CRs-TAs two way dimensional table

	Out-of-roundness	Socket diameter	Socket depth	Welding section	Observation	Wiring depth	Wiring pitch	Position type	Product structure	External dimensio	Raw material	Design power	Welding time
Good appearance						3		5	5	5			
Suitable matching	5	5											
Short welding time												5	5
Safe operation					3	3						3	3
Easy operation	5	5	5	1				3					
Good pressure resistance				3			5		5	3	3	1	3
Long service life									3	1	5		
Good dust proof effect									5		3		
Good warning ability for welding quality					5		5					3	
Good ductility											5		
Strong environmental adaptability	5	5	3					3			3	3	3
Accurate positioning	3	3	3					5					

3.1.5 Quality designing

Assuming n CRs and m technical attributes, the importance rating for technical attributes can be calculated by the following equation:

$$T_j = \sum_{i=1}^{n} RW_i R_{ij} \quad (1 \le i \le n, 1 \le j \le m) \qquad (2)$$

where i, j, Tj, RWi, Rij denote the ith row of customer requirement, the jth column of technical attribute, importance rating for the jth column of technical attribute, relative weight for the ith row of customer requirement, relationship strength of the ith row of customer requirement and the jth column of technical attribute. Based on the technical competitive assessment of products of the present company, competitors' products and importance rating for each technical attribute, the target level of the corresponding technical attribute was determined, as shown in Table 6. If the target level is higher than the current technical level and the technical attribute is highly ranked, the technical attribute can be identified as critical technical attributes. In Table 5, technical attributes including socket diameter, product structure, design power and welding time were selected for improvement and their background was colored in red.

Table 5. Quality designing

Technical attributes	Out-of-roundness	Socket diameter	Socket depth	Welding section	Observation hole depth	Wiring depth	Wiring pitch	Position limiting	Product structure	External dimensi	Raw material	Design power	Welding time
Importance rating	1.24	1.24	0.62	0.79	0.93	0.65	1.62	0.82	1.82	0.97	1.98	1.47	1.78
Current company	5	3	5	5	4	3	4	3	3	4	5	3	3
Competitor 1	4	3	5	5	4	3	3	4	4	4	4	4	3
Competitor 2	5	4	5	5	4	4	4	4	4	4	5	4	4
Target level	5	4	5	5	4	3	4	5	5	4	5	4	4
Need improvement	Maintain	Improv	Maintain	Maintain	Maintain	Maintai	Mainta	Maintain	Improve	Maintai	Maintai	Impro	Improve

3.1.6 House of Quality

Based on the collected CRs, technical attributes, quality planning, CRs-TAs relationship matrix and quality designing tables, the HoQ (house of quality) for electro-fusion fittings was constructed as shown in Table 6. Based on the first phase of QFD analysis, key technical attributes, such as socket diameter, product structure, design power and welding time of EF fittings were obtained. These technical attributes are the main impacts on the customer satisfaction of EF fittings.

Table 6. House of Quality

	Out-of-roundness	Socket diameter	Socket depth	Welding section	Observation	Wiring depth	Wiring pitch	Position limiting	Product structure	External dimensi	Raw material	Design power	Welding time	Importance	Current company	Competitor	Competitor	Target level	Improvement ratio	Sales point	Absolute importance	Relative importance
Good appearance						3		5	5	5				0.02	5.00	4.00	5.00	5.00	1.00	1.50	0.03	0.02
Suitable matching tightness	5	5												0.10	3.00	4.00	4.00	4.00	1.33	1.00	0.13	0.09
Short welding time												5	5	0.03	3.00	2.00	4.00	4.00	1.33	1.00	0.04	0.03
Safe operation					3	3						3	3	0.22	3.00	4.00	4.00	4.00	1.33	1.00	0.30	0.20
Easy operation	5	5	3	1				3						0.04	4.00	4.00	4.00	4.00	1.00	1.00	0.04	0.02
Good pressure resistance				3			5		5	3	3	1	3	0.18	3.00	2.00	5.00	5.00	1.67	1.25	0.38	0.25
Long service life									3	1	5			0.12	4.00	2.00	4.00	4.00	1.00	1.25	0.14	0.10
Good dust proof									5		3			0.04	4.00	4.00	4.00	4.00	1.00	1.00	0.04	0.03
Good warning ability for welding					5		5					3		0.08	3.00	3.00	4.00	4.00	1.33	1.00	0.10	0.07
Good ductility											5			0.03	4.00	4.00	4.00	4.00	1.00	1.00	0.03	0.02
Strong environmental adaptability	5	5	3					3			3	3	3	0.07	3.00	2.00	4.00	5.00	1.67	1.25	0.14	0.09
Accurate positioning	3	3	3					5						0.07	3.00	4.00	4.00	5.00	1.67	1.00	0.11	0.07
Importance rating	1.24	1.24	0.62	0.79	0.93	0.65	1.62	0.82	1.82	0.97	1.98	1.47	1.78								1.59	1.00
Current company	5	3	5	5	4	3	4	3	3	4	5	3	3									
Competitor 1	4	3	5	5	4	3	3	4	4	4	4	4	3									
Competitor 2	5	4	5	5	4	4	4	4	4	4	5	4	4									
Target level	5	4	5	5	4	3	4	5	5	4	5	4	4									
Need improvement	M	I	M	M	M	M	M	M	I	M	M	I	I									

3.2 FMEA Application

EF fitting manufacturing processes were then analyzed by FMEA to predict the possibility of accidents and occurrence of main failure modes. FMEA provides a robustness analysis to the safety, reliability, maintainability and effect of manufacturing processes by predicting all possible failure modes, severity and causes etc. Manufacturing processes of EF fittings include material feeding, drying, pouring and molding, pipe clamping fitting, internal boring, wiring and installation. Identified failure modes include material feeding stoppage, air pores, unstable depth of the observation hole, etc. Then the failure causes were investigated and failure severity, frequency of occurrence and difficulty of detection were assessed. Failure modes with relatively high RPN indices were marked in red, as shown in Table 7. In the present case items with RPN index higher than 100 are chosen. Suggestions and solutions were given accordingly to eliminate the possible failure modes or at least decrease its frequency of occurrence. For example, the cause of poor welding quality is inappropriate wiring depth and inappropriate process design. Suggestions were provided, such as to use standardized clamp and cutting tool, specify wiring processes and conduct simulation tests under harsh environment.

Table 7. Failure mode and effect analysis on manufacturing processes

No.	Failure process	Failure mode	S*	Failure cause	O*	D*	RPN index
1	Material feeding	Material feeding stopage	1	Breakdown of vacuum material feeding machine	1	1	1
				Lack of material	1	2	2
2	Drying	Poor appearance; air pores	4	Drying machine breakdown	2	2	16
				Over-saturated raw material	4	2	32
				Not enough drying time	4	2	32
3	Pouring and molding	Large error in size	6	Large error in die size	5	3	90
				Inappropriate process	7	4	168
				High contraction coefficient of raw	3	1	18
		Bad looking	3	Poor processing quality of raw material	6	4	72
				Inappropriate processes	7	4	84
		Poor ability in pressure resistance	8	Poor quality of raw material	3	4	96
				Inappropriate process	7	4	224
				Inappropriate design of die	6	4	192
		Product is not well produced	4	Inappropriate processes	5	2	40
4	Pipe clamping fitting	Large discrepancy in wall thickness of end faces	3	Error in clamp size	4	4	48
				Unstandardized pipe clamping	6	4	72
		Unstable depth of observation hole	5	Error in clamp size	4	4	80
				Unstandardized pipe clamping	6	4	120
5	Internal boring	Large error in size	6	Unstandardized operation	5	2	60
6	Wiring	Electric resistance deviation	3	Poor quality of resistance wire	4	2	24
		Poor welding quality	8	Inappropriate wiring depth	4	8	256
				Inappropriate process design	6	7	336
		Poor appearance	3	Inappropriate wiring depth	4	8	96
				Wear of cutting tool	3	3	27
7	Installation	Position ring is not fixed	5	Size mismatch	3	3	45
		Broken resistance wire; Defective contact	8	Size mismatch; Unstandardized operation	4	2	64

4. Discussion

Improved solutions were proposed for technical attributes and manufacturing processes based on QFD and FMEA analysis, respectively.

4.1 Solutions for technical attribute improvement

Socket diameter, product structure, design power and welding time were identified for improvement as listed in Table 6. Solutions were given accordingly as follows.

The socket inner diameter of fittings was increased as shown in Figure 2. Therefore, pipes can be easily plugged into the fittings.

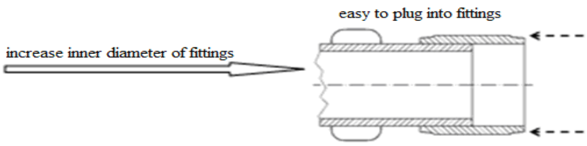

Figure 2 Improvement of socket inner diameter

To optimize product structure, partition design was suggested, in which the EF fitting is divided into welding zones and cooling zones, as shown in Figure 3. The welding zone is used to connect pipes and fittings, where electric resistance is wired for heating. To make sure that no leakage occurs from the gap between pipes and fittings in the welding zone, two cooling zones were arranged on the both sides of the welding zone to form an enclosed system. A certain melting pressure due to thermal expansion ensures sufficient fusion between pipes and fittings, and therefore prevents water leakage under pressure test.

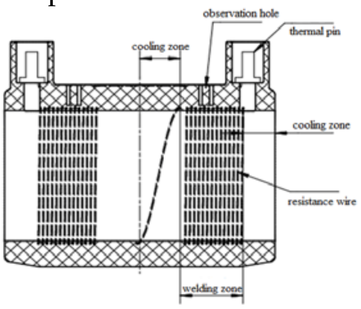

Figure 3 Schematic sketch of an improved EF fitting

Resistance wire and wiring distance were redesigned based on the thermal power of the EF fittings to optimize design power and welding time. Power density was reduced and welding time was prolonged to ensure no material-spraying and no smoking, as shown in Figure 4. Besides, the cooling zone was enlarged.

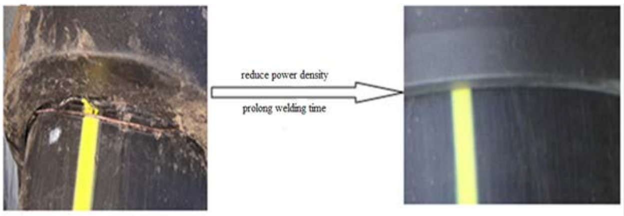

Figure 4 Improvement in design power and welding time

Based on the above discussion, the proposed solutions for quality improvement of EF fittings are summarized in Table 8.

Table 8. Improved results of technical attributes

Critical problems	Proposed solutions	Effects
Socket diameter	Increase inner diameter	Appropriate size, easy to construct and to plug in
Product structure	Partition design	No water leakage
Design power, welding time	Decrease the power density, heating slowly Enlarge the width of the cooling zone Change the wiring pitch of electrofusion, balance the power	No material spraying or smoking, proper welding time and qualilifed test

4.2 Solutions for manufacturing process improvement

Based on the analysis of EF fitting manufacturing processes, items with high RPN indices were identified through FMEA application, as shown in Table 8. Suggestions are summarized in Table 9.

By applying QFD and FMEA to EF fittings, quality control from both technical design and manufacturing design was guaranteed. The qualification ratio of EF fittings was improved and customer complaint decreased accordingly.

Table 9. Improvement strategy of manufacturing processes

Critical problems	Proposed solutions
Inappropriate process during pouring and molding	Strengthen process monitoring, optimize process parameters
Inappropriate design of die	Introduction of scientific design software of die
Unstandardized pipe clamping	Manual for pipe clamping in details, process monitoring
Inappropriate wiring depth	Standardize clamp and cutting tool, specify wiring processes
Inappropriate process design	Optimize design parameters, simulation test under harsh environment

This case study was carried out in 2013. Product qualification ratios in February and March were compared with those in June and July, as shown in Table 10.

Table 10 Comparison chart of product qualification ratio

Month	Feb.	Mar.	Jun.	Jul.
Product qualification ratio	86%	86.27%	96.35%	98.4%

Based on QFD analysis and FMEA application, several common key items were obtained, such as inappropriate wiring depth and poor welding quality, which lead to customer complaints including material-spraying and smoking. Improvement strategies were proposed from these two aspects based on the combined QFD-FMEA analysis, e.g., decrease in power density and increase in welding time, clamp and cutting tool standardization, redesign of wiring, etc. The overlapped analysis results from QFD and FMEA are expected. QFD and FMEA investigate quality problems from different perspectives, so the customer satisfaction can be ensured in a wider range. It is further shown that QFD is the voice of customer while FMEA is the voice of engineers.

5. Conclusions

A hybrid QFD-FMEA method was proposed to solve the problem of high customer complaint rate and to improve the quality of EF fittings. Critical technical attributes, such as socket diameter, product structure, design power and welding time were identified by the QFD as the key items which affect the customer satisfaction. Meanwhile, FMEA was adopted to analyze possible failure modes during manufacturing processes from an engineering perspective. Improved solutions were proposed accordingly. By applying the combined QFD and FMEA method, significant improvements were achieved. Customer satisfaction increases due to reduced customer complaints. Product qualification ratio has been improved by approximately 12%. The hybrid QFD-FMEA method may have some disadvantages, such as time-consuming and coordination demand among different departments. At present, it is difficult to calculate the return on investment. The combination of QFD and FMEA worked well for the quality improvement of EF fittings. It is recommended to practice the hybrid methodology in other industries, and more case studies are expected to verify its effectiveness.

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