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USE OF QUALITY PLANNING METHODS IN OPTIMIZING WELDING WIRE QUALITY CHARACTERISTICS

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The quality of a product is given by the extent, to which the product meets customer requirements. It is generally accepted that the extent, to which the product meets such customer requirements, and, consequently, the resulting quality of the product itself, substantially depend on the early stages of the product lifecycle, i.e. on the design and development stages. Appropriate means for effective product quality planning can be found among quality management methods and tools. These methods are typically employed in engineering production and automotive industry. This paper focuses on exploring the potential of Quality Function Deployment (QFD) and Failure Mode and Effect Analysis (FMEA) methods for use in metallurgical production, an industrial branch where they have not been commonly employed as yet.

Key words: welding, wire, quality, planning

INTRODUCTION

Product quality is one of the most important factors of organizational competitiveness and sustainable economic growth. For high quality of products and the resulting customer satisfaction to be achieved, a quality management system must be implemented and continually improved by the organization. Customer satisfaction is largely dependent on this part of the quality management system, which deals with pre-production stages. These consist of quality planning centered on the design and development of the product and product realization processes. Product and process quality planning can be performed effectively with the aid of appropriate methods and tools. Various methods are used in different stages of product realization. Their close interaction is an advantage in this process.

EXTENT OF USE OF VARIOUS METHODS AND TOOLS IN INDUSTRY

Methods employed in product quality planning include, for instance [1]: QFD (Quality Function Deployment), Design and Process FMEA (Failure Mode and Effect Analysis), process capability analysis, measurement system analysis, seven basic and seven new quality management tools, design of experiments and others. A survey of organizations based in the Czech Republic was conducted to determine the scope, in which individual methods of this kind are employed. It was found that some quality planning tools and methods are not used to adequate extent in Czech companies. The survey of 230 organizations revealed that with many methods the extent of their use strongly depends on the state of the organization's quality management system (QMS) certification. Figure 1 shows the use of QFD, Design FMEA and Process FMEA in organizations at various levels of QMS certification. The figure suggests that the proportion of organizations that used QFD is very small. On the other hand, FMEA is used by a much larger proportion of organizations. Its dependence on the level of QMS certification is very strong. This reflects the fact that standards of automotive industry, as well as some customers from other branches, strictly require application of this method. Lower using of Design FMEA is a consequence of the fact that a number of suppliers do not develop the products and manufacture them only.

Results of the survey and the data on using of the methods are confirmed in part by the literature search concerning quality planning applications. A number of publications have dealt with QFD and FMEA applications [2-5]. Despite that, QFD is relatively rare in metallurgical industry, although some sources mention its use [6]. For instance, statistical process control in metallurgical production is not unusual. It was explored by Noskievičová [7-8]. At the same time, virtually no publications can be found on deployment of QFD in metallurgical industry. The above summary may suggest that QFD is only effective in automotive industry and mechanical engineering. However, correct understanding and application of this method may greatly benefit organizations in metallurgical industry.

In order to prove this statement, QFD was employed by an organization operating in metallurgical industry for identifying and optimizing quality characteristics of cold-drawn welding wire.

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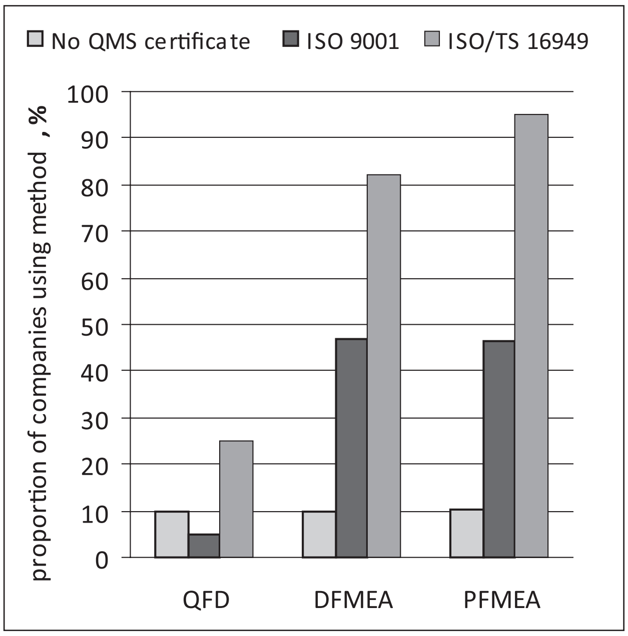

Figure 1 Proportion of companies using QFD and FMEA methods vs. their QMS certification level

QUALITY FUNCTION DEPLOYMENT (QFD)

QFD is teamwork and matrix diagram-based method used primarily during the product and process design and development. Its purpose is to transform stakeholder requirements (particularly those raised by customers) into next phases of product and process design and development. There are several approaches to QFD application. They differ primarily in the number of matrix diagrams used in the transformation of requirements into product and process features.

QFD is typically used for converting customer requirements into basic technical parameters (quality characteristics) of the product. The resulting matrix diagram is termed the "House of Quality" (HOQ). It is developed by a team composed of employees of various specialized departments, namely marketing, development, engineering design and quality control. Figure 2 shows the basic structure of the HOQ diagram. In the first step, the requirements for the product – WHAT – are identified. Then, a customer evaluation is used to assign every requirement an importance level and to assess the customer satisfaction with how the requirements are met in comparison with competing products. The output of this stage is a set of relative weights of individual requirements.

At the next stage, each identified requirement is assigned certain quality characteristics that have impact on its fulfillment – HOW. The central part of the HOQ is a matrix of interrelationships. It contains an analysis of relationships between product quality characteristics and the customer requirements. The analysis of these interrelationships provides data for identifying possible missing quality characteristics and allows to identify key quality characteristics (those with most substantial impact on fulfilling customer requirements). The HOQ

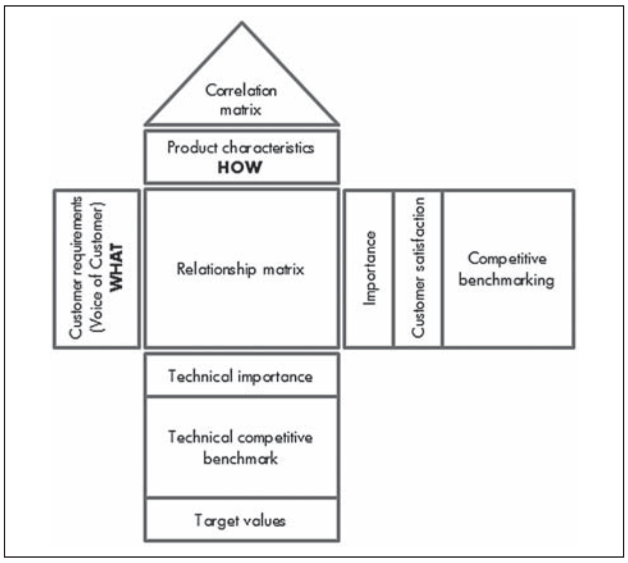

Figure 2 House of Quality

roof contains an analysis of the interrelationships between those quality characteristics, the knowledge of which is important to optimizing the target values of quality characteristics. The output is a set of measurable target values of quality characteristics and their permissible tolerances for meeting customer requirements and achieving customer satisfaction.

FAILURE MODE AND EFFECT ANALYSIS (FMEA)

FMEA is a tool for optimizing a product or process design from the perspective of potential failures. Design FMEA includes an analysis of the product's fitness for given purpose. It allows the risks of potential failures to be minimized. A Process FMEA explores how well the production process (or any other process) is designed. It allows the risks of failures that might occur during production to be minimized. FMEA represents a systematic approach to preventing poor product quality and to minimizing the risk of problems. When used correctly, it can make the product and process quality planning substantially more effective.

APPLICATION OF QFD IN WELDING WIRE DESIGN

At the first stage of QFD application it was necessary to identify requirements for the welding wire. The final product was packaged welding wire wound on a coil. With using affinity and systematic diagrams they were processed information about customer requirements, requirements derived from complaints of customer, product requirements stipulated by the producer but omitted by the customer who believed them to be self-evident, legal requirements and specifications based on technical standards. A total of 24 requirements have been identified.

With using methodology described in they were performed assessment of requirements importance, a comparison of producer and competitor ability to meet these requirements and assessment of the impact of meeting individual requirements on the product saleability. On the basis of these data, relative weights of individual requirements were determined as percentage values. The entire process of constructing the House of Quality diagram was carried out using MS Excel environment. The highest weights for a particular situation with the producer were found to be associated with the following requirements [9]:

- nice appearance of the package
- cohesion of the protective copper layer
- suitability of the package in protecting the wire during transport and storage
- fitness of the coil for its purpose
- secure attachment of wire ends to the coil
- effective corrosion protection provided by the package
- clean surface free from dirt and defects
- smooth and continuous feeding of the wire
- adequate identification of each smallest packaging unit
- correct chemical composition of the wire
- adequate elongation of the weld metal
- adequate tensile strength of the weld metal
- adequate yield strength of the weld metal
- adequate impact energy at the specified temperature
- the surface and type of finish of the wire must not impair the properties of the weld metal, and others

A surprisingly high relative weight was found with the nice appearance of the package of the coiled wire. This was connected with the fact that the packaging appearance was one of the weaknesses of the manufacturer's production.

In the next step, those wire quality characteristics were identified which affect the meeting of individual requirements. The strengths of their interrelationships were evaluated and relative weights of quality characteristics were calculated. A total of 44 quality characteristics were identified, which have impact on compliance with requirements for the product. The highest relative weight was found for following quality characteristics:

- copper uptake
- manganese content
- carbon content
- adhesion of copper layer
- occurrence of surface defects
- packaging strength
- phosphorus content
- sulphur content
- surface cleanness
- variance in copper layer thickness
- graphic design of the package
- coil shape integrity
- molybdenum content, and others

In the next phase of construction of the House of Quality, the data on quality characteristics were compared with those for competing products. An analysis of the interrelationships between quality characteristics was conducted and embodied in the roof of the HOQ. Finally, target values of welding wire quality characteristics were proposed on the basis of all data contained in processed House of Quality. Target values for quality characteristics with the highest relative weights are summarized in Table 1.

Table 1 **List of proposed target values for quality characteristics of the welding wire**

Welding wire quality characteristic	Target value (incl. tolerances)	Relative weight/%
Copper uptake	$2^{\pm 1}$ g/m^2	7,07
Mn content	1,4 – 1,55 % (wt.)	6,54
Carbon content	0,06 – 0,09 % (wt.)	6,45
Adhesion of copper layer	no adhesive failure	4,76
Occurrence of surface defects	no surface defects	4,04
Packaging strength	no failure during handling and transport	3,64
Phosphorus content	≤ 0,02 % (wt.)	2,95
Sulphur content	≤ 0,02 % (wt.)	2,95
Surface cleanness	no dirt	2,86
Variance in Cu layer thickness	1,1 – 3,4 µm	2,77
Graphic design of the package	attractive appearance, setting it apart from competing products	2,53
Coil shape integrity	no shape and dimensional deviations	2,40
Mo content	≤ 0,05 % (wt.)	2,39

APPLICATION OF FMEA IN DESIGN OPTIMIZATION

Design FMEA was used for optimizing the design of the welding wire. One-by-one, all potential failures of welding wire have been identified, which may occur during its use, their possible effects and possible causes. The severity, probability of occurrence and likelihood of detection were evaluated for each failure. A risk priority number (RPN) was assigned to each failure and compared with critical value. Where this critical value is exceeded, appropriate preventive actions should be proposed, particularly in terms of the welding wire design, to reduce the risk of the failure in question. The application of FMEA led to the conclusion that the risk priority number for none of the potential failures exceeds the critical value. The analysis, however, revealed several opportunities for design improvements. For instance, it was proposed to add a note to the operation manual that the customer should use protective equipment while handling the wire to prevent wire contamination as a direct contact between the skin and wire surface may lead to corrosion. In addition, it was recommended to alert the customer to the fact that a poor condition of the welding machine may cause the copper layer to peel, leading to nozzle clogging and welding tip fusion.

CONCLUSION AND BENEFITS

The research showed that application of QFD and FMEA methods in metallurgical production may lead to a number of new and useful findings that substantially enhance the product design and development process. This, in turn, may improve the quality of final products, customer satisfaction and the organization's competitiveness. For quality planning methods to be deployed in a broader context, organizations should eliminate obstacles to their application. In particular, the awareness of appropriate quality planning methods should be improved and their use should be supported by the management.

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Note: The responsible translator for English language is J. Drnek, Ostrava, Czech Republic