COMPLEX METHODOLOGY OF POKA-YOKE IMPLEMENTATION IN CONDITIONS OF WELDED STEEL TUBES PRODUCTION

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Abstract

Poka-yoke (mistake-proofing) is one of the lean manufacturing methods. It ensures that proper conditions exist before actually executing a process step, preventing mistakes from occurring in the first place. Where this is not possible, poka-yoke has a detective function, eliminating defects in the process as early as possible. The application of simple poka-yoke methods in product and process design can eliminate both mechanical and human errors. Modern production systems are based on principles and instruments of the lean, agile and resilient approaches to manufacturing. For these conditions the poka-yoke system preventing errors is the most desirable. This paper deals with design of the complex methodology for poka-yoke implementation for such manufacturing. The methodology is based on the following principles: 1. principle of prevention; understanding poka-yoke as a change and innovation; implementation of poka-yoke as a change and innovation management. In the paper there are described particular steps of the designed methodology: 1. identification of all potential risks; 2. giving reasons for suitability of the poka-yoke implementation; 3. selection of the poka-yoke type; 4. design verification and its realization; 5. description and documentation. In the last part of the paper two cases of implementation of the designed methodology in conditions of the production of welded steel tubes are described: poka-yoke preventing usage of the non-correct rollers and poka-yoke preventing undesirable interchangeability and loss of the production dispatch notes.

Keywords: Lean approach, agile manufacturing, resilience, poka-yoke

1. INTRODUCTION

Modern production systems are based on principles and instruments of the lean, agile and resilient approaches to manufacturing.

The lean approach is widely considered to be the next big step in the evolution of manufacturing beyond Ford's mass production. It can be described as a strategy based on cost reduction and flexibility, focused on the process improvements via systematic identification and reduction of all "wastes" (non-value adding operations (muda), results of unevenness in workloads (mura), and results of overloading (muri)) in order to create value for the customer . It can be said that lean manufacturing is all about minimizing costs. It also focuses on the organization´s core competencies whereas outsourcing many other productive activities. Lean production is not just a technological system but also a concept implemented through the whole company, which especially requires consensus on corporate culture [1]. The lean approach performs better in conditions where there is a higher volume, low variety, and predicable demand with certain supplies.

Agile manufacturing is often viewed as the next step after lean in the evolution of the production methodologies. One of the former definitions of agile manufacturing states that it is "the ability of an enterprise to survive in a competitive environment with continuous and unanticipated change and to respond quickly to rapidly changing markets that are driven by the customer valuing the products and services" [2]. Agile manufacturing is especially oriented to low volume/high mix production adding responsiveness (velocity) and flexibility to the manufacturing process. It is the most effective in conditions where customized configurable or specialized orders offer a competitive advantage.

Agility development in organization requires dynamic and truly integrated management systems that are able to support a continuous change, and hence agile manufacturing cannot effectively operate without an optimal supply chain. Agile manufacturing will be really effective when there is a potential market for a personalized fast-delivery version of one of the current products; there is a new product that can be developed within the company's sphere of competence (or alternately co-developed with a partner) that would strongly benefit from personalization and fast delivery.

Resilience is the ability of a system to return to its original state or move to a new desirable state after being disturbed**.**

In fact, agile principles should be seen as a natural extension and evolution of the lean principles. Katayama and Bennet [3] say that lean, flexible and agile production systems considerably overlap (increased product variety and lower fixed costs for the new product development and grouping parts into families in order to decrease setup times and WIP inventory). Flexible manufacturing, agility and leanness are considered as mutually supporting concepts.

Poka-yoke (mistake-proofing) is one of the lean manufacturing methods. It ensures that the proper conditions exist before actually executing a process step, preventing mistakes from occurring in the first place. Where this is not possible, poka-yoke has a detective function, eliminating defects in the process as early as possible (see **Figure 1**). The application of simple poka-yoke methods in product and process design can eliminate both mechanical and human errors.

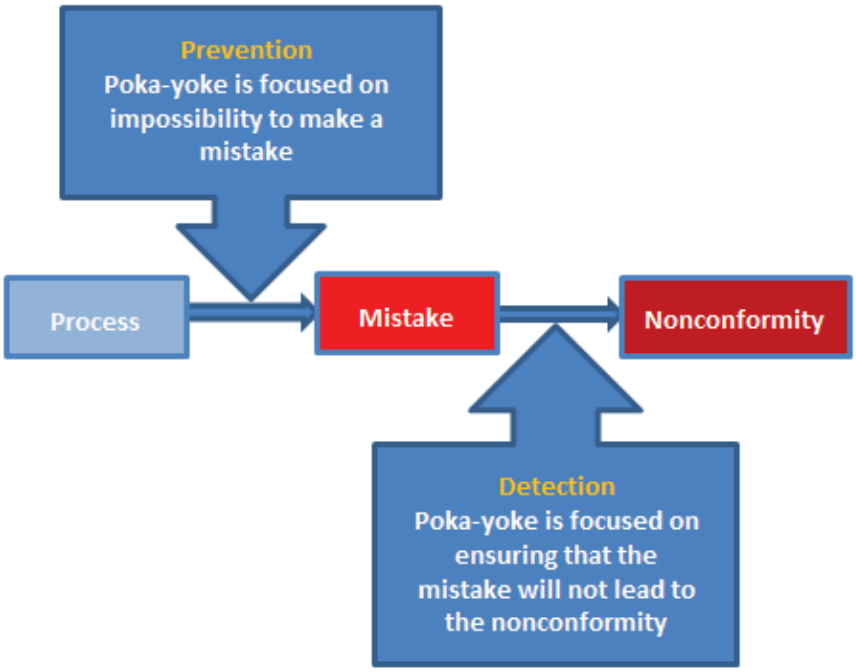

Figure 1 Principle of poka-yoke [4]

For the conditions of the modern combined manufacturing system based on the synergic effect of the lean, agile and resilient approaches the poka-Yoke system preventing mistakes is the only acceptable form.

This paper deals with design of the complex methodology for poka-yoke implementation in the manufacturing conditions combining approaches mentioned above. The methodology is based on the following principles: 1. principle of planning and prevention; 2. understanding poka-yoke as a change and innovation; 3. deployment of poka-yoke as a change and innovation management.

In the paper there are described particular steps of the designed methodology: 1. identification of all potential risks; 2. giving reasons for suitability of the poka-yoke implementation; 3. selection of the poka-yoke type; 4. design verification and its realization; 5. description and documentation.

In the last part of the paper two cases of application of poka-yoke on the welded steel tubes production are described: poka-yoke preventing usage of the non-correct rollers and poka-yoke preventing undesirable interchangeability and loss of the production dispatch notes.

2. DESIGN OF COMPLEX METHODOLOGY OF POKA-YOKE IMPLEMENTATION FOR METALLURGY

The design of the methodology of poka-yoke implementation is based on three principles (see subchapter 2.1) and consists of 5 steps (see subchapter 2.2).

2.1 Principles of the designed complex methodology of the poka-yoke implementation

The designed methodology is based on the following principles: 1. principle of planning and prevention; 2. understanding poka-yoke as a change and innovation; 3. deployment of poka-yoke as a change and innovation management.

For the conditions of the modern manufacturing system based on the synergic effect of the lean, agile and resilient approaches the poka-yoke system preventing mistakes identified in the phase of the planning the production process is the only acceptable form (see **Figure 2**). Very suitable method for realization of principle 1 is the modified FMEA (see chapter 3).

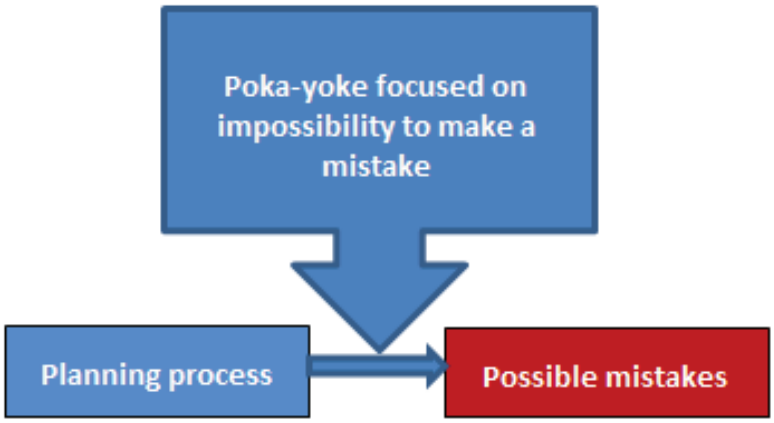

Figure 2 Principle of poka-yoke suitable for the modern combined manufacturing systems (own source)

Poka-yoke could be considered an operating change in processes, technology and projects [5] as it is some mechanism or equipment that enables to prevent workers or production equipment doing mistakes (principle 2). Management of this change represents a set of actions and processes that enable smooth change in system incorporating technology and people (principle 3). Poka-yoke as a change must be considered to be a process innovation.

2.2 Steps of the Complex Methodology of Poka-Yoke Implementation

In this subchapter there are described particular steps of the designed methodology: 1. identification of all potential risks; 2. giving reasons for suitability of the poka-yoke implementation; 3. selection of the poka-yoke type; 4. design verification and its realization; 5. description and documentation.

Step 1 Identification of all potential risks

The main goal of step 1 is definition of all potential mistakes that can be done in the planned process and their risks (negative effects) including also possibility to produce nonconformities. It can be realized through the realization of very simple well-known approach - brainstorming. But very effective method for this analysis is FMEA in the modified form which was designed in the frame of [5]. As compared to the conventional process FMEA the central object of the modified FMEA is not potential nonconformity (defect) but the potential mistake (error). The first step in the modified FMEA is defining all possible mistakes that can occur during the process steps. The next step is an analysis of the effect of these possible mistakes. After that the causes of the mistakes are defined and suitable poka-yoke or other mechanisms to prevent such mistakes are designed.

The modified FMEA serves for the evaluation of severity (SM), occurrence (OM) and detectability (DM) of the mistakes. It is designed to use 5-points scale - see **Tables 1 - 3** [5]. The severity of mistake is evaluated from the point of view of the amount of harm or damage the mistake may cause to a product or a process and its elements. Expected mistake occurrence is expressed by probability of the mistake occurrence in the planned process and detectability means likelihood of the mistake detection. Every possible mistake is evaluated using the risk priority number RPNM which is computed using the following formula:

$$RPNM = SM \times OM \times DM \quad (1)$$

Based on RPNM every mistake must be judged using **Table 4** [5].

Table 1 Evaluation of occurrence of possible mistakes in modified FMEA

Probability of mistake occurrence	Rate	Rating
High - the mistake can occur very often	1/200	5
Medium - the mistake can occur often	1/1000	4
Low - the mistake can occur in a smaller rate	1/3000	3
Very low - the mistake can occur very rarely	1/7000	2
Improbable occurrence of mistake	0	1

Table 2 Evaluation of mistakes severity

Severity of mistake		Rating
Impact on manufacturing process	**Impact on customer**	
Endanger - mistake can put operator in danger or it can result in endanger product defect	Endanger - mistake can result in product defect that endangers customer safety and violates regulations	5
Serious - mistake can put operator in danger or it can result in serious product defect	Serious - mistake can result in the defect that endangers customer safety but it do not violates regulations	4
Medium serious - mistake can result in the defect causing possibility to scrap some part	Medium serious - mistake can result in the nonconformity, the product is functional but it it does not fit the customer requirements	3
Nearly none - mistake can have minimal impact on the birth of the product defect	Insignificant - negligible mistake resulting in the nonconformity which can be noticed by 50% of customers	2
Improbable - the influence of mistake cannot be noticed	No impact	1

Table 3 Evaluation of the likelihood that the mistake will *not be* detected

Probability of the mistake detection	Rating
Insignificant - mistake that will be detected during the long-term stability testing	5
Very low - the mistake could not be detected visually	4
Low - mistake that could be detected with difficulty	3
Medium - easily detected mistake	2
High - mistake that will be certainly detectable	1

Table 4 Interpretation of RPNM

RPNM	Risk characterization
1 - 30	Acceptable risk - process and procedures are out of danger
31 - 50	Moderate risk - process is out of danger conditioned by the operators training or inpections with higher frequency
51 - 90	Undesirable risk - application of protective actions
91 - 125	Unacceptable risk - urgency of application of protective actions

Step 2 Justification of the poka-yoke implementation suitability

Based on the results of the modified FMEA there must be decided if Poka-yoke as a protective action will be effective solution. Poka-yoke can be effective is the case of random nature of the mistake when 100 % control is a suitable form [5] of the process control and the cost of this measure will be acceptable.

In conditions of the modern agile manufacturing conditions Poka-yoke is suitable to apply in the following possible cases [5]**:** wrong equipment adjustment or incorrect instruments application; incorrect mearsurement process; nincorrect important part of the product; missing parts of the products; nincorrectly excecution of some operation.

Step 3 Selection of the poka-yoke type

The next step is the selection of a suitable type of Poka-yoke which will enable to prevent making mistakes defined in the step 1. It could be Poka-yoke preventing mistakes such as process step omission, erroneous assembling, wrong fixing of workpiece, missing parts, wrong part processing, wrong operation performing, equipment nonadjusting, nontightened part.

If it is possible, several variants of the solution should be designed.

Step 4 Verification and implementation of poka-yoke

Then verification and implementation of Poka-yoke will follow. Each of designed variants (see the previous step) must be evaluated from the point of the technical and economical point of view and the best one will be chosen and realized at first in the frame of testing mode. When the testing mode will show that the selected solution prevents making related possible mistake, it can be incorporated into the process design.

Step 5 Description and documentation of poka-yoke

Description and documentation of the poka-yoke is the last step of the designed methodology. This documentation must be an inseparable part of the documentation of the designed process.

3. SELECTED APPLICATIONS OF POKA-YOKE ON THE PRODUCTION OF WELDED STEEL TUBES

In this chapter there are described two cases of application of the designed methodology on the tubular products manufacturing: poka-yoke preventing usage of the non-correct rollers and poka-Yoke preventing mistaking or loss of the production dispatch notes [5].

3.1. Poka-yoke preventing usage of the non-correct rollers

Step 1

Usage of the non-correct rollers for production of tubes was defined as very serious mistake that occurs especially when new employees start to work. Present marking of the type of the roller has not been sufficient. The risks related to this mistake were defined as follows: production of product that does not fit customer requirements; loss of reputation, loss of customers and high costs.

Step 2

This mistake can occur randomly. For that reason it is suitable to watch every selection of every roller using some low cost solution - Poka-yoke.

Step 3

Two low cost preventive solutions were designed [5]:

- implementation of the new marking the rollers;
- modification of instructions for fixing rollers into the stands.

Step 4

Both proposals were assessed from the point of view of technical and economical viewpoints. The first proposal was rejected. It was unsuitable to mark every individual roller as it was reccommended because it is not economically advantageous to use some set of the rollers only for a certain produced dimension.

Modified working instructions were considered to be effective way to protect selection of incorrect roller. As compared to the present instructions the proposal have supposed digital form, additional visual form of instruction and more precise information about application of the correct roller. This Poka-yoke was verified during one month period and the effectivity of this measure was proved. No complaint for the incorrect dimensions of tubes caused by usage of the incorrect rollers has appeared. It has ment no cost due to this nonconconformity as compared to 12 400 € related to 8 complaints during last 3 months before testing the proposal [5].This economical assessment have supported acceptance of the proposal.

Step 5

The new working instruction was made and introduced into the practice.

3.2. Poka-Yoke preventing loss or mistaking the production dispatch notes

Step 1

Mistaking or loss of the production dispatch notes was defined as another undesirable mistake that can occur after taking this document from the steel roll and before inserting information from it into PC. The way of ordering the dispatch notes before their uploading into PC can lead to the mistaking or loss of them. There is the risk that uploaded information will not correspond to the related part of the steel roll that is actually coiled on the machine and will be actually processed. It can embarrass searching for causes of prospective nonconformities on the processed rolls. And it can result into the time and financial sources waste.

Step 2

This mistake also can occur randomly. For that reason it is suitable to apply some low cost solution - poka-yoke.

Step 3

Three preventive solutions were designed [5]: implementation of the new way of storing the dispatch notes using small bayonet; application of QR code into the dispatch note; change in the organizaton of material coiling.

Step 4

Usage of bayonet where the dispatch notes are sticked in the right order was accepted as the short-term solution. Benefits and weaknesses of this solution were defined because the economic assessment was difficult to do. Verification proved the bayonet usefulness. This solution enabled to identify the original roll for the reason of the complaint very quickly. QR codes and the change in the organization of coiling the rolls were accepted as a long-term solution.

Step 5

Workers were trained to use this Poka-yoke and it was implemented into the strandard conditions of the process.

4. CONCLUSION

This paper dealt with design of the complex methodology for poka-yoke implementation in the conditions of the modern combined manufacturing system based on the synergic effect of the lean, agile and resilient approaches. The methodology is based on three principles: 1. principle of prevention; understanding poka-yoke as a change and innovation; implementation of poka-yoke as a change and innovation management. In the paper there are described particular steps of the designed methodology: 1. identification of all potential risks; 2. giving reasons for suitability of the poka-yoke implementation; 3. selection of the poka-yoke type; 4. design verification and its realization; 5. description and documentation. In the last part of the paper two cases of implementation of the designed methodology in conditions of the tubular products manufacturing are described.

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