5 A METHOD TO COMPLEMENT PRODUCT REQUIREMENTS LIST TO DESIGN FOR A POKA-YOKE ASSEMBLY-DFPYA

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DFPYA is an approach focused in prevents assembly failures or issues since early design stages by identifying the potential assembly issues that product can experience based on customers and professional assembly expectations during overall life phases of a system. This work propose a method to structure the DFPYA approach in clusters, defining the connections among elements of each cluster in order to perform a qualitative evaluation since product planning and clarifying the task stage to organize and synthesize the applicable poka-yoke assembly design requirements to product been developed and based on this analysis to prepare a requirement list matrix to complement the general requirement list document of the product.

Keywords: Poka-yoke assembly, Life phases of a system, Mechanical products, Quality assembly issues or failures, Design process, Manual assembly.

1. INTRODUCTION

The poka-yoke or error proofing technique developed by Shigueo Shingo has been successfully used to reach zero defects on many companies,[1] this technique help to prevent the occurrence or detect on time defective parts during manufacturing or assembly processes; these improvements are possible by means of product or process design changes.[2]

Even poka-yoke redesigns can be considered as efficient way to eliminate quality defects it can be more efficient if instead of redesign product, after experience product rejections or customer complaints, it is evaluated since early design stages the potential defects, failure, rejections, complaints etc., that can occur in the type of product been developed in order to aid designers to anticipate to these issues and make appropriate poka-yoke decisions oriented to prevent them.

This research is focused in assembly issues due to they represent a significant proportion of quality defects in many companies.[3] In order to prevent quality assembly issues since early design stages it was developed in previous works an approach "Design For Poka-Yoke Assembly-DFPYA"; details of this approach is described in Section 4.

This work proposes a method to structure the DFPYA approach elements to perform a qualitative evaluation since product planning and clarifying the task stage to organize and synthesize the applicable poka-yoke assembly design requirements to product been developed and based on this analysis to prepare a requirement list matrix to complement the general requirement list document of the product.

The requirement list is an essential document for designers to state the design specifications of the product[4] and it is important to define in this document that product been developed is potential to present specific quality assembly issues.

Poka-Yoke assembly design requirements (Rx) Classification	
PRODUCT ARCHITECTURE DEFINITION *Define modular product oriented to be safety and easy assemble and disassemble product to:* R1. Inspect and test product during assembly operations. R2. Change product configuration and give maintenance to product. R3. Remove modules for recycling or further use.	**TYPE OF MATERIAL SELECTION** *Select parts material properties oriented to:* R4. Resistance to assembly devices. R5. Be flexible to easily insert parts by hand.
PART FEATURES DESIGN *Design features in parts oriented to:* R7. Just correct assembly is possible due to matting faces design. R8. Be used by poka-yoke detection devices. R10. Do not look symmetrical when they are not. R11. Bring stability to part face in contact with assembly device. R17. Integrate alignment specification into dimensions of parts.	**FASTENING METHOD SELECTION** *Design parts oriented to:* Comply with: R1, R2 and R3. R6. Integrate small parts in bigger parts to reduce quantity. R9. Use appropriate fastening methods to reduce effort for manual assembly.
TOLERANCE ALLOCATION *Allocate tolerance in parts considering the following:* R14. Not excessive effort to manual parts insertion. R15. Comply to alignment specifications. R16. Variations of materials during life cycle stages.	**ASSEMBLY SEQUENCE** *Design assembly sequence in order to:* R12. Assemble small parts after free access are enclosed. R13. Assemble a part after assure that other assemble operations will not damage it.

Figure 1. Classification and brief definition of poka-yoke assembly design requirements-R_x.

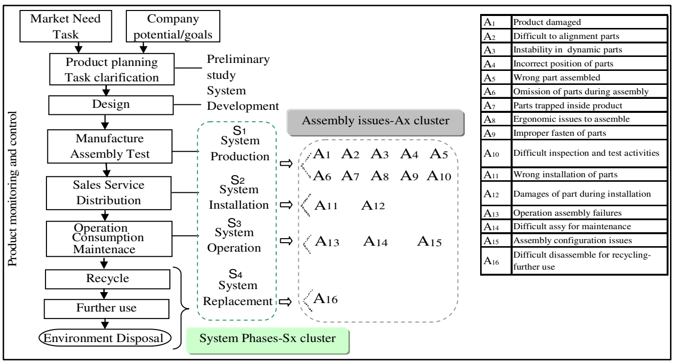

Figure 2. Design within the framework of Guideline VDI 2221 as part of the life phases of a system describing A_x and S_x clusters.

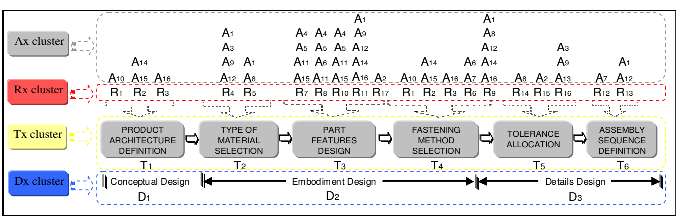

Figure 3. DFPYA approach describing A_x, R_x, T_x and D_x clusters.

2. RESEARCH METHOD

The DFPYA approach developed in previous works[5,6] was translated as a “1” and “0” matrix of connections among elements of the five key parts that conform this approach these are: life phases system phase, quality assembly issues, poka yoke assembly design requirements, type of design decisions and design stages; these key concepts were defined as clusters (see Figure 2 and (3). In order to visualize how elements of these five clusters are connected it was realized a tree diagram (see Figure 4) and then based on DFPYA approach it was represented these connections in a document called DFPYA guide matrix, see Figure 5 and Figure 9 (B).

After define the DFPYA guide matrix it was analyzed the systematic approach of design process by Pahl and Beitz that proposes how to elaborate a requirements list during product planning and clarifying the task stage; this analysis was used to identify activities that are needed to incorporate the analysis of DFPYA approach into requirement list process, see Figure 6 and 7 and example showed in Figures 8 and 9.

3. DESIGN FOR ASSEMBLY ORIENTED TO REDUCE QUALITY ISSUES

There are several DFA approaches that help to reduce assembly quality issues, these are following described.

Das propose an approach to evaluate in a product which components have more possibilities to present aq-issues based on key product design factors, these are: (i) factor variables and (ii) influencing factors.[7] Booker defines two main causes that impact on final assembly quality of product (i) components design decisions and (ii) assembly technology selection; these authors assign a value to different type of decisions made in a component design, for example it is asked if a specific component can be assembled in a wrong way, if the answer is "yes" the value is 2.0 and if the answer is "no" the value is 1.0, at the end of the analysis components with higher value means that need to be redesigned.[8]

The AREM approach proposed by Suzuki[9] use an evaluation formula constructed on a fault occurrence model, this approach discusses the variance of assembly operations such as component position and joining. When variance is larger than allowed for the product structure or assembly process, a fault occurs. This method is used to evaluate the quality of product design from an assembly reliability point of view.

Design For Assembly-DFA[10] considers assembly aspects since product design stage, but it is mainly oriented to increase productivity during assembly process, although in DFA are proposed guidelines that offer some benefits to avoid assembly defects specially on manual assembly it does not make emphasis in how to avoid specific quality assembly issues presented in overall product life cycle stages.

Another important contribution is proposed by Gv̈ngör that even is not focused in design for assembly quality it contributes to prevent specific quality assembly issues; this author proposes a model to evaluate alternative connectors that helps designers to make better decisions when selecting product connectors.[11]

Design For Poka-Yoke Assembly-DFPYA proposes an approach to identify potential quality assembly issues since clarifying the task stage and also establish poka-yoke assembly design requirements referenced as R_x that guide designers to think in poka-yoke solutions to orient product design to prevent specific potential quality assembly issues that can be experienced in the overall life phases of a system.[5,6]

4. DFPYA APPROACH AND THE QUIDE MATRIX

DFPYA approach consists in guide designers to identify the potential quality assembly issues-A_x that can occur during the life phases of a system-S_x, then for each assembly issue identified as potential it is proposed a poka-yoke assembly design requirement (listed on Figure 1) from a list of seventeen-R_x that indicates how a specific type of design decisions-T_x during process design stages-D_x can be oriented to prevent the potential A_x by complying with the proposed R_x. The purpose of DFPYA guide matrix is to summarize all connections among elements of S_x, A_x, R_x, T_x and D_x. The steps performed to elaborate the DFPYA guide matrix are described in 4.1, 4.2 and 4.3.

4.1. Definition of Clusters

To realize the DFPYA guide matrix it was defined five clusters; there are two clusters with specific elements clearly defined by the approach, these are the sixteen quality assembly issues referred as A_x and the seventeen poka-yoke assembly design requirements referred as R_x the other three clusters are: S_x cluster that correspond to the four life phases of a system where a product can experience physical assembly issues, T_x to define the six different type of design decisions that are made during design process and the three design stages after planning and clarifying the task stage is defined as the D_x cluster, see elements of each cluster in Figures 1, 2 and 3.

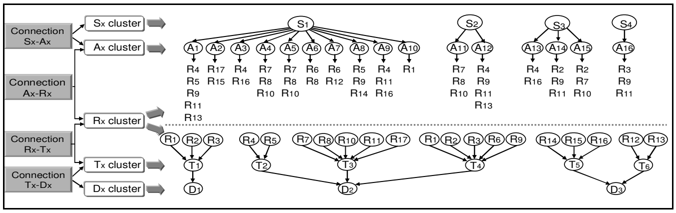

Figure 4. Tree diagram to represent connections among elements in S_x, A_x, R_x, T_x and D_x clusters based on DFPYA approach.

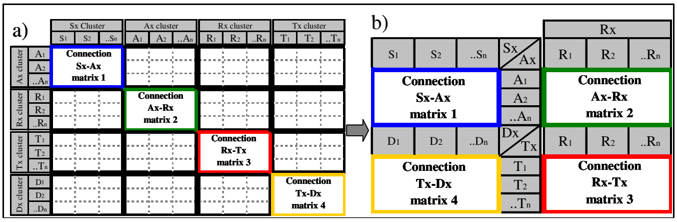

Figure 5. (a) Matrix of clusters connections based on DFPYA approach; (b) Structure of matrix results based on DFPYA approach.

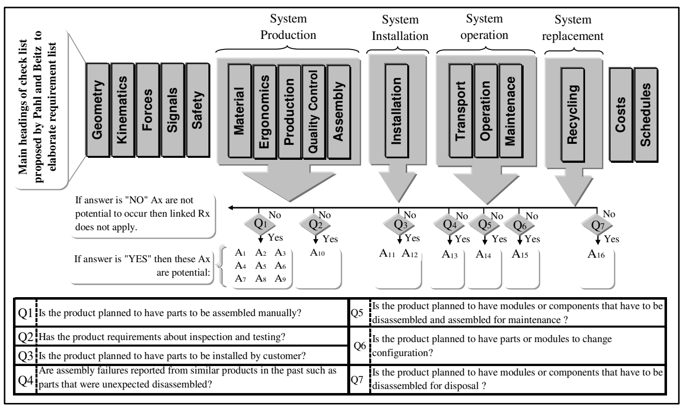

Figure 6. Pahl and Beitz method of compiling a requirements list including additional steps to integrate poka-yoke assembly design requirements.

4.2. Relation Among Elements in DFPYA Clusters

In Figure 4 is showed in a tree diagram the five DFPYA clusters are their connections among them, in this diagram is showed first the S_x cluster because the first step to execute DFPYA approach is identify for each life phase of a system the potential assembly issues; then for each system phase is defined the assembly issues that can happen.

For each assembly issue it is listed the elements of the R_x cluster that help to prevent the specific assembly issue. Once designers know which R_x has to be considered then they need to know when, during the design process stages, is the best moment to comply with them; for this reason the elements of R_x cluster are showed for second time in the diagram (Figure 4), this time the elements of R_x cluster are classified by the type of design decision that is associated to. These six of design decisions conform the T_x cluster which it is also classified according to the design stages-cluster D_x where these decisions are made during design process. See Figure 4.

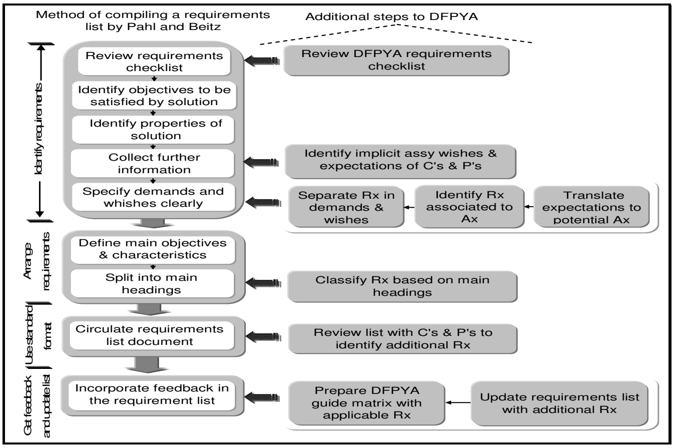

Figure 7. DFPYA Check list to elaborate a requirement list for new product development.

4.3. Clusters Connections Matrixes

The four connections showed in Section 4.2 and Figure 4 are described now as connections matrixes where 1 means there is a connection and 0 it is not. In Figure 5 (a) is described a general matrix where it is described in rows and columns the five clusters and their elements in order to visualize which clusters are connected to other clusters.

Based on DFPYA approach represented as a tree diagram in Figure 4 there is a connection among S_x and A_x cluster; this connection is referred as matrix 1; connection A_x–R_x by matrix 2, connection R_x–T_x by matrix 3 and connection T_x–D_x by matrix 4. See Figures 4 and 5. In order to summarize these four matrixes in one general matrix it is proposed the array showed in Figure 5 (b).

Connection S_x and A_x clusters is matrix 1; the character “1” is assigned to A_i that according to DFPYA approach a specific A_i is potential to be experienced in a specific S_i; a “0” is assigned to represent that an issue A_i is not potential to occur in a S_i. Connection A_x–R_x clusters is matrix 2; in this matrix is represented the applicable R_i that are able to prevent a specific A_i. Connection R_x–T_x clusters is matrix 3; this matrix represents which poka-yoke assembly design requirements-R_x cluster correspond to a specific type of design decisions T_x-cluster. Connection T_x–D_x clusters is matrix 4; this connection establishes that there are six types of design decisions that designers made during design process and according to Pahl and Beitz systematic approach [4] those types of decisions belong to a specific design stage-D_i.

5. THE REQUIREMENT LIST PROCESS ORIENTED TO DFPYA

In order to define how poka-yoke assembly design requirements can be incorporated during the elaboration of the requirement list of a product been developed it was analysed the method of Pahl and Beitz that describes the format, check list and steps that are used to prepare a requirement list.

5.1. Requirement List Process by Pahl and Beitz

Pahl and Beitz propose a method to elaborate a requirement list, it consists in four general steps: (i) identify the requirements, (ii) arrange the requirements in clear order, (iii) enter the requirement list on standard forms, iv) examine objections and amendments;[4] this process was analyzed in order to identify how DFPYA approach can be integrated.

5.2. Approach

Based on previous analysis of method proposed by Pahl and Beitz to compile a requirement list it was represented in the Figure 7 each phase of this method and the specific task proposed by these authors. In this Figure it can be observed at left the Pahl and Beitz method and at right the additional proposed steps to orient the task clarification design stage to design for a poka-yoke assembly.

In last sections were mentioned what it is needed to orient the requirement list method to DFPYA approach; these steps are:

1. Review DFPYA requirements check list: See as reference the main headings on check list showed in Figure 6.
2. Identify implicit assembly wishes and expectations of customers and professionals (C's & P's), to perform this task it is suggested to ask the seven questions specified in Figure 6, if the answer is yes, then potential assembly issues-A_x linked to that question will be translated in step (3) as a quality assembly issue-A_x and if answer is No, then any quality assembly issue linked to this expectation will be considered as potential.
3. Translate expectations to potential A_x: Identify which A_x are linked to each question in Figure 6.
4. Identify R_x associated to A_x: Specify in the DFPYA guide matrix (see Figure 5 and example on Figure 9 (B) the applicable requirements based on linked A_x identified in questions answered as affirmative in step (2) and (3). For those A_x where answer was "No" it will be described in the DFPYA matrix, in all cell of the corresponding A_i row, as "0" or cancelled connections row in order to express that linked requirements-R_x do not need to be complied.
5. Separate R_x in demands and wishes: Evaluate based on experience of previous products and severity of consequences in case of potential A_x occur. Pahl and Beitz propose a layout of requirement list where there is a "D_W" column to specify if a requirement is considered as wish to put a 'W" and a "D" if considered as demand.
6. Classify R_x based on main headings: See proposed classifications stated in Figure 6.
7. Review list with customers and professionals and corresponding departments involved to identify additional R_x.
8. Update requirement requirements list with additional R_x: If departments involved identify an additional assembly expectation that can be translated to specific A_x then the row of this A_i should be activated with the corresponding connections linked to A_x–R_x.
9. Prepare DFPYA guide matrix and requirement list format. Review the DFPYA guide matrix and assure all applicable poka-yoke design requirements were stated in the requirement list format.

6. CASE STUDY

In this Section is showed an example about how this approach can be implemented in an industry. This Company develops and manufactures precision slides for several types of applications; the most common application of the slides that this company designs is in drawers to facilitate to close and open the drawer of kitchens, desks and oven racks in stoves also in the automotive industry for the arm rest device of cars.

Company procedures show that a requirement list is elaborated based on eight key characteristics, these are: (i) application of the product, (ii) size of drawers-slide, (iii) maximum load, (iv) materials and finish, (v) Open / Close mechanisms, (vi) environment during application, (vii) specifications of durability test, (viii) selection of series to manufacture the slide. In Figure 8 is represented an example of check list that shows the eight items described before; the items that correspond to actual company practices are A, B, C, D, E, J, L and M. This example shows also the items that were added to implement the DFPYA requirement list approach; these items are F, G, H, I, K and N. In Figure 9 (A) is showed the seven questions described in Figure 6; these seven questions are integrated as part of the check list used by the Company to elaborate a requirement list for NPD project. The four items added as part of DFPYA approach are: (F) assembly, (G) quality control, (H) installation, (I) product operation and maintenance and (K) recycling. In each new item are describing the corresponding questions Q_x that

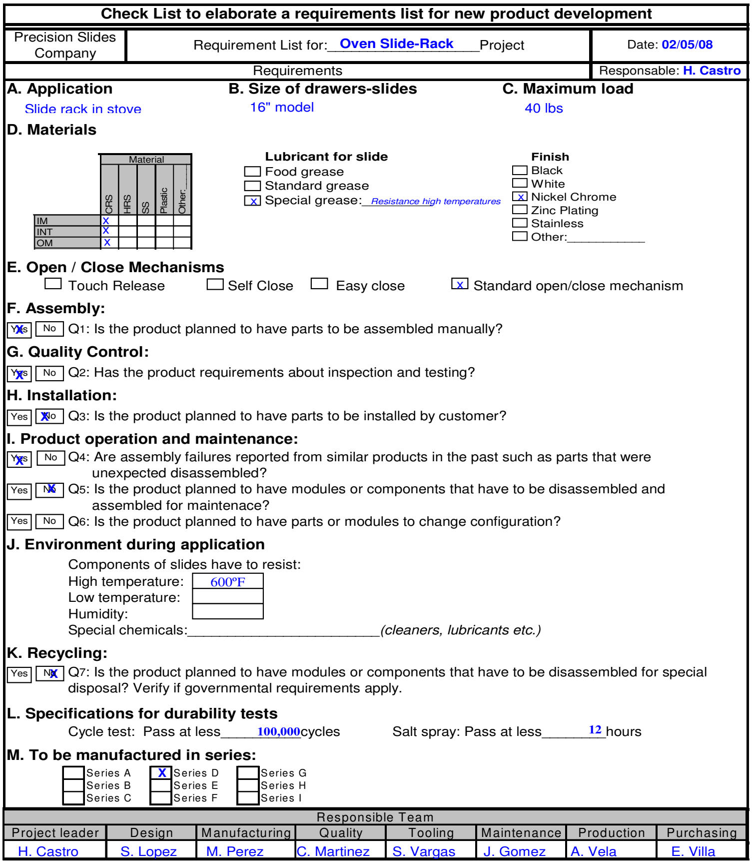

Figure 8. Main headings of check list proposed by Pahl and Beitz adapted to identify potential assembly issues by asking seven questions.

help to identify the potential quality assembly issues that are potential to occur in the product being developed therefore it can be identified the applicable R_x linked to potential A_x.

In Figure 9 is described an additional sheet that is proposed to complement the design requirements check list showed in Figure 8 to comply with DFPYA approach. This attachment has two sections; Section A) oriented to respond the seven questions, if answers to Q_x is yes it means that corresponding A_x are potential to occur in the product therefore designers must pay attention to comply with corresponding R_x. There are some cases where several questions are linked to same R_x it means that same requirement can be used in different ways to prevent more than one A_x.

7. CONCLUSIONS AND FUTURE WORK

DFPYA is a guide that identifies during the first design stage the possible actions or opportunities that can be incorporated by the poka-yoke assembly design requirements-R_x in order to implement them in the product in a proper design stage. The DFPYA approach is oriented to anticipate and identify the need of issues that can become later in poka-yoke redesigns but anyway this approach can also be applied in later stages but if this approach is used before then the need of poka-yoke redesigns will be reduced; if companies start using this DFPYA approach in each new product development projects each time will be more efficient; the challenge is to eliminate the redesigns in later stages.

A) Check list to identify applicable Rx

Rx	If apply mark ✓	Qi	Potential Ax linked if Qi is "Yes"
R1	☑	Q2	A10
R2	☐	Q6	A15
R3	☐	Q7	A16
R4	☑	Q1	A1, A3, A9, A12
R5	☑	Q1	A1, A8
R6	☑	Q1	A6, A7
R7	☑	Q1	A4, A5
	☐	Q3	A11
	☐	Q6	A15
Ri	☐	Qi	Ai

(Rx apply if answer to *Qi* is "Yes")

B) Guide matrix to identify applicable Rx to potential Ax

S_1	S_2	S_3	S_4	Sx \ Ax \ Rx	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_i
1	0	0	0	A_1	0	0	0	1	1	0	0	0
1	0	0	0	A_2	0	0	0	0	0	0	0	0
1	0	0	0	A_3	0	0	0	1	0	0	0	0
1	0	0	0	A_4	0	0	0	0	0	0	1	0
1	0	0	0	A_5	0	0	0	0	0	0	1	0
1	0	0	0	A_6	0	0	0	0	0	0	0	0
1	0	0	0	A_7	0	0	0	0	0	1	0	0
1	0	0	0	A_i	1	0	0	0	1	0	0	0

D_1	D_2	D_3	Dx \ Tx \ Rx	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_i
1	0	0	T_1	1	0	0	0	0	0	0	0
0	1	0	T_2	0	0	0	1	1	0	0	0
0	1	0	T_3	0	0	0	0	0	0	1	0
0	1	0	T_4	1	0	0	0	0	1	0	0
0	0	1	T_5	0	0	0	0	0	0	0	0
0	0	1	T_6	0	0	0	0	0	0	0	0

Figure 9. DFPYA Check list to elaborate a requirement list for new product development.

This approach helps for those redesigns oriented to solve assembly issues but similar methodology can be used to prevent other type of redesigns. A future work of this research is to develop an integral methodology able to prevent all type of redesigns in later stages.

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