INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITÉ DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

AN APPROACH TO AVOID QUALITY ASSEMBLY ISSUES SINCE PRODUCT DESIGN STAGE

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ABSTRACT
Even poka-yoke is a useful technique to avoid fabrication and assembly issues by means of product and process design changes, it is commonly used in later stages of product development when fabrication and assembly issues had been already faced during mass production or even worst in the product operation stage. The final purpose of this research is systematize the poka-yoke technique to make possible apply this technique since early stages of product development to assist designers to avoid specific assembly quality issues during design process. In order to comply with this purpose a classification and characterization of assembly issues was developed based on design within the framework of Guideline VDI 2221 as part of the life phases of a system. Then seven questions were formulated to be asked by designers during design process to support them identifying product design characteristics that require modification to avoid assembly issues; also seventeen design requirements were defined which have to be considered since early stages of product development to develop product design with specific characteristics that allow a poka-yoke assembly, this was possible by analyzing the causes of assembly issues associated to product design by using sources such as i) literature, ii) applying interviews and surveys to industry and iii) several examples of poka-yoke redesigns observed in literature and product development study cases in industries. As results of this paper it was developed an approach titled "Product Design Method for Poka-yoke Assembly (PDM-PYA)" to avoid quality assembly issues since product design stage.

Keywords: Poka-yoke design, quality assembly issues, manual assembly, mechanical product

1 INTRODUCTION
The assembly defects represent a significant proportion of quality defects in many companies [1]; to reduce these type of defects the Poka-yoke technique (error proofing) developed by Shigeo Shingo [2] to reach zero defects has been successfully used on many companies to avoid and detect on time specific errors that produce defective parts on manufacturing or assembly processes, these improvements are possible by means of product or process design changes [3]. Although the Poka-yoke concept and functions, types of poka-yokes have been defined [2], it does not exist a formal methodology that describes how to use Poka-yoke on a systematic manner [4], on DFA a detailed methodology is proposed to consider assembly aspects since product design stage, but it is mainly oriented to increase productivity during assembly process [5], 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. Generally the Poka-Yoke Technique is used after the product development process when the issues were already faced during production or even worst by final users during product operation stage, when this type of incidents occurs they have to be urgently solved, resulting in product or process redesigns.
The final purpose of this research is systematizing the poka-yoke technique by developing a methodology for the designers to be used since early stages of product design process. This methodology will cover the following aspects: i) detection of potential quality risks on product assembly, ii) detection and analysis of design characteristics associated to assembly quality issues, iii) utilization of Poka-yoke principles on product design oriented to avoid assembly quality issues, iv) product final assessment, from the perspective of quality potential assembly issues.

This work describes the first phase to systematize the poka-yoke technique oriented to avoid quality assembly issues, the aim of this first phase of the research is a) to define the different assembly quality issues, that commonly appear during the different stages of mechanical products life cycle and the b) main causes of these issues associated to product design, with the purpose of c) establish the requirements that designers have to consider to achieve a Poka-yoke design oriented to avoid quality assembly issues based on these results it was developed an approach titled “Product Design Method for Poka-yoke Assembly (PDM-PYA)” (section 7) which propose seven questions to be asked by designers that can be answered by using the developed classification of assembly issues (section 3), causes of assembly issues relation matrix (section 4) and design requirements (section 6).

2 METHODOLOGY RESEARCH

To ensure that this investigation consider the different assembly quality issues occurred after design stage, it was decided to analyze each of these stages to establish an assembly issues classification, to achieve this it was performed an analysis of the whole life cycle of a system [6], describing the actors according to definition of Prudhomme et al. 2003, that mentions that actors in the product life cycle stages are customers and professionals [7]. Based on a bibliographical analysis, study of product recall cases found in internet, interview and surveys to companies and investigation centres with experience on mechanical product development, it was identified for each stage the main assembly quality issues that are faced by customer and professionals on each stage of system life cycle, with the results obtained of this work it was possible to establish a classification of the assembly quality issues (see section 3, figure 1).
In addition, it was performed an analysis of the assembly quality issues causes that are associated to product design (section 4) and there were studied several examples of poka-yoke redesigns (section 5) in order to define the product design requirements for a poka-yoke assembly (section 6) and formulate specific questions that have to be answered by designer during design process to identify product design necessities oriented to avoid assembly quality issues (section 7).

3 QUALITY ASSEMBLY ISSUES

In this section are presented the activities performed to compile the specific assembly quality issues; based on identified problems it was established a classification according to type of assembly issues and the system life cycle stage where issues appears.

3.1 Identification of specific quality assembly issues

The criteria used to select the type of issues that are considered on this work as assembly quality issues are the following: i) to appear on mechanical products, ii) are caused by an incorrect manual assembly, iii) difficulties in any product life cycle stage associated with any product assembly or disassembly characteristic. Different type of source were consulted to find out what type of assembly issues are experimented in the different life cycle stage of a product, these are A: identified just in the literature (the author reference is specified for each assembly issue) C: Identified just in industries and CDEI[2], (marked with “X” for each case), B: identified in both type of sources A and C (the author reference and “X” mark is placed in those cases). See table 1.

Table 1. Quality assembly issues identified and corresponding source

No	List of Quality Assembly Issues	Type of source where issue was identified		
		A	B	C
1	Difficult to assemble and disassemble product for maintenance		[10]X	
2	Difficult to disassemble parts for recycling and/or further use	[9] [10]		
3	Improper fasten of parts		[8]X	
4	Incorrect assembly position of parts		X [2]X [3]X [8]X	
5	Omission of part(s) during assembly			
6	Product damaged			
7	Wrong part assembled			

8	Parts trapped inside the product		[11]X	
9	Difficult to realize inspection and test activities during assembly process		[12]X [13]X	
10	Assembly configuration issues			X
11	Difficult to alignment parts		[8]X	
12	Instability in dynamic parts			X
13	Damages of part during installation			X
14	Ergonomic issues to assemble parts			X
15	Product assembly failures			X
16	Wrong installation of parts			X

3.2 Quality assembly issues classification

Once it was compiled the greater quantity of possible quality assembly issues it was established a classification; in this classification 4 categories were defined based on the system life cycle stage where the assembly quality issues where faced, these are: i) system production, ii) product installation, iii) system operation, iv) system replacement. Different types of assembly issues were defined within these categories; some of these issues are subdivided also on more specific issues, for example, the type of problem that belongs to the issue category “system production” denominated as “assembly error causing defective parts”, it was subdivided in 5 specific issues such as: missing parts, parts in wrong position, parts trapped inside the assembly, etc. In the figure 1 is the classification established based on the system life cycle stages described in VDI 2221 norm [6].

Das et. al., 2000 defines a classification of quality issues occurred during assembly process, it consists on 6 defect types and each type identifies specific problems related to assembly [8]; on this classification is observed that are not differentiated the cases where a specific assembly issue was faced within or outside the company, this author is focused just is system production stage without considering the rest stages such as: product installation, system operation and system replacement.

It is important to separate the assembly quality issues according to the system life cycle stage where the issue is faced, Prudhomme et. al., 2003 emphasizes that according to concurrent design practices the needs of different actors that participate on each life cycle stage have to be considered, where notions are identified related to these needs: i) customer needs to express the customer expectations and professional needs to express the expectations of the people involved on the product life cycle [7]; based on this author [7] in this paper is considered a quality assembly issue if expectations and needs of the actors related to assembly aspects are not fulfilled by the product. This classification is necessary because in some cases issues can not be treated in the same manner because even an issue characteristics can seem the same assembly defect type; this can be faced on a different product life cycle stage, therefore the severity and the way to solve it is different, because it happens in different conditions. See figure 1.

3.3 Definition of assembly quality issues

3.3.1 System production assembly issues

A_1.-Product damaged

In this category is included those cases that due to the interaction between the faying surface of the product and the device used to perform the assembly operation some times components get damaged such as scratches, dents, blows, wearing downs, etc. causing defective products in appearance or even worst functional issues.

A_2.-Parts difficult to align during assembly

There are parts that have to comply with alignment specifications when they are assembled; this defect is observed when assembly operators have to perform many adjustments repeating several times same operations to the assembled part in order to satisfy alignment requirements.

A_3.-Instability in dynamic parts

Dynamic parts are referred to those parts that by a determined mechanism have to realize displacements or movements to execute a function during operation system stage; issues occurs when the trajectory that has to follow the dynamic parts do not comply with product specifications.

Assembly errors in parts or sub-assemblies:
This category includes (A4, A5, A6, A7) those issues that are presented during assembly process due to operator mistakes or assembly devices that frequently causes quality assembly defects; such as:
A_4.-Parts assembled in incorrect position: this issue occurs when a part is assembled in a position that does not correspond to the correct position of assembly product specifications.
A_5.-Wrong part assembled: this issue occurs when an assembled part does not correspond to the place where it was assembled.
A_6.-Missing parts in the product or sub-assembly: this defect appears when it is omitted to assemble a part that is necessary in the product according to the specifications of this.
More details about A4, A5, A6 see [8].
A_7.-Parts trapped within the product or sub-assembly: this kind of issue is faced when some part, especially small parts, accidentally falls in some cavities of a sub-assembly during the process without to be immediately detected resulting in a part trapped within the product, causing some times noise and/or functional issues. In the aerospace industry this type of defect is one of the main causes of FOD Foreign Object Damage [15].
A_8.- Ergonomic issues during assembly
This classification is related to those cases where parts were designed in a way that operators during assembly operations suffer some type of physical damage because they have to make an excessive effort and difficult movements to complete the necessary operations to assemble parts in the product.
A_9.- Improper fasten of parts
In this category is included those cases of assembly issues where two or more parts are not completely fixed or fasten during assembly operation, also include those cases that even parts were assembled according to assembly instructions they present a poor assembly due to inefficient parts design that does not allow to remain assembled during overall product life cycle stages causing loose or fallen parts in the product.
A_{10}.- Difficult to realize inspection and test activities. This includes those cases in which the parts and/or sub-assemblies of products can not be easily and efficiently inspected or tested during assembly process causing problems to operators to perform these activities and in worst cases do not detect product failures to inefficient inspection and tests and accept defective parts as good parts.

3.3.2 System installation assembly issues
A_{11}. Wrong installation of parts or sub-assemblies
This type of problem happens when the end users, with or without following the instructions of installation of product, they make by error an incorrect assembly of the parts, causing with this mistake that product does not work according to specifications; in worse of the cases causing serious damages to users when they start to use product.
A_{12}. Parts damaged during installation
This issue apply to those types of products that require to end user conducts certain assembly operations to complete product installation. The issue happens when responsible people to make the installation of the product with or without the aid of installation instructions they cause physical damages for example: scratches, deformations of parts, material cracks, etc.; to different parts involved in the operations of assembly.

3.3.3 System Operation assembly issues
A_{13}. Operation assembly failures
This issue is related to those cases of failures in the product faced by the end users; due to unexpected partial or complete disassembly in any product subassembly or component causing a non-desirable product operation. Note: Within this classification of issues there are only considered those cases in which the cause of unexpected assembly is due to product design because cases in which the failure is due to badly assembly of the parts is considered in section 3.3.1.
A_{14}. Maintenance assembly issues
This issue is related to the cases in which it is necessary to make activities of assembling and disassembling to give maintenance to the product during this operation stage, the problems start when i) performing the operations of disassembling it results difficult and confuse to people perform these activities causing by accident product damages or ii) when maintenance was finished and people try to

assemble the parts again it is difficult to put again parts correctly causing an incorrect assembly that it is not detected in that moment. If incident “ii)” occurs it can causes serious damages to end users.

A_{15}. Assembly configuration issues

In this classification are the issues experimented by users in the operation system stage, the issue occurs when they want to perform a different product configuration and they have to assemble or disassemble some module or part of the product but due to product characteristics they can not perform easily causing complications and or/ mistakes to complete correct configurations.

3.3.4 System replacement assembly issues

A16. Difficult to disassemble parts for recycling and/or further use:

This category describes those cases in which the product have to be disassembled to separate the parts that can be recycled or be reused; issue occur when it is complicated or impossible to people disassemble these parts with the conventional tooling and causing desired parts to be reused get damaged.

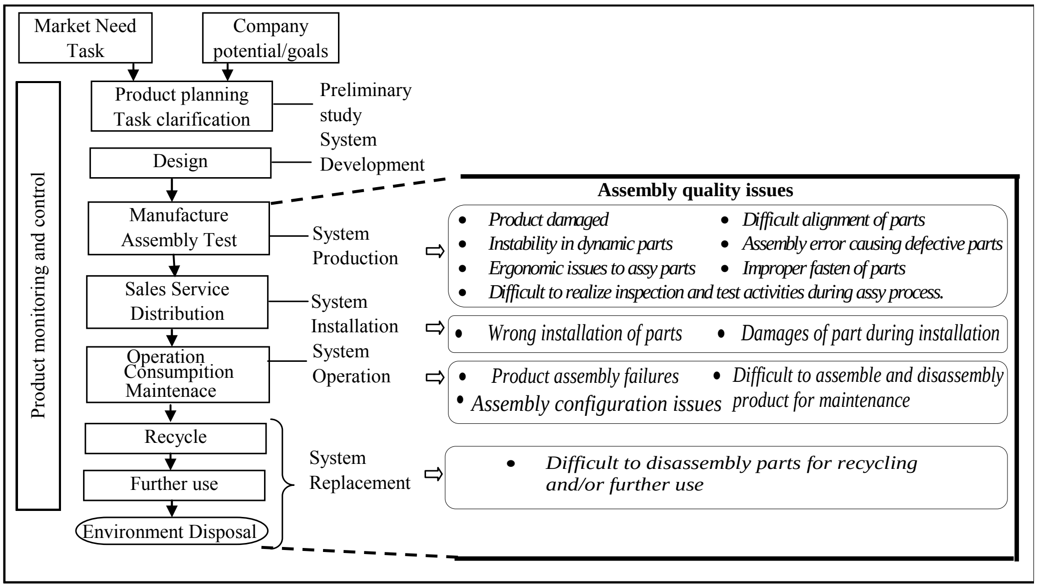

Figure 1. Design within the framework of Guideline VDI 2221 as part of the life phases of a system describing common assembly quality issues presented in each phase.

4 CAUSE ANALYSIS ASSOCIATED TO PRODUCT DESIGN

In this section the different assembly issues are analyzed in order to know the causes associated to product design that affect in the occurrence of this type of issues. The results of this study was based on the causes previously identified in literature for a certain problem of assembly, considering in addition, information of causes provided in interviews and surveys to CDEI[2] and industries.

Different decisions are made during the new product development process; many of these affect the occurrence of assembly quality issues, decisions related to design characteristics such as: product architecture, material type, part size [6] matting face, part features, type of fastening, part symmetry, contact surface between part and assembled device [2, 3, 5]; assembly sequence [11], tolerance allocation [14], design of parts with similar appearance.

Next are described each one of these characteristics of design and the most relevant of unhelpful decisions, that are taken during the design stage of the product and how they affect the occurrence of assembly quality issues.

C_1.-Product architecture: when the product architecture is integral it has a negatively effects in the capacity of the product to be inspected and tested also in the stage of system operation it affects in the accomplishment of its maintenance [13, 14]. Some products during their operation stage have to be configured of different manner by assembling and disassembling modules or parts but if the product architecture is not appropriate then difficulties for the user can happen. The product architecture is also associated with the accomplishment of a suitable disassembling of parts for its recycling, future use and/or environmental disposition [9].

C_2.-Material type: there are cases where product selected materials do not resist the handling, insertion and fastening operation during the assembly process causing damages on the surface such as scratches, dents or fractures; these are observed in examples in [3] and issues presented in industry. Some times friction between materials during the assembly operations execution has negative effects to obtain an appropriated fastening between the parts and/or ergonomic issues for assemblers in the case of manual assembly.

C_3.- Part size: when parts are very small compared to the rest of the parts of product these small parts can be trapped inside accesses or cavities formed in sub-assemblies or final product incidents like this can happen due to necessary handling activities to realize assembly operations. Another defects associated to small parts is A_6 "missing parts in the product", since it can be difficult to identify part absence due to small size.

C_4.- Matting face: the matting face is the part section that makes contact with another part to make a joint; when more than one matting face exists in a part and more than one manner to place the part exists but only one of these faces is the correct the possibility to make a mistake in the assembly increases [2, 8].

C_5.- Part features: the specific features in the parts are useful to i) differentiate them during the assembly process when they are very similar to each other, ii) to identify if a part is present or absent on the product, iii) to avoid the part to be placed on an incorrect position; actually is possible to find very efficient devices that are useful to detect the presence or absence of a given characteristic of the part, but it results very complicated to implement when the part does not contain features that can be used as reference by the detection devices, many examples related to this situation are observed in [2, 3]. Specific part features are also useful to bring stability in parts that will be in constant movement during its function.

C_6.- Assembly fastening type: A part can be fastened in different manners as shown in figure 2, the authors [5] ordered from "a" to "d" according to the increment of the manual assembly cost, but additional to the cost, there are another factors associated to fastening type, for example snap fitting, although is the one with lowest cost, if it is not designed properly and combined with the material type can be possible to be damaged during insertion and/or represent ergonomic issues to operators to insert it manually. Also if selected joint methods are: screws, rivets, nuts, washers, etc. they can increase the possibilities to present trapped parts inside the product or subassembly [11].

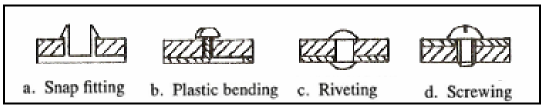

Figure 2. Example of fastening method [5]

C_7.-Parts Symmetry: one of the main causes of placing parts in incorrect position is due to parts seems to be symmetrical but they are not then apparent symmetry is difficult to operators notice the difference between the right position and the wrong one.

C_8.- Contact surface between part and assembly device: this characteristic includes also surface to disassemble product. Contact surface is the face used to support, insert and fasten parts during assembly operation or in the opposite case to disassemble the part; when there is not a support surface where device can be stable during assembly or disassembly activities it can occurs negative effects such as damages on parts and/or damages in aside parts due to device out of control also difficulties to perform the desired assembly or disassembly activities.

C_9.- Assembly sequence: There are parts (part B) that can damage other parts (part A) when they are assembled it can happen due to part B characteristics and impacts generated by manipulation, insertion and fasten of this part B but sometimes problem can be avoided if part A is assembled after assemble part B. Also it occurs that by errors small parts falls, during assembly operation, inside free access in sub-assemblies and the part remain trapped inside the sub-assembly; this type of mistake can be avoided if assembly sequence is defined in a way that small part is assembled when there are not free access in the sub-assemblies or products [11]. Other issue is when it is difficult to inspect or test a sub-assembly or product due to a part that was already assembled it is obstructing the access to perform properly these inspections and testing activities. Assembly sequence can also affect to assemble incorrect parts if two or more similar parts (P1, P2, P3) that can be inserted in a wrong place are in sequence without any other different part between them.

C_{10}.-Tolerances: component alignment is a critical factor and some times difficult to meet with the alignment specifications due to component tolerances are very wide and the alignment tolerance is very close. Also some times the allocated tolerances to parts could be very close and be inappropriate for manual assembly, this is demonstrated in a company where assemblers faced ergonomic issues and part damages due the excessive force needed to insert parts manually. Other implication is when tolerances are assigned without considering the variations that environment, or other factors, changes on materials during system life cycle stages; these variations could increase or decrease the size of a component and avoid that one part or module can be assembled correctly during the installation stage or could not be disassembled for maintenance.

C_{11}.- Design of parts with similar appearance: although this type of characteristic is implicit in some of the previous C_x such as matting face, part symmetry and part feature, it is defined by separate to emphasize the impact that it has in the occurrence of assembly quality issues; it is a common practice of designers to design different parts but with very similar appearance in size, shape, matting face, fastening method; one of the most common issues associated to these practices is assembling wrong parts by mistake on the product. The design of parts with similar appearance can occur in different level i) similar parts in the same product, ii) similar parts from a product that owns of the same model that are usually manufactured in same production line with different set-up, and iii) the most difficult to detect, similar parts between current product in development to previous products already developed that are been manufactured in the same company.

Matrix of relation between Quality Assembly Issues Axs and Design Characteristics Cxs

Relation of design characteristics associated to assembly issues occurrence: ● 9.High; ◉ 3.Medium; ○ 1.Low

	Quality Assembly Issues																	
	System Production										System Installation		System Operation			System Replacement	
	Product damaged	Difficult to alignment parts	Instability in dynamic parts	Incorrect assembly position of parts	Wrong part assembled	Omission of part(s) during assembly	Parts trapped inside the product	Ergonomic issues to assembly parts	Improper fasten of parts	Difficult inspection and test activities	Wrong installation of parts	Damages of part during installation	Operation assembly failures	Difficult to assemble/disassem. for maintenance	Assembly configuration issues	Difficult disassemble for recycling-further use	
Design characteristics	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	Impact level chart of design characteristics associated to the occurrence of assembly issues
C1 Product architecture										●	○		○	●	●	●	40
C2 Type of material	●		◉					◉	◉			●	●				36
C3 Parts size						●	●								○		19
C4 Matting face			●	●	◉						●						30
C5 Part features		●	●	●	●	●				●	●			◉	●	◉	78
C6 Type of Fastening	◉	●		◉			◉	●	●			◉	●	●	◉	●	69
C7 Part symmetry		○		●	●						●			◉	●		40
C8 Contact surface to assembly/disassemble	●	●		○					◉			●		●	●	●	58
C9 Assembly sequence	●				●		●			●	●	●					54
C10 Tolerances	◉	●	●					●	●			◉	●	◉	◉		57
C11 Similar appearance parts				●	●						●				●		36
Impact level chart of assembly issues that are negative affectted by design characteristics	33	37	30	40	39	18	21	21	24	27	46	33	30	36	52	30	

Figure 3. Relation between design characteristics and assembly issues.

5 ASSEMBLY POKA-YOKE REDESIGNS

Three poka-yoke redesigns are showed and analyzed in this section; redesigns that have been developed to solve a specific assembly issue. The purpose of this analysis is to understand how that redesign solution was developed since problem description to final redesign solution. With this analysis was possible to determine 7 questions that designers have to respond since design stage to identify if a design characteristic C_x needs to be changed in order to avoid the occurrence of assembly issues Ax.

Poka-Yoke example No. 1
Assembly issue: A_3 Instability in dynamic parts
Description of problem: Part A should be sliced over part B (in direction showed by red arrow) but sometimes part A unexpectedly go to different directions (see blue arrows) causing undesirable trajectory.
Description of poka-yoke redesign: In this case a feature was modified to reduce the matting face areas of Part A and B in order to reduce variation that cause displacements of Part A in undesirable directions, bringing with this change more stability between part A and B. See b) and d) in figure 4.

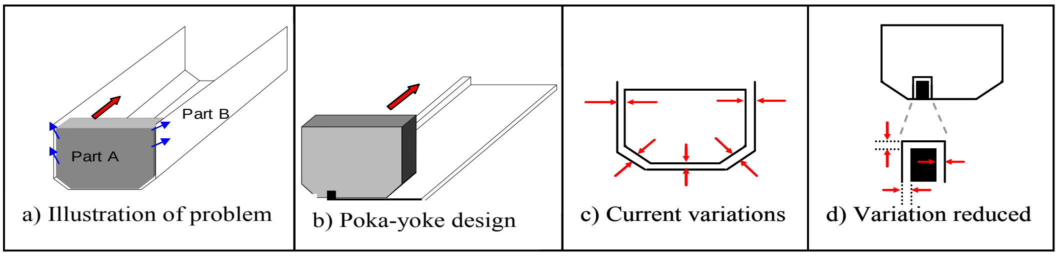

Figure 4. Poka-yoke redesign to avoid A_3 instability in dynamic parts

Poka-Yoke example No. 2
Type of assembly issue: A_2 difficult part alignment
Description of problem: The two grey bars A and B are assembled in part C, using screws to attach them. These parts A & B have to comply with specific parallelism specification but usually many adjustments on these bars have to be performed to comply with this specification. See figure 5 a).
Description of poka-yoke redesign: To avoid this issue a "poka-yoke part" was designed considering the parallelism specification, when this part is placed over part A and B it assures the correct distance between them. See figure 5 b).

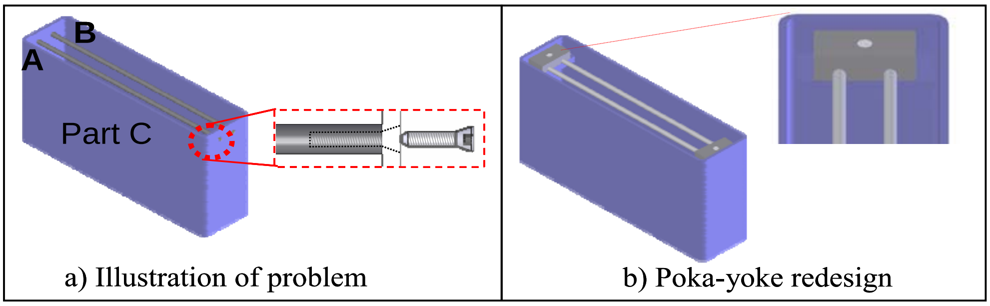

Figure 5. Poka-yoke redesign to avoid A_2 difficult part alignment

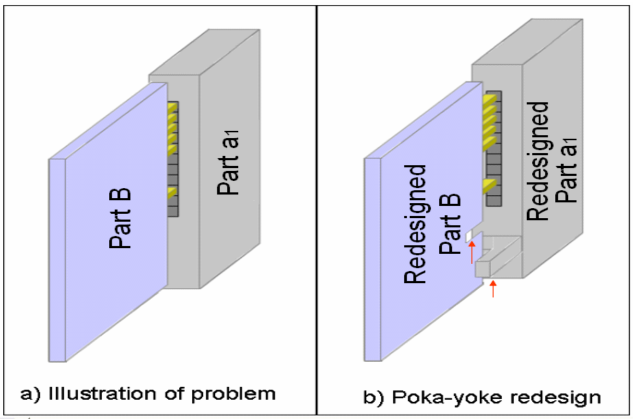

Figure 6. Poka-yoke redesign to avoid A_5 wrong parts assembled [3] and also can be applied to A_{11} wrong installation of parts.

Poka-Yoke example No. 3
Type of assembly issue: A_5Wrong part assembled
Description of problem: Quality defects due to products with wrong part assembled are very common in industry. In this example a part B is wrongly assembled in part a_1; in part a_1 should be assembled other different part that looks very similar to part B. See figure 6 a).
Description of poka-yoke redesign: To avoid that part B can be inserted in part a1 a special feature was added to both parts; with these features just the correct part can be inserted in part a1. See figure 6 b).

6 PRODUCT DESIGN REQUIREMENTS FOR A POKA-YOKE ASSEMBLY

As results of analysis performed in previous sections it was possible to determine the most common design requirements that are necessary to satisfy expectations of customer and professionals. The purpose of these requirements is to guide designers during design process to orient product development in order to minimize common quality assembly issues by following the poka-yoke philosophy. Following are described these design requirements (R_x) and in figure 7 is presented a matrix where is specified the quality assembly issues (A_x) and design characteristics (C_x) associated to that R_x requirement.

R_1: Conceptualize a modular product architecture focused to bring interfaces in modules that have to be inspected and tested during assembly operations.
R_2: Easy and safety for the user to change those modules that have to be disassembled and assembled to change product configuration and give maintenance to product.
R_3: Easy and safety for the user in system replacement stage to remove modules that will be recycled or taken for further use.
R_4: Material properties of parts used have to resist tensions, pressure etc, that will applied by assembly devices during system operation and installation stages.
R_5: Avoid use of materials that present excessive resistance to be assembled by manual method especially if the fastening method is snap fitting.
R_6: Integrate the function of small parts into another bigger part, to minimize the quantity of small parts; for example using the snap fitting fastening method instead of independent components such as screws, rivets, nuts etc.
R_7: Design features in mating faces in a way that just the correct assembly combination between mating face of part A and matting face of part B is physically possible; other possible wrong combinations can not been performed because the wrong matting faces does not match each other.
R_8: Design features on parts such as holes, shapes, slots, stops, etc. that can be used as reference by some detection device during assembly process to detect immediately if a part is present, wrong assembled or in incorrect assembly position.
R_9: To parts that will be assembled by manual methods use fastening methods that can be easily inserted in order to avoid damages and excessive fatigue to assembly operators.
R_{10}: Avoid parts that look symmetric when they are asymmetrical.
R_{11}: Stability between the part face that will be in contact with the assembly device.
R_{12}: Design assembly sequence to assemble small parts after free access in sub-assembly is enclosed.
R_{13}: Design assembly sequence to assemble part A after assembly part B which is potentially to damage part A due to manipulation of sub-assembly and devices during operations. Especially in products that will be installed by final users who do not necessary have the enough training to perform this activity.
R_{14}: Allocate tolerances considering the effort that has to be performed by the operator to assemble parts that will be assembled manually.
R_{15}: Allocate tolerances in parts that can comply to alignment specifications.
R_{16}: Allocate tolerances in parts considering variations that can experience material in the different life cycle stages of the product.
R_{17}: To those parts that have critical alignment specifications design specific features on those parts or design an additional part to physically bring the specification required. See example on figure 5 b).

Design Characteristics Cx	Quality Assembly Issues Ax															
	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}
C_1										R_1				R_2	R_2	R_3
C_2	R_4, R_5		R_{16}					R_5				R_4	R_{16}			
C_3						R_6	R_6									
C_4				R_7, R_8	R_7, R_8						R_7					
C_5		R_{17}		R_7, R_8, R_{10}	R_7, R_8	R_8					R_7					
C_6	R_9					R_6	R_6	R_9				R_9				
C_7				R_7	R_7						R_7					
C_8	R_{11}											R_{11}				
C_9	R_{12}						R_{12}					R_{12}				
C_{10}		R_{15}	R_{16}					R_{14}					R_{16}			
C_{11}																

Figure 7. Matrix of corresponding R_x for each C_x and A_x

7 RESULTS

Based on results of previous sections it has been observed that development process of a poka-yoke solution could be separated into different steps by asking and responding the following seven questions:

Q_1) Which assembly issues are potential to occur in the type of product been developed and in which life cycle stage they can happen? See classification of quality assembly issues in figure 1 to identify them.

Q_2) Which activities would be performed by the customer or professionals when problem could occur?

Q_3) How this activity has to occur in an ideal way to satisfy customer and professional expectations? Illustrate this situation elaborating a detail diagram explaining this “ideal” condition.

Q_4) How this activity in an ideal way could be interrupted, deviated or performed in a wrong manner? And which of these situations can affect in the occurrence of A_x? Realize diagram illustrating this undesirable conditions.

Q_5) Which type of design characteristic C_x is associated to this problem?. See relation matrix showed in figure 3.

Q_6) Which physical conditions in those parts involved can avoid that undesirable conditions observed in Q_4? Q_7) How C_x can be designed to bring these desired physical conditions that can avoid the A_x? See from section 6 design requirements applicable to this A_x.

The first input to this process start with the question Q_1 then the answer (output) for this question is the input to ask the next question Q_2 and the same process to next questions, by following this process of seven questions designers will be able to identify the design requirements from the seventeen established to orient product to avoid the quality assembly issues defined A_x. This approach called “Product design method for poka-yoke assembly” is illustrated in figure 8.

8 DISCUSSION

This approach offers to designers a tool to make an advance analysis of quality assembly issues that are potential to appear in the overall life cycle stages of product that is been developed and based on the seventeen design requirements R_x previously established in this work they can apply them to develop a product to avoid these potential assembly issues do not appear in the later stages.

The purpose of poka-yoke examples described in this paper is to give an idea to the designers about how it is possible to solve a specific assembly issue with a small change and how it can be possible since early product design stages, where is less expensive to realize it than do it in later stages when defective parts by such kind of issue cause rejections. By means of this approach it is desired to stimulate the creativity of the designers in order to make them develop and decide which type of characteristic is more adequate to design in the product based on their knowledge, capacities and limitations of the company.

The matrix of relation between C_x and A_x was developed according to literature and cases of companies that have experienced assembly problems; this matrix can be used as general reference but due to it can have variations it is suggested to adapt this matrix according to the specific necessities of the product in analysis, to perform this, it is necessary that involved equipment review and analyze these relations and determine which variations exists to perform a precise adaptation.

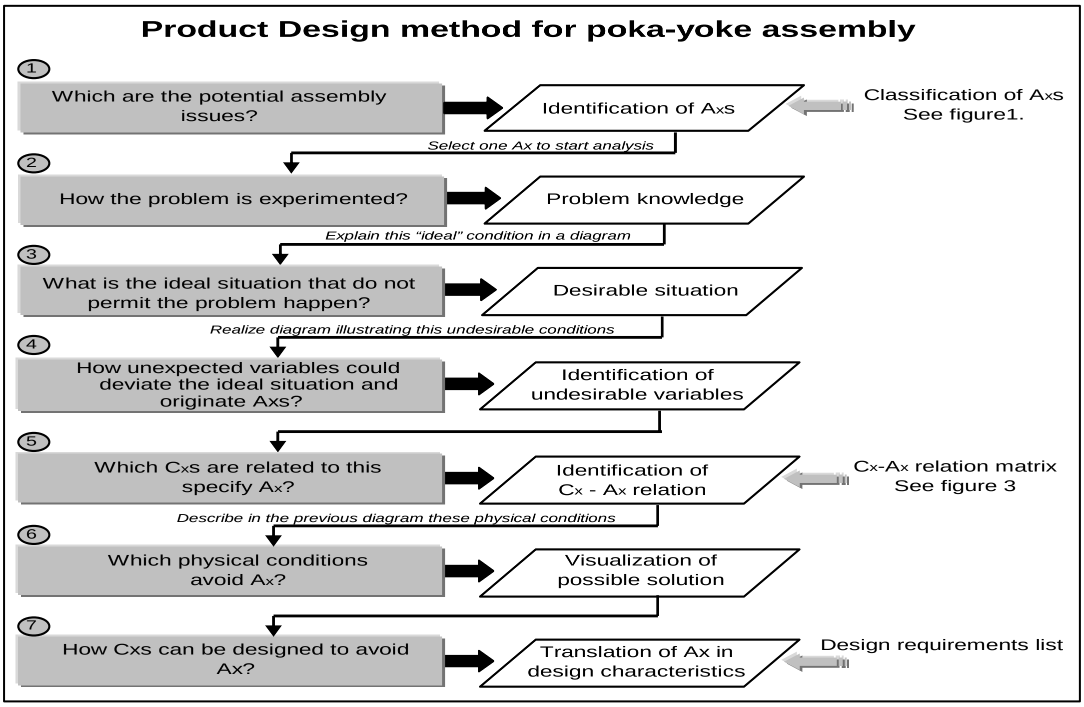

Figure 8. Illustration of product design for poka-yoke assembly approach

Established questions Q_x indicate to designer how they can orient the development of a Poka-yoke solution since early design stages in order to identify that a necessity exists and then make a change in corresponding design characteristics C_x to be able to avoid in later stages a condition that affects negatively in the occurrence of quality assembly issue A_x. The results of this first investigation will be useful to develop the following phase of the investigation that will consist in systematizing assembly poka-yoke principles applicable to product process design. It has been emphasized that this approach focus in designers to avoid them make redesigns in later stages to eliminate redesigns costs, defective parts and customer complaints but also could be used by manufacture engineers to generate ideas and then to propose designers how a specific part must be redesigned to reduce the occurrence of a certain assembly issue.

In this approach it is not possible still to make cost analysis to evaluate how feasible the poka-yoke redesign ideas resulted are by the application of this approach, what we know is that this research is based on poka-yoke redesigns cases that were successful in the industry where they were applied; this mean that even designs changes could be expensive they are cheaper than excessive costs caused by the occurrence of quality assembly issues and considering also that this approach is focused in detect these design changes during early design stages these changes will be definitely cheaper than other later decision. The importance of this approach is to avoid that designers make a poor risk analysis of potential assembly issues that could happen with the present design that is been developed by them and also bring designers the opportunity to assign necessary resources during design process, when we know that it is cheaper, instead of redesign a product in later stages when significant quantities of product was already manufactured and drawings, work instructions, suppliers, processes, etc. had been already developed for the initial part that was decided to be redesigned later.

9 CONCLUSIONS AND FUTURE WORK

It was considered as product customers all people involved in some way in the overall life cycle system stages in order to know their needs and expectations related to assembly concerns and to be considered by designers to make decisions oriented to satisfy those needs and expectations. All these necessities and expectations were captured in function of the issues that experience these customers and professionals where assembly factors are involved, after performing a classification there were identified causes associated to product design characteristics and also by analyzing different product redesign cases that were performed to solve some type of assembly issue in a robust manner according to the Poka-yoke philosophy, it was possible to translate the customer and professionals needs and expectations to specific design requirements that have to be considered during design phase. Every redesign was analyzed in detail, in order to find out how engineers and designers could translate the quality assembly issue in a poka-yoke redesign solution. An approach was presented to describe how a problem can be analyzed by asking during process design seven questions Q_x in order to identify design characteristics C_x associated to specific assembly issue A_x and detect the corresponding design requirements R_x from the seventeen established in this paper that have to be followed to develop a poka-yoke design idea that can be useful since early design stages or by manufacturing or quality engineers for analyzing an assembly issue with a high occurrence and propose to designers a manner to solve it based on poka-yoke philosophy.

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