PRODUCT VERIFICATION AND DEFECT REPAIR – STATUS AND CONSIDERATIONS

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ABSTRACT

Product verifications have become a cost-intensive and time-consuming aspect of modern electronics production, but with the onset of an ever-increasing miniaturisation, these aspects will become even more cumbersome. One may also go as far as to point out that certain precision assembly, such as within the biomedical sector, is legally bound to have 0 defects within production. Since miniaturisation and precision assembly will soon become a part of almost any product, the verifications phases of assembly need to be optimised in both functionality and cost. Another aspect relates to the stability and robustness of processes, a pre-requisite for flexibility. Furthermore, as the re-engineering cycle becomes ever more important, all information gathered within the ongoing process becomes vital. In view of these points, product, or process verification may be assumed to be an important and integral part of precision assembly. In this paper, product verification is defined as the process of determining whether or not the products, at a given phase in the life-cycle, fulfil the established specifications. Since the product is given its final form and function in the assembly, the product verification normally takes place somewhere in the assembly line which is the focus for this paper.

INTRODUCTION

Product or process verification has not been well-addressed issues by the precision assembly R&D community, a fact which is underlined by the increasing instability of many processes, and the unsuitable re-engineering phase approaches. Any product or process defect causes losses, and these will be repeated unless a more formalised approach to the problem is taken. Today verifications are necessary but a difficult phase in industry which results in both unnecessary extension of lead-times and increased costs, O'Connor (2003). This is even the case at Toyota as discussed in Baudin (2002). The difficulties are caused by lack of time and knowledge of how to plan and perform the verifications in the assembly system; and how to design products which are suitable, or at least facilitate, verifications. In this paper product verification is defined as *the process of determining whether or not the product at a given phase in the life-cycle fulfils its properties.* This definition includes common used words as inspection, control, and test, but also the planning, validation and documentation of the verification. In addition, numerous of authors point out the difficulties that ensue with an increase of product variants with shorter life cycle. Since every new variant introduced in the assembly line has its own properties, it also needs its own specific verification: the process that handles its assembly has not been finalised. One way to handle lead-time and cost in verification is to reduce the verification itself. Although this will cut cost and time, Varma (1995) points out that it is more important to focus on the product profitability and verification strategies. The same discussion is made by Junkkari (1999), meaning that verification tools, together with automation and information tools, should "form an easy to use multifunctional package". That is, verification is an integrated part of a production system and needs a strategy which considers more than the actual verification. In addition, verification of precision assembly is not only confined to micro-electronics. In fact, the assembly of airbags, insulin pumps, and a large range of non-electronic products are obliged to maintain a defect-free production for customer safety reasons. This implies a highly sophisticated assembly process, often integrating very tight tolerances to high process traceability. It is hence of some importance to clarify new approaches to product verification since the topic is becoming relevant to precision assembly. This is underlined by Moretti (2003) who say that 51% of all computer chips do not pass the first verification in which 74% is functional defects. The objective with this paper is to present results from case studies in four companies (A, B, C, and D) regarding product defects and causes. Furthermore, it will attempt to discuss the emerging need for companies to develop an adequate re-engineering strategy in terms of how to verify their product and repair any defects.

RELATED WORK ON VERIFICATION AND DEFECT REPAIR

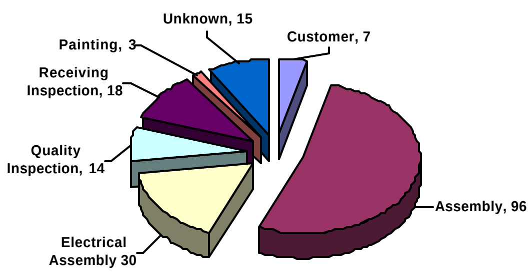
Normally the verification takes place during assembly, when the product is given its final physical shape and function, with the objective with to have a qualitative product. Although quality is a broadly used word, "fitness for use" mentioned in Juran et.al (1974) is an appropriate meaning. The fitness for use is achieved by the quality characteristics in the product (products properties). In the literature, different approaches and examples have been discussed on how to verify and repair products. Baudin (2002) discuss inspection and verification sequencing and points out that only a defect-free product passes all verification stations. It is also mentioned that repair of assembly defects should be made by the station on which it occurred (on-line repair), which implies that it is beneficial to have the verification station close to the assembly. The benefits from having workers repairing their own mistakes is that tools, assembly instructions and fixtures already is available at the assembly station, but also an decreased defect rate due to awareness of possible defects, which is also pointed out in Robinson et al. (1988). In Baudin (2002) offline repair in three variants is discussed. In all three off-line repair stations the defects are repaired at the end of the line. In these three variants, the defect needs to be repaired within takt time. In Robinson et al. (1988) the asynchronous line with buffers between each station combines the benefits with off-line repair, which not interfere with the on-line production rate.

So far, several researchers and the companies studied agree that the product verifications should be early in the value chain, discussed by Baudin (2002), Robinson et al. (1988), and Nevins and Whitney (1989). Here, value chain denotes the series of operations which take place in order to design, manufacture, assemble and deliver the product. The more time spent on embodiment the product, and the more parts manufactured and added to the product, the greater the value added. At the same time the complexity of the product increases, i.e. more parts are added which give the product more details and functions. The approach to verification the product early in the value chain is specifically beneficial in a modularised product assortment where specified functions and interfaces in each module can be verified already at the module assembly workshop, so called module property verification (MPV), Kenger et al. (2003). These benefits have been discussed by among others Baldwin and Clark (2000), Erixon (1998), Baudin (2002) and Stake (2000). As pointed out in Kenger and Onori (2003), by performing MPV's, detected defects can be repaired at module level where less parts have to be disassembled, spare parts are already available at the module assembly workshop, and no additional assembly or verification tools are necessary since they are available at the module assembly workshop. Property verification implies that it is the property of the product which should be verified, and not its technical solutions. Even though there are several benefits by performing MPV's, there may be reasons for performing the verifications at product level, so called product property verification (PPV). PPV may be more beneficial to perform when the number of defects per product (defect rate) is relative low. Only a final control of the product is performed as a precaution to ensure the compatibility of the parts or modules building up the product. Compared with MPV, there is less number of separate verifications in PPV since one PPV might correspond to several MPV's. That is, at module level each module may need its own verification while there may be enough with a single verification on product level.

Verification starts early in the development of a product, it can be a full scale working prototype, a computer model for simulation or an appropriate concept as discussed in Ulrich and Eppinger (2000). Although, early verification of products gives an estimation of the product properties, the product has not been given its final properties. Therefore it may be necessary with verifications of the assembled product where all parts have been put in place. The verification is a search for defects, where the intention is to detect defects as early as possible at a wanted point, without jeopardise the final product property, and before the product is shipped to customer. Here, *a defect is a fault that causes the product not to fulfil its properties*, i.e. the product does not work or look correctly. Defects themselves are a symptom of bad machines, designs and routines where the defect origin is human. In Barkan and Hinckley (1994) a relation between defects and increased manual assembly time is discussed. They mention that longer assembly times are related to difficult assembly tasks which increase the probability that a defect may occur. Five assembly factors are also identified related to a qualitative product. (1) Assembly operations, (2) assembly quality control, (3) assembly operation complexity, (4) number of parts, and (5) part defect rate. Baudin (2002) and Shingo (1986) mention that inspections (verifications) is waste of time and resources since it does not add any value to the customers' interpretation of the product. Thereby, the most profitable way to verify is not to verify at all which in turn is related to increase risks of having defect products shipped to customers. Also, the verifications itself does not contribute to lowering the defects. Nevertheless, this has been the subject for Shingo (1986) and Hirano (1988) discuss the poka-yoke (mistake-proofing) as an effective way to reduce assembly mistakes. Also, statistical methods of monitoring machine tolerances are discussed in i.e. Juran et al. (1974). However, statistical methods can only eliminate variations and not operator mistakes, Hinckley and Barkan (1996). In addition, Nevins and Whitney (1989) say that people tend to cause more random defects while automatic assembly is more predictable. Also, Juran et al. (1974) distinguish between sporadic and chronic defects. The sporadic defects cause minor economical losses and requires 'fire fighting' measures while the chronic defects causes major losses and tend to become an acceptable quality level. This implies that even if automatic assembly is used to reach uniform quality, small deviations may cause major costs. Case studies show that zero defects is an utopia, at the same time demands on verifications increases from customers, standards and governments. Therefore, verifications is necessary but should be performed with a minimum of resources and time. This means that personnel, verification equipment, documentation and preparation have to be optimised and verify the exact demanded properties. Questions on how to repair defects and demands on how to verify products, together with company visions formulate verification and repair method. Within the method, the predictable cost of verifications should be balanced against the (less) predictable cost of repair late detected defect (unwanted point of detection), including defect detected by/at customers. In order to identify which approach to use, e.g. PPV, MPV or any other, a method is necessary which companies can use with their own specific products and assembly system which is also addressed in Hinckley and Barkan (1996). Today, the approaches to reduce defects and how to repair varies, giving companies numerous of tools and methods to use. However, it is still missing a way to estimate the cost of changes in the product architecture, assembly system or point of verification in comparison to the costs of today. That is, will the cost of bad quality decrease if changes are made, in that case, how much?

CASE STUDIES

Results from case studies show that products may have several defects which need to be adjusted, Figure 1. In company A, the defects per unit (defect rate) were in average 1.08 from 1996 to 2002, with 0.82 as the lowest defect rate in 2000. The first seven month in 2003 the defect rate was 1.92, with 1.15 as the lowest. The trend in company A is an increasing defect rate with increased cost and lead-times. Interviews with workers and assembly line managers indicate that more variants and shorter delivery time may cause the negative trend in defect rates. And, since defects extends the lead-time due to repairs, the pressure on the assembly and verification workers increases, resulting in even more defects. The vicious circle is a fact. In addition, at company A the verification itself is the bottleneck and causes extensions in the lead-time even though no defects need to be repaired.



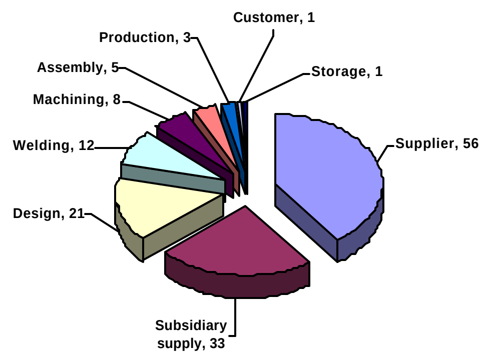


Figure 1: (Left) point of detection of 183 defects in 150 units, defect rate 1.22 during one produced order, (right) 140 known defect causes of 183 defects in 150 units at company B.

Based on Figure 1, the later in the value chain the defect is detected the more costly and time demanding the adjustment become. For example, it can be a magnitude of 100 in difference on adjusting a defect part detected on part level then a defect part detected by customer. It is also known that “rule of 10”, Robinson et al. (1990), states that it is ten times more costly to repair a defect late in the assembly line (or off-line) then it is to repair the defect as it occurs. In addition, although suppliers cause 89 defects only 18 are detected at the receiving inspection, Figure 1. All-in-all, the verification and defect repair causes quality costs for millions each year. At company B this cost was 12.5% of their turnover. Company C develops and assembles automatic and semiautomatic assembly systems for e.g. heavy diesel engines, gearboxes. A heavy diesel engine line may consist of more than 50 automatic stations. Depending on the size of the system, parts or the whole system is put together at the company for a FAT, Factory Acceptance Test, where the customer can see the system and also test it. After the FAT the system is disassembled and shipped to the customer’s site. The system is build up again and a SAT, Site Acceptance Test is performed. For company C it would be valuable to assemble the lines, or stations, separately anywhere in the world and be sure that each station fulfil its properties and are compatible with the other stations in the system, before the system is realised. This is a matter of standard solutions and modules, but also of utilising a MPV approach on station level, and predicting the whole line property. Company D should benefit to perform MPV’s and a small stock with finished modules waiting for final assembly. From case studies and Figure 1 the following four grouping of defects and causes can be made. (I) *Part defects* - The part is defect due to machine operator mistake, machine tolerances or handling. (II) *Design defects* - The design is defect (does not work as intended) due to wrong way of thinking. (III) *Assembly defects* - The assembly is defects due to use of wrong parts, incorrect insertion or missing part. These assembly defects is also mentioned in Nevins and Whitney (1989) who also point out assembly defects caused by damaged part that is used anyway, dirt or other contamination between parts, and damaged caused by insertion or handling. (IV) *Verification defects* – The verification itself is incorrect in that sense that the defects are not detected and the defective product is shipped to customer or next assembly station. The repair of defects in the studied companies contained the following four measures. (I) *Part defect* – rework, scrap or part redesign, (II) *Design defects* – redesign, (III) *Assembly defect* – disassembly and reassemble the correct part(s), disassembly and reinsertion, making sure all parts available, and small sub-assemblies may be scrapped, (IV) *Verification defects* - adjust equipment and tools, adjust to verification right properties, and control operator routines.

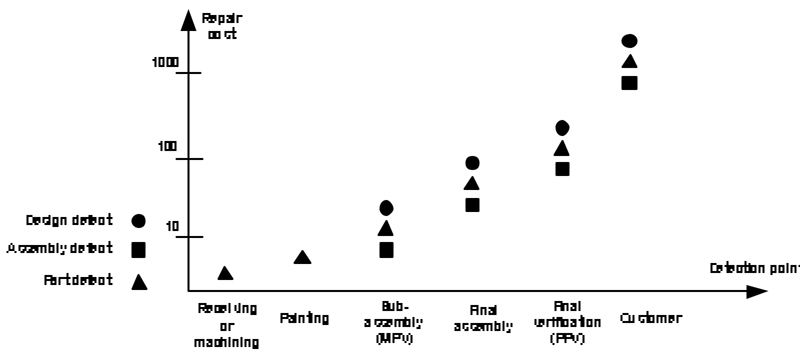


Figure 2: Repair cost as a function of defect and detection point, schematically.

In order to develop a verification strategy the cost today to repair any defects need to be known as well as the cost to prevent defects to occur. That is, what does it cost to repair n_i defects of defect d_i detected at point p_j? It is not a question of how to reach zero defects; it is an estimation of the cost of detecting defects at a wanted point, and the cost for any repair. It is therefore necessary to gather statistical data on (1) defect rates (2) defect types (3) detection points and (4) cost (or time) to repair. Figure 2 shows schematically the cost to repair defects as a function of the defect and detection point. Figure 2 is based on the "role of ten" by Robinson et.al (1990) and on cost of quality losses in company B. Based on the repair cost, the product design and the assembly system, the cost of having certain number or verification operations need to be known. The result should be an approximate cost of having late detected defects and the cost of having several verification operations detecting any defects at wanted points. When an approximation of the verification costs and the cost of repair n_i defects of defect d_i detected at point p_j is made, different potential improvements in product design, assembly system, defect repair and verifications shall be evaluated.

SUMMARY

This article intends to illustrate how and why product defects and product verification are not considered in an acceptable manner in industry today. Scrap production and verification of products will be important as long as the processes are not perfect and as long as standards and customers demand verifications. In view of the instability of micro-assembly processes, the increasing level of miniaturisation, and the lack of standards, these issues should be addressed more seriously. Although numerous authors have shown different approaches on how to verify and to repair defects, companies still incur huge losses (quality costs) each year.

There is a need for a strategic and methodological approach for product verification in the assembly process with the objective to decrease cost related to verifications and defect repair. Within a verification strategy, it should be possible to document and control the actual verifications as it is done today, and to serve as information during redesign of the product or assembly system. During redesign, the verification strategy is used to compare the new product or assembly system with the old, to make sure that the redesigns do not cause extensions of lead-time or increased costs due to increased defects or verifications. A potential approach may lie within re-engineering methodologies which focus on the exploitation of knowledge for future product and system generations.

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