Product Reuse and Reliability

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Efforts of those who champion the cause of environmentally-considerate manufacturing are enhanced by overcoming the resistance of others to the adoption of those methods. Past experience with the implementation of continuous-improvement principles and procedures suggests that new manufacturing and design considerations do take some time to be integrated fully. There has been a great deal of research and development done by many organizations on product and process improvements in order to reduce environmental impact. Besides the documentation of the technical improvements, much of the literature describing the methods deals with the anticipated concerns of implementation. The performance of reused, high-reliability products, such as electronics has not often been considered in the adoption of new methods. With further development of recovery and reuse strategies, the concerns regarding implementation will subside, and more time and effort can be directed toward advancing the technical methods of environmentally -considerate manufacturing.

With the advent of take-back legislation and increase in the original equipment manufacturer's (OEM) accountability for products, recovery of products and materials that can be recycled and reused becomes increasingly critical to the manufacturer. OEMs are charged with the disposition of the returned products, where those items that can be reused, repaired, or reworked make for a more environmentally -positive and cost-effective disposition. Steps that enable the development of a high-reliability-product reuse policy include identifying applications where a reused product with decreased reliability would be sufficient based on performance requirements, developing retesting procedures that measure reliability of reused products, developing field-repair procedures similar to in-shop rework processes, and managing product service life with a maintenance schedule. In addition to developing the procedures, the true life-cycle costs of all steps must be calculated for cost-benefit analysis.

This paper explores the issue of reliability of reused products; specifically the performance of reused, high-reliability products, such as electronic assemblies. Also explored is the consideration of reuse as part of an environmentally -considerate design and manufacturing operation. Reuse is an integral part of a Design-for-the-Environment (DFE) program, where the goal is reduction of adverse effects on the global environment by manufacturing processes. Impending legislation will make OEMs more accountable for disposition of their products. Therefore, it is imperative that manufacturers consider recovering and reusing products whenever possible to reduce the amount of product materials that will require disposal. It is also necessary to consider the impact that a reused product might have on reliability. This paper considers the background and definitions of Design for the Environment and its components, reuse, repair, and rework. Also, reliability issues are presented with a slant towards their place in electronics manufacture. Specific areas that must be addressed when forming a reuse policy that meets reliability specifications are suggested.

Environmental Consideration

A major focus on the effects that manufacturing has on the environment is the consideration of the environment during design, so that adverse impact can be minimized early in the product-realization process. The intent is the betterment of the environment through elimination, reduction, and prevention. If smaller quantities of materials, hazardous or not, are used, less waste material needs to be disposed. Various philosophies suggest an ideal of zero waste, but industries faced with regulation, legislation, and customer environmental awareness need more practical approaches. One approach is Design for the Environment (DFE), which includes several specific considerations including materials elimination and substitution, process optimization, energy reduction, and product disposition.

Design for the Environment is the design of products in order to minimize waste during item production, use, and disposal[1]. DFE considers the environment at a product's design phase, including all materials and energy requirements and their effects over the life cycle of the product. In addition to product material and energy requirements, DFE principles must be applied to manufacturing processes. Energy usage includes the energy required to manufacture the product, to use the product, and to dispose of the product. The life cycle of the product goes beyond what is traditionally considered as the useful life, beginning at the initial stages of raw-material extraction and continuing through the final product disposition.

One piece of the disposition picture is the reuse of products either directly or after some necessary rework. In either case, the second or succeeding customer expects assurance as to the quality and reliability of the product. The potential customer needs to know what performance level to expect as well as the predicted lifetime of the product. The approaches of how to handle electronic product reuse vary in practice, but the common goal is to make products last longer so that the need for replacement is lessened. With longer life, less disposal is required, and with less demand, fewer replacements will need to be produced.

Reliability of reused products is an issue that must be addressed in order to determine the feasibility of a reuse policy. For the good of the global environment, the primary approach toward reuse should be to determine its feasibility and to make it a reality and should not be to avoid it for performance concerns. If product specifications are standard to ensure that the most critical needs are met by reused products and that non-critical requirements don't unnecessarily preclude reused items, then a policy can be established. In the study and application of reliability and maintainability of electronic products, consideration of the environment has traditionally been of the conditions in which a product will be used. This use environment includes the temperature, humidity, and cleanliness of the surroundings, where their effects on the performance and the reliability of the product are of primary concern. As important as the use environment is to the performance of the product, the manufacture and the use of the product are important to the global environment. All product and process materials come from and eventually return to the environment, such that the residual effects are critical to global well-being.

The main drivers for environmental consideration activities can be divided into those that are internal to the organization and those that are external. Internal drivers are those that result from conscious business policies, such as environmental stewardship, and from an employee- or community-oriented business plan, that may have developed from continuous-improvement strategies. Interest in environmental considerations is often enhanced when the cost of improvements to the products and processes is quantified. Using less material means reducing costs as well as environmental hazards. The natural internal drivers in many companies are not fully explored and developed in other companies until external drivers demand action.

Two prominent types of external drivers are increased governmental regulation and increased customer awareness. Regulations that demand proper consideration of the environment are being developed at the state, federal, and international levels. Bans on chlorofluorocarbons and other ozone-depleting substances that were regulated at the international level have provided the impetus for many product and process changes in the electronics industry, among others. Internationally, the European Community leads the process of developing I SO 14 000 that will deal exclusively with environmental issues. British Standard BS-7750 has already been issued with the same intent[z]. The United States Congress, Office of Technology Assessment conducted a study on green products in light of a possible re-authorization of the Resource Conservation and Recovery Act (RCRA) of 1976. The purpose of the study was to present "the challenge to Congress to employ a mixture of regulations and economic instruments to give designers the incentives to make choices that promote RCRA's goals of protecting human health and the environment."

DFE Hierarchy and Reuse/Repair/Rework

The correct definition of a DFE hierarchy can lead to an understanding of how to handle materials that become part of the life cycle as they enter a manufacturing stage. The steps that appear in the hierarchy may vary with specific products, although their order should be consistent. The hierarchy should be used at the design phase for all new products, and should be implemented wherever practical for existing products. This may not be possible; for example, it may not be practicable to break down components that were never designed for disassembly. The DFE hierarchy for products has the following levels in descending order of impact: elimination, reduction, reuse, repair, rework, disassembly, recycling, and disposal. The hierarchy for manufacturing processes is similar except that the repair, rework, and disassembly levels do not apply.

The first step is eliminating any materials that do not add value to the product. Next comes reducing the amount and variety of the materials used on a product or in the process, to minimize later disposal volumes. Eliminating and reducing processing materials is a move towards resource conservation. The third step is reusing any assemblies, subassemblies, or process materials. In addition to environmental improvement, reusing a durable product decreases costs due to a lessened demand for new products and decreased disposal costs. The next steps are repairing and reworking any assemblies or subassemblies that could subsequently be reused. Repair is done in the field, while rework usually takes place in the factory. In the electronics industry, the objective of rework or repair is "to remove/replace/reorient a defective or misaligned component without affecting adj scent components." Process inspection will generally identify opportunities for rework, typically needed because of a process-related problem or defective component. Rework is more controllable than repair in the field[4]. Following rework is disassembly. At this stage, component parts are separated for reuse and recycling. Another step in the hierarchy is recycling the product and process materials from all possible operations. The last step, already common, is proper disposal of product materials that cannot be otherwise recovered. The more effort that is placed on the earlier steps of the product and process hierarchies, the less material that will need proper disposal.

Reliability in Electronics

Reliability is defined as measure of the time that a product can be used without experiencing degradation or failure under a prescribed set of operating conditions. Reliability testing applies various stresses to components, assemblies, and entire systems to predict the product's useful life. In terms of reliability, the word "environment" has traditionally referred to the conditions that the component, assembly, or system will see in practice and in testing. Consideration of the use environment at the time of product design, called Design for Reliability, is extremely important in itself in the design and manufacture of electronic products. On the other hand, as discussed previously, Design for the Environment refers to consideration of the global environment as it is affected by electronic products and processes. DFE and reliability are connected because, in order for electronic products to be reused or repaired for continued use, they must be durable; product's durability over its useful life is measured as its reliability. More complex relationships between reliability and the global environment are reflected in how the materials, selected to enhance reliability, affect the global environment as they are used or disposed.

In order to achieve success in the market, electronic products must have excellent reliability. Ensuring this level of reliability begins at the earliest stages of product definition, with assessment of all materials, designs, and manufacturing technologies that will affect the product's performance. Accelerated test methods and statistically designed experiments are used to verify that performance objectives are met. If they are not, the root cause of the deficiency is investigated so corrections can be made. For manufacturing yields that meet reliability objectives and are priced competitively, the following must be achieved:

- creation of a data base of materials properties, performance, and interactions with the global environment,
- consideration of processing technology during the design phase leading to robust designs that have the required properties despite process variability,
- development of an accelerated life test strategy aimed at all functional levels of a product, including devices, components, assemblies, and systems, and
- "establishment of critical processing parameters and the relationships between materials and process variations through statistical evaluation.

Achieving reliability objectives in practical application challenges both design engineers and process engineers to work together to eliminate structural, materials, and process variations that contribute to yield loss and product degradability.

Reliability testing applies various stresses to a product so that its useful life can be predicted. As materials substitutions are made in consideration of the global environment, the materials need to undergo the battery of tests that assess product life. Reliability testing uses accelerated conditions to inflict stresses on the product. Typical conditions that are subjects of tests are physical and chemical mechanisms that the product will likely see in use. Stresses imposed include thermal, electrical, and mechanical stresses, humidity, radiation, shock, corrosive gas, and corrosive particles. Use environment testing is done by exposing the product to higher concentrations of humidity, airborne particles, and gases than it would see in its useful lifetime. The effects of these stresses are accelerated during tests by elevating the temperature. Test results are compared to actual field performance results when available, or can be extrapolated to estimate reliability and performance under field conditions

Reliability and Reuse

Stepped obsolescence is defined as a unique means of facilitating reuse[6]. A product that is considered high-tech in its design will be purchased only by early adopters, who are those customers who look for the latest and most advanced features. After some time in use, the manufacturer can take back the product, test it, and rework it if necessary, then sell it to the late adopters. Late adopters are those customers who can do without the most advanced features of a product as they become available but are interested in the features when they become more cost effective to own. As the scenario develops, the early adopters would continue to purchase the most recent products, while the late adopters would become the reuse market. A product would become obsolete only after it had been passed through a chain of owners from the earliest to the latest adopters. If the OEM is involved in the recovery of the products from the first owners, then it benefits from a larger customer base due to the secondary-use market. The concept can be paired with reliability to establish a reuse policy. In those applications where high-reliability is not as critical as others, second-use customers could be satisfied with a reused product, based on the assurance gotten by conducting the appropriate reliability tests.

The measure of the reliability of a reused product could be the same as the measure for the original product just by using the same tests and specifications. When an OEM recovers the product from its original owner, the OEM can retest the item in the same manner and against the same standards as was done originally. Analysis of the test methods must be done to assure the manufacturer that a reused product that performs as well as a new product will in fact have a comparable reliability.

Depending on customer requirements, new specifications based on the amount of service time that a product has seen could be developed. The service life of the product might be a consideration based on how it was used and what use environment it saw. Tests that are based on a known service life will be more difficult to establish than those that don't consider past usage. A pre-determined useful life could be set for a product, so that it can be reused and retested as long as the useful limit is not reached. With a reuse policy that is dependent on past usage, a monitoring procedure is necessary to track the time in use.

Regardless of the reuse policy, all of the methods must be analyzed for the true cost of the steps taken to reuse a product. If the retesting procedure becomes too complex, the cost of recovering a product and testing it may be prohibitive. Based on the cost benefit, disassembly and then recycling of product materials may prove to be easier to justify than reuse.

Actions for Reuse Policy Development

Reuse is an important part of the Design for the Environment effort. The natural reaction to the idea of reusing a high-reliability product is to say that it is too risky and that it should not be done. However, the need for the extension of the useful life of a product in order to decrease the demand on the global environment is evident. The following steps should be taken to develop a workable reuse policy for high-reliability products.

1. Review the customer requirements based on performance in order to reveal applications where a reused product with a decreased reliability could be a sufficient substitute for a new item.
2. Develop the mechanisms necessary to recover used products from the initial customer; develop the necessary rework and retest procedures for recovered items, and establish the means to distribute the reused product to the secondary-use market.
3. Develop retesting procedures that measure product reliability of reused products. Determine if the retest specifications should be identical to new product specifications or if the requirements should be adjusted for reused products.
4. Manage the product service life by means of scheduled maintenance for high-reliability products. Develop a tracking system to monitor the length of service life of products in order to make the scheduling of maintenance more accurate. Determine if a maximum useful life for each product would be beneficial to product management.
5. Review product specifications to ensure that the most critical needs can be met by reused products. Also, the review should focus on any artificial barriers that could prevent the choice of a reused

item without just cause.

6. Develop a field-repair procedure for products that is similar to in-shop rework procedures. The field-repair process should be feasible for the customer to do and should include necessary testing methods for the product to be checked before reuse. Currently, these rework-and-repair procedures are done in the shop after defects have been identified by testing. If the process methods can be made portable while maintaining effectiveness and reliability, the customer could repair circuit board assemblies and keep them in service, so that less replacement boards would be needed.

7. Analyze all proposed steps in a reuse policy for the true costs of each step. Costs for all procedures should be calculated based on the life cycle of the product, where the life cycle is measured from raw-material extraction to final waste disposal.

Summary

A product-reuse policy can be established as long as product quality and reliability are assured. Product take-back and redistribution methods can be accomplished for durable goods and are reasonable for high-reliability items such as electronics products. Designing products for reuse includes making them more durable and easier to maintain, both of which are improvements that can help the quality and reliability ratings of the products. The benefit of reusing products rather than using new ones is significant. Our disposable society is limited by the global carrying capacity for waste products. With some effort, we can make products that are durable and reusable within our reliability requirements. Legislative and regulatory actions that dictate product take-back and reuse policies must account for the expected reliability of those products and allow for the timely development and implementation of such policies.

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