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PRODUCT REDESIGN FOR EASE OF MAINTENANCE: A CASE STUDY

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ABSTRACT

This paper reports a study on the maintainability of a domestic product from the aspect of design modularity. In this study, the clustering technique was applied to a domestic product, an electric coffee maker in order to identify its functional components and the interactions between the components. The service modes of the product were determined so as to ascertain the level of servicing difficulty faced by the user. Guidelines in design for maintenance were applied during modifications to the existing design, focusing on three components in the main module of the product namely the cover of the base, the spraying unit and the cover of the strainer aperture. Results from the study has shown that taking into consideration the design modularity and maintenance requirements at the early stage of product design, has enabled product servicing to be identified and planned in more systematic and effective manner. The new design of the electric coffee maker that takes into consideration ease of maintenance is presented and discussed in this paper. The proposed design has certainly enhanced the product's maintainability as well as reliability.

Key words: Product life-cycle, Design for Maintenance, Serviceability, Modular design, Product Architecture

INTRODUCTION

One of the characteristics of a good design is consideration on the product's life cycle requirements (Dieter, 2000). Maintenance which is the topic of interest in this paper is one aspect of product engineering life cycle that refers to the level at which a design can be maintained or repaired efficiently and economically (FitzGerald, 2001; Kuo et al., 2001). In many of the existing domestic appliances, design for ease of maintenance were not taken into consideration. Due to this, products were disposed off even though the defects are minor and repairable. According to FitzGerald (2001), if the maintainability of products are considered from the early stage of design, servicing cost and down time can be reduced. From the aspect of cost, studies have shown that an additional cost of 5% on design improvements of components is capable of reducing product's life cycle servicing cost by 25% (Barkai, 2005). Desai and Mital (2006) noted that reduction in maintenance requirements can only be done by building mantainability into products/systems at the design stage. According to Ullman (2003), difficulty in servicing by the user can be due to design mistakes which are done on purpose. In addition, components that can be replaced are limited to certain models only. Users are also negligent on maintenance that can be partly due to producers' refusal to share information openly with their customers. This has led to reduction in products' efficiency, wastage and increase in the quantity of waste disposal. This phenomenon would certainly discourage initiatives on designing for the environment or the green design.

Awareness on the importance of product life cycle for maintenance from the perspective of product architecture can be seen in earlier studies by Gershenson and Ishii (1991), Ulrich and Tung (1991) and Newcomb et al. (1998). Product architecture according to Ulrich and Eppinger (2004) is a scheme on how product's functional elements are arranged in a physical block and how these blocks interact. Mostia (2004) noted that modular design divides a system into physical and functional modules that can be arranged to facilitate design and servicing. Product design architecture can be categorised into integral design and modular design. Modular architecture differs from integral architecture in terms of the former product's functional element that is performed by one physical block. The advantage of the modular architecture is that it enables design improvements to be conducted on a particular block only.

The aim of a modular design architecture is to allow independence and interchangeability between units in fulfilling the various functions of the product (Huang and Kusiak, 1998). Modularity enables modification to several product functional elements separately without affecting the design of the other elements. Modularity emphasised product module expansion with minimum dependency on other components For maintenance, each components of the same module should have maximum similarity while maintaining minimum similarity with components outside the module. Maximum similarity in the module helps to facilitate servicing on the components of a certain module since each component are more or less similar in its physical and function.

An important consideration when defining modularity is the choice on the level of servicing (Gershenson and Prasad, 1997). Servicing comprised several tasks. According to Ullman (2003) servicing reflects ease of diagnosis and repair on a product. A product may be modular from the perpective of design but may be otherwise from the perspective of servicing operation. In this study, the design architecture of an electric coffee maker is reviewed and service modularity applied. Results from the study then form the basis for design improvements to the electric coffee maker in view of improving maintenance.

METHOD OF STUDY

In order to identify the main modules of the electric coffee maker, the clustering technique as proposed by Ulrich and Eppinger (1995) and Cutherell (1996) was deployed in the study. The clustering technique is an effective technique in identifying modules from the description of product functionality. Otto and Wood (2001) also noted that module interface and interactions can be obtained from the use of this technique. The clustering technique involves several steps such as developing the product function structure and aggregating elements in modules. The components, functions and operations of the product are then identified in order to determine design modularity and maintainability mode in view of modifying its existing design for ease of maintenance.

For the purpose of the study, product function structure was developed using the input-output diagram. Different types of lines were used as input and output to reflect dependency on material, energy and information (signal) in order to relate the different blocks. All the sub-functions in the function structure are then clustered as blocks. The function structure is capable of displaying similarities in the structure. Elements are clustered based on dependency of the sub-function groups. During clustering, simple interactions between modules are encouraged so that each group will be more independent, hence reduction in the probability of problems occurring due to module interaction. For purposes of redesigning the product for ease of maintenance, three aspects of product modularity were studied namely maintaining independence among components, components similarity and maintaining interchangeability (The Manage Mentor, 2003).

RESULTS AND DISCUSSION

Understanding functions and interactions of product components

This study is performed on a commercially available electric coffee maker. The product was chosen as it is a common household appliance that requires maintenance during its service life. In order to study the function, sub-functions, operations and the interaction of the components, a product tear-down was performed.

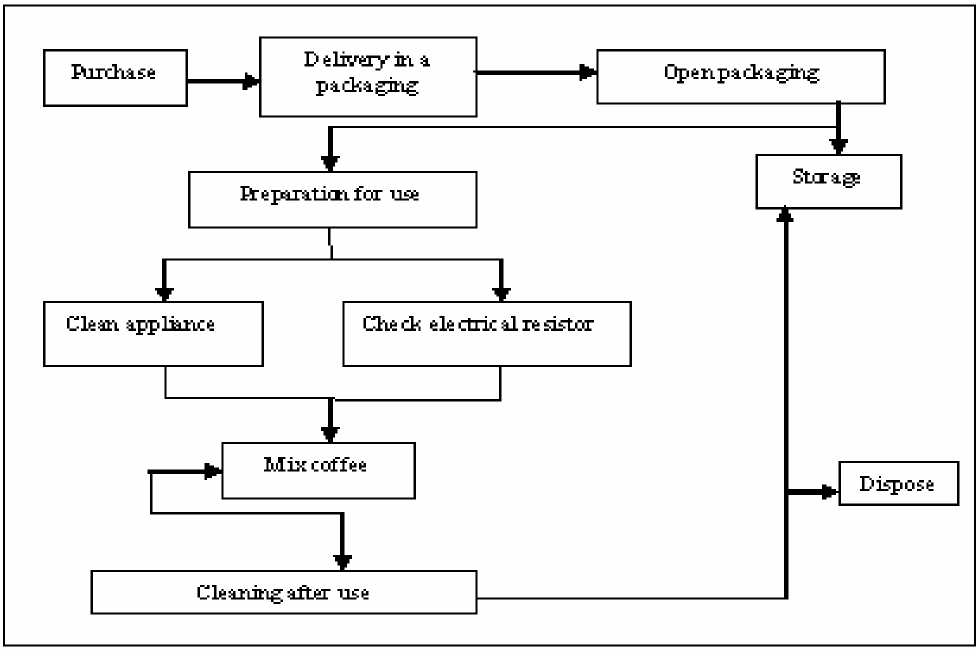

Figure 1 High level activity diagram of the electric coffee maker

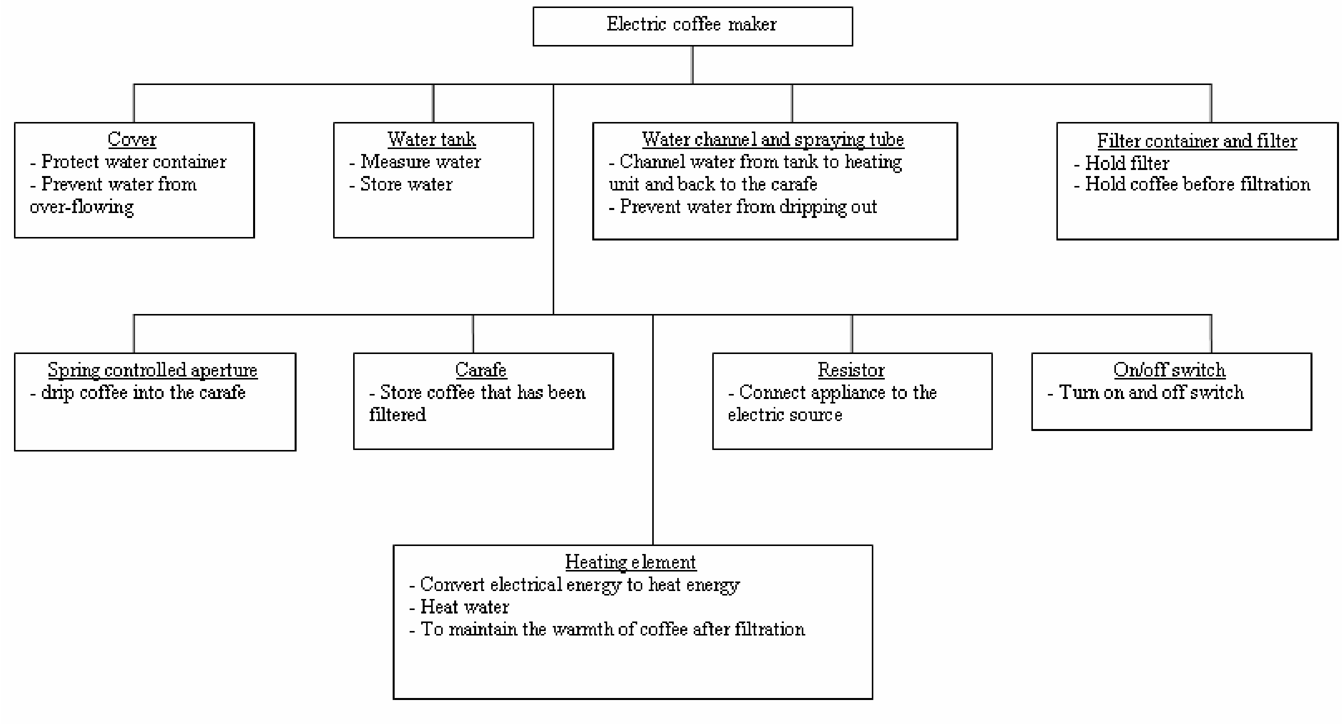

Figure 2 Physical and functional decomposition chart for the electric coffee maker

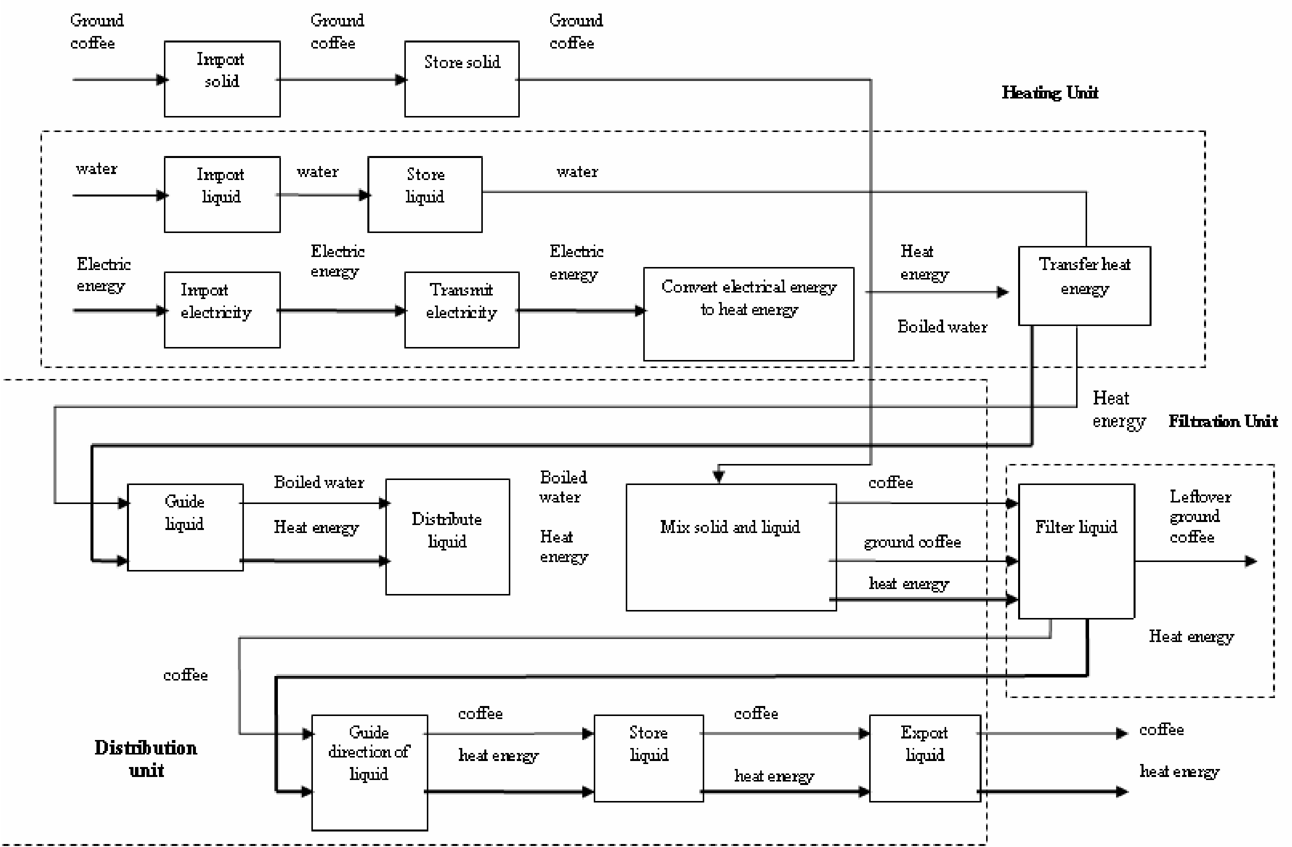

Figure 3 Functional model of the electric coffee maker

Table 1 The common mode of servicing for the electric coffee maker

Defects	Mode of servicing	Effect to the user	Diagnosis	Operations
Unit not functioning	Inspect the whole unit	Coffee mixer not functioning	Power indicator is activated but heating unit does not function	Loosen screw at the base, check for power source at the heating unit, wire connection, short circuits and faulty components
Liquid not siphoned	Inspect the whole unit	Coffee mixer not functioning	Cracks to the plastic spraying tube	Open cover, detach plastic spraying tube. Unscrew the base, check U tube and heating unit and other tubings
Coffee does not stay hot	Inspect heating unit and switch	Coffee will get cold easily	Loose connection between the heating unit and the heating plate or defects to the temperature switch	Loosen screw at the base, inspect wire connection and heating unit and heating plate.
Leakage	Check tubing for cracks or detachment	Coffee mixer not functioning	Indicator lamp is activated but liquid is not sucked into the spraying tube.	Open cover, detach plastic spraying tube. Unscrw the base, check metal U tube and replace the components if necessary.
Carafe crack or broken	Inspect carafe and heating temperature	No container for mixed coffee	Material for the carafe is easily breakable	Replace with a new carafe.
Blockage of spray header	Inspect spraying head and its connection	Coffee will not drip into the carafe	Liquid is not sprayed	Open the top cover, detach the spraying head and clean to prevent blockage

From the analysis, the sub-functions and operations of the product are identified as follows:

1. Water which is poured into the container flows through the aperture and enters the heating tube
2. Water then flows through a one-way valve and heated in the heating tube. Part of the water is channelled to the spraying tube. This phenomena occurs naturally due to gravity.
3. When the switch is turned on, the heating element heats the aluminium tube which in turn boils the water that flows through. During boiling, bubbles rise to the spraying tube.
4. Lastly, water drips onto the ground coffee and finally into the carafe.

Prior to the development of the functional model, the basic processes on the use of the electric coffee maker were studied. The basic processes are outlined in an activity diagram as shown in Figure 1. The activity diagram shows three levels of activity namely preparation, implementation and disposal (Otto and Wood, 2001).

The preparation level involves activities such as purchasing, product delivery, opening of the packaging, and storage after use. The implementation stage involves appliance cleaning, inspection of the electrical resistor and mixing coffee. At the disposal stage, the appliance undergoes cleaning after use, storage and finally disposal at the end of its service life. From the analysis of the high level activities, the characteristics of the product such as its boundary, flow path either sequential or serial, choice of processes and interactions between product functions and users can be determined.

From the analysis, parts and components that support the sub-functions of the product are identified. Figure 2 is a chart showing the physical and functional decomposition of the product. The chart indicates that some components are critical to the functioning of the electric coffee maker. Each component has its own function in delivering the main function i.e. to mix coffee. Next the black box model is generated to explain the relationship between material, energy and information that enter and exit the boundary of the system. The model relates the needs of the user to the main function i.e. `mix coffee`. For the electric coffee maker, the inflow and outflow involves material and energy only. The material inflows are water and ground coffee while the energy inflow is electrical energy. These inflows enter the system boundary in order obtain ground coffee, coffee drink and heat energy as outflows from the system.

For each inflow, the sub-function chain that implements the flow is developed. The sub-function chains are then aggregated into a single functional model as shown in Figure 3. In the single model, additional functional chain is added to show the connection to the three chains. Without the additional functional chain, the sub-functions cannot be related directly to the user needs. For example, the `transmit heat` function requires water and heat energy to produce boiling water. Heat energy is then guided and distributed until it reaches the function of `mixing solid and liquid` when ground coffee is added. Aggregation on the sub-function chains indicates the overall path of the sub-functions in a structured and clear manner. With a systematic and structured function model, the main function of `mixing coffee` is said to have fulfilled its main specification.

In order to identify the modes of servicing and operations for the electric coffee maker, a failure analysis was performed on the product. Using the brainstorming method and literature search, common failures of the electric coffee maker were identified together with the effects of failure effects. Table 1 presents the results of the study on common mode of failures to the components and their effect to the functioning of the product, as well as the diagnosis and servicing operation of the product. For example, a user may find that his coffee gets cold very quickly. This failure could be due to the product's inability to maintain the right temperature for the coffee. The servicing mode for this failure is inspection to the heating unit that requires disassembly of the screw at the base and checking the connections of the wire and heating unit to the heating plate. Failure to function may be due to several factors such as a loose connection between the heating unit and the heating plate or a faulty temperature switch. Results from the analysis showed that most of the servicing and repair work involves inspection to the heating unit and electrical connection at the base of the electric coffee maker. Since the product is not too complex, access to faulty components or units must be emphasised in the product design.

PROPOSED DESIGN MODIFICATIONS FOR CASE OF MAINTENANCE

For the purpose of studying the product's service modularity and suggesting design improvements for ease of maintenance, the study focuses on three components of the main module namely the base cover and internal parts of the heating unit, spraying head in the distribution unit and the cover of the filtration unit, as shown in Figure 4.

Figure 4 Components of the main module in the electric coffee maker

For the electric coffee maker, screws are generally used as fasteners. At the base cover and the joint between the water container and the body frame, non-standard screws are used. The use of non-standard screws as fasteners are not recommended as they do not support modularity, causing difficulty in servicing. Earlier studies by Watson (2002) has emphasised the use of standardised components, minimising the number of component layers and placing fault-prone components near to the surface, in order to enhance maintenance.

Therefore, the assembly mechanism needs to be changed so as to enable accessibility to the units at the base of the product. In order to improve the design for ease of maintenance, it was suggested that a press fit cover or rubber threaded cover be used to replace the base cover so as to improve accessibility to the heating unit and wire connections at the base. The proposed press fit mechanism as shown in Appendix A, has several small threads at the sides of the base cover. These threads will fit to the base when pressed. To open, the cover will need to be pulled out from the fittings. Another possible alternative is to use a hooked press fit that is equipped with two hooks at the sides of the cover and base. The hook will fit to the base when pressed.

In the existing design, the spraying tube is separated from the spraying head. This means that if the tube is cracked or broken, changing the tube will require the head to be detached from the tube. From the aspect of modularity, the tube is not independent and replacement of the tube may cause damage to other components. In order to maintain independence among components for maintainability, the spraying head and the tubing were combined so that the whole component can be replaced without affecting other components. From the aspect of maintenance cost, the design will provide cost saving as it will not affect other components. Furthermore, the development of combined components will be more cost effective in terms of manufacturing and assembly as compared to separate components. This modification will certainly improve the reliability of the product. The proposed design for the spraying unit is a bend-shaped unit with a larger spraying aperture as shown in Appendix A. The new design will prevent blockage in the spraying unit.

The spring controlled aperture at the filter swivel is in direct contact with the liquid that flows through the aperture, causing the spring to rust easily. To overcome this problem, the design of the spring controlled cover was modified to prevent fluid from flowing through the spring when the rubber cover is opened. This new design will certainly enhance the reliability of the spring. The table in Appendix A presents a summary of the design modifications and improvements made for ease of maintenance.

CONCLUSION

The results presented in this paper has shown that enhancement to product maintenance starts with a clear understanding of the interface among the product modules that enables identification of functions, components and operations of the product. From the study on servicing mode, the existing design was modified taking into considerations requirements for ease of maintenance. Design modifications to the product, namely on the heating unit, the storage and distribution unit and the filtering unit was implemented without affecting the interaction and operations of the product in order to retain design modularity. Several design improvements were proposed such as redesigning the cover of the base to improve accessability, replacement of non standard fasteners and component independence. This study has generated a framework for enhancing product maintenance using the modularity approach. An early infusion of the guidelines on design for maintenance during the design architecture stage has enabled configuration determination, component inspection and selection of servicing modes to be identified in a more systematic and efficient manner.

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