

FUNCTIONAL MODELLING APPROACH IN THE DESIGN OF AN ELECTRICAL SHOE DRYER

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Abstract

Functional basis is a design language consisting of a set of functions and a set of flows that are used to form a sub-function. This paper presents the application of functional basis to develop a functional model during the conceptual design of an electrical shoe dryer. In this research, reconciled functional basis was employed to develop the functional model of the electrical shoe dryer. Later on, the means to achieve the required sub-functions are identified based on the designer's experience. In the embodiment design stage the identified means of the required functions are arranged to form the final layout of the electrical shoe dryer. In conclusion, the application of functional basis in the development of an electrical shoe dryer is able to facilitate design engineers to address the required functions into the final product.

Keywords: Functional model, function chain, conceptual design, function-based design

Introduction

The reasons behind the existence of products are the products' functions (Stone and Wood, 2000). Functions are usually defined by statements consisting of a verb and a noun, for example "reduce pressure," "transmit torque", and "increase speed" (Pahl and Beitz, 1996). In function-based design methodology, functional modelling is the critical step of the design process (Suh, 1990; Pahl and Beitz, 1996). Functional modelling provides an abstract representation for understanding the overall product function. Functional modelling also guides design activities such

as decomposition, physical modelling, product architecting, concept generation, and team organization (Hirtz *et al.*, 2002). Functional modelling has been used to analyse the critical sequences of events that must occur for complex space programs (Hutcheson *et al.*, 2006); identifying modules for product architecture (Stone *et al.*, 2000), identifying potential risks during the conceptual design (Krus and Grantham Lough, 2007), and supporting conceptual design through a function-based design synthesis approach (Xu *et al.*, 2006). Thus, the research is aimed

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towards understanding the advantages of a functional design approach to support the conceptual design of a product. This paper reports the application of this approach during the conceptual design of an electrical shoe dryer. In addition, the drawback of this approach is highlighted from the perspective of the authors to initiate ideas for improvement.

Glossary of Terms

- *Product function*: the general input/output relationship of a product having the purpose of performing an overall task
- *Sub-function*: a description of part of a product's overall task
- *Function*: a description of an operation to be performed by a device
- *Flow*: a change of material, energy, or signal with respect to time
- *Functional model*: a description of a product in terms of elementary functions
- *Functional structure*: a graphical representation of a functional model
- *Functional basis*: a design language consisting of a set of functions and a set of flows that are used to form a sub-function (Stone and Wood, 2000).

Background

Perhaps the most difficult and critical phase of engineering design is the fuzzy front-end of the process known as conceptual design. This difficulty is perhaps due to the evolving strategies and methodologies that exist for this design phase. However, over the past few decades, design methods have matured and systematic approaches to conceptual design have emerged (Pahl and Beitz, 1996; Otto and Wood, 2001; Ulrich and Eppinger, 2004). In the prescriptive design model, (Pahl and Beitz, 1996; Pugh, 1997), the conceptual design phase is the second phase in the design process. The conceptual design phase is an important phase as it takes up to 80% of the total development cost of a product (Ullman, 2003) and it is the phase where the initial design solution is devised so as to fulfil the

required functions (Pahl and Beitz, 1996).

There are many methods proposed in engineering design books for the conceptual design phase. Cross (2000), proposed several *creative techniques* to facilitate creative thinking, e.g. a morphological chart, analogy, and the method. In general, all these techniques aim to increase the flow of ideas by removing mental blocks that hinder creativity (Cross, 2000). *Rational methods* that are more commonly regarded as systematic approaches to design, cover all aspects of the design process from problem classification to detailed design. The functional modelling approach is one of them and the one that concentrates on what has to be achieved by a new design and not on how it is to be achieved. This approach comprises 5 steps, namely; 1) express the overall function in terms of conversion of inputs into outputs, 2) break down the overall function into a set of essential sub-functions, 3) draw a block diagram showing the interactions between sub-functions, 4) draw the system boundary to define the functional limit of the product and, 5) search for appropriate components to perform the sub-functions and their interactions (Cross, 2000). One of the well-known *functional modelling* frameworks is that of (Pahl and Beitz, 1996) which was developed based on the concept of flow. This framework modelled the overall function of a product and decomposed it into sub-functions based on the flow of energy, material, and signal.

A functional model is a description of a product or process in terms of the elementary functions that are required to achieve its overall function or purpose. A graphical form of a functional model is called functional structure, represented by a collection of sub-functions connected by the flows on which they operate (Pahl and Beitz, 1996). Functional models provide the benefits of an explicit relationship to customer needs, comprehensive understanding of the design problem, enhanced creativity, innovative concept generation, and systematic organization of both design problems and the design team (Otto and Wood, 2001; Ullman, 2003). It facilitates the

designer to see what types of functions are performed without being distracted by any particular form the artefact may take and increases the clarity of the design problem and the tracking of input and output flows (Pahl and Beitz, 1996). Functional models, when applied during preliminary design, provide flexible models for problem abstraction, which can help answer numerous design questions (Otto and Wood, 2001). However, the problem with many of these functional modelling approaches is their inability to produce repeatable functional models of a particular product. The lack of a precise definition for small, easily solved sub-functions casts doubt on the effectiveness of this approach (Pahl and Beitz, 1996; Ullman, 2003).

Early efforts for standard design language to describe functions and flows were made by Pahl and Beitz (1996). They listed 5 generic functions and 3 types of flows, at a very high level of abstraction. Hundal (1990) formulated 6 function classes complete with more specific functions in each class in order to make function-based design computable. The latest effort is a design language known as *functional basis* (Stone and Wood, 2000) and *reconciled functional basis* (Hirtz *et al.*, 2002). Functional basis consists of a set of functions and a set of flows that are used to form a sub-function that is capable of describing the mechanical design space. It is a tool to generate a functional model of a product. Functional basis is intended to be broad enough to span the entire mechanical design space while not being repetitive. Functional basis consists of 2 sets of terminology: the first containing action verbs to describe function, and the second containing nouns to describe flow. Functional basis spans all engineering domains while retaining independence of terms.

The function set of functional basis is broken down into 8 categories termed the primary classes. These classes have further divisions, called the secondary and tertiary levels that offer increasing degrees of specialization. The primary class represents the broadest definition of distinct function

while the tertiary class provides a very specific description of function. The secondary level of the function set, containing 21 action verbs, is the most often used class of the basis (Hirtz *et al.*, 2002). Examples of the primary class and secondary class of function and flow are shown in Tables 1 and 2, respectively. Similar to the function set, there are 3 distinct classes within the flow set of the functional basis. Within the primary class of the flow set, there are 3 main categories used to describe flow: material, signal, and energy – as popularized by Pahl and Beitz (1996). The review shows that the advantages of functional modelling for the conceptual design phase have been acknowledged by several researchers and repeatable function models can be achieved through the employment of functional basis. Thus the hypothesis of the study is that applying functional models will facilitate design engineers to come up with a conceptual design of a product based on the customers' needs.

Methodology

This section presents the application of Stone and Wood's functional model derivation approach using the functional basis of Hirtz *et al.* (2002). The 3 tasks of functional model derivation technique (Stone and Wood, 2000) and task 4 that derives sub-solutions of an electrical shoe dryer is presented in this section.

Task 1: Generate Black Box Model

The first task in the development of a functional model is to create a black box model; a graphical representation of product function with input/output flows. The overall function of a product was expressed in the verb-object format.

Task 2: Create Function Chain for Each Input Flow

In task 2, a chain of the sub-functions that operate on each flow was developed. To develop a chain for each flow, each operation on the flow from entrance until exit of the

product (or transformation of another flow) was considered and expressed in the verb-object format. Next, the functional model was arranged with respect to time. The concept of parallel and sequential dependencies of flow and sub-functions was applied in this case. In the sequential function chain the sub-functions were performed in a specific sequence to generate the desired result (Stone and Wood, 2000).

Task 3: Aggregate Functional Chains into a Functional Model

The final task of functional model derivation was to assemble all functional

chains into a single model. To accomplish this task, the interface between the functional chains was identified.

Task 4: Derive Sub-solutions

In this task the potential solution of each sub-function was identified based on the designer's experience and with the aid of the product catalogue.

Results and Discussion

In the development of the black box model of an electrical shoe dryer, one of the researchers acted as a customer and attempted to tell the

Table 1. Function examples from the reconciled functional basis of Hirtz *et al.* (2002)

Class	Secondary	Class	Secondary	Class	Secondary
Branch	Separate	Control magnitude	Actuate	Signal	Sense
	Distribute		Regulate		Indicate
			Change		Process
			Stop		
Channel	Import	Convert	Convert	Support	Stabilize
	Export				Secure
	Transfer				Thermal
	Guide				
Connect	Couple	Provision	Supply		
	Mix		Store		

Table 2. Flow examples from the reconciled functional basis of Hirtz *et al.* (2002)

Class	Secondary	Class	Secondary
Material	Human	Energy	Human
	Gas		Acoustic
	Liquid		Biological
	Solid		Chemical
	Plasma		Electrical
	Mixture		Electromagnetic
Signal	Status	Hydraulic	
	Control	Magnetic	
		Mechanical	
		Radioactive/nuclear	
		Thermal	

researchers about the the needs as a customer in relation to the product. At the end, a list of customer needs was produced and formed the basis for the black box development. For the black box model of an electrical shoe dryer, the flows (material, energy, signal) were wet shoes, hand, air, electric, and ON/OFF. Figure 1 shows the black box model of an electrical shoe dryer with input/output flows of material, energy, and signal.

Five flow chains were developed for an electrical shoe dryer of which 3 flows were of material, 1 flow of energy, and 1 flow of signal. The 5 function chains for an electrical shoe dryer are shown in Figure 2. To designate a flow, the researchers thought of the necessary operations in the flow of hand, wet shoes, air, electrical energy, and ON/OFF from the entrance until exit of the product. For example, 3 sub-functions are required to operate on electricity before it is converted to thermal energy and rotational energy, 4 sub-functions for the flow of air, 2 sub-functions for the flow of wet shoes, and only 1 sub-function for the flow of hand and ON/OFF. The functional chains were expressed in the standard design language (functional basis) as in Table 1. Functions and flows were combined in verb-object form for describing sub-functions.

For an electrical shoe dryer, the flow of air produces a sequential function chain as 4 sub-functions must operate on the flow of air before it exits the product, as shown in Figure 3(a). Parallel functional chains consist

of sets of sequential functional chains sharing 1 or more flow. Graphically, they are represented by a flow which branches in a functional model. Figure 3(b) shows the parallel functional chain of an electrical shoe dryer. In it, the flow of electricity branches to form parallel chains of sub-functions. The 2 chains operate independently of each other (the first is concerned with converting electricity to rotational energy and the second is concerned with converting electricity to thermal energy).

There are 4 interface points in the functional model of an electrical shoe dryer. These interface points are identified through 2 arrows pointing toward the functional box, as shaded in Figure 4. The interface point between function chains for the flow of electricity and air is at 'import gases' and 'transport gases'. At this interface the rotational energy is transmitted for actuating air flow, meanwhile thermal energy is transmitted to the flowing air to generate hot air. The flow of hand and wet shoes meet at the 'position solid' as the human hand is required to take the wet shoes and bring them into the product boundary. Afterwards the wet shoes will be positioned and the hot air will blow towards the wet shoes to dry the shoes before they exit the product. The result of this task is an assembly of functional chains that are called a functional model of an electrical shoe dryer, as shown in Figure 4, expressed as the functional basis.

The first standard products/components to satisfy the sub-functions are identified.

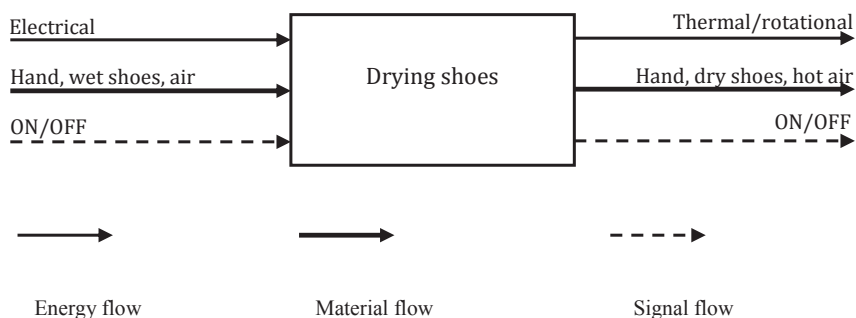


Figure 1. A black box model of an electrical shoe dryer

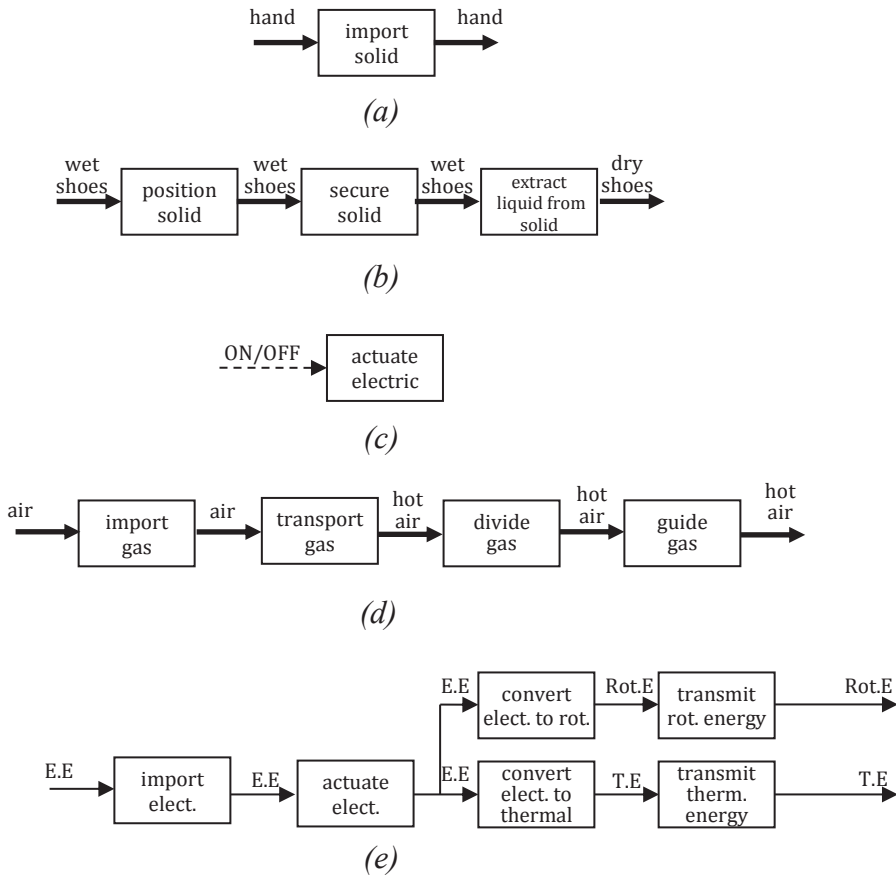


Figure 2. Five functional chains for an electrical shoe dryer: (a) functional chain for the flow of hand, (b) functional chain for the flow of wet shoes, (c) functional chain for the flow of ON/OFF, (d) functional chain for the flow of air, and (e) functional chain for the flow of electrical energy

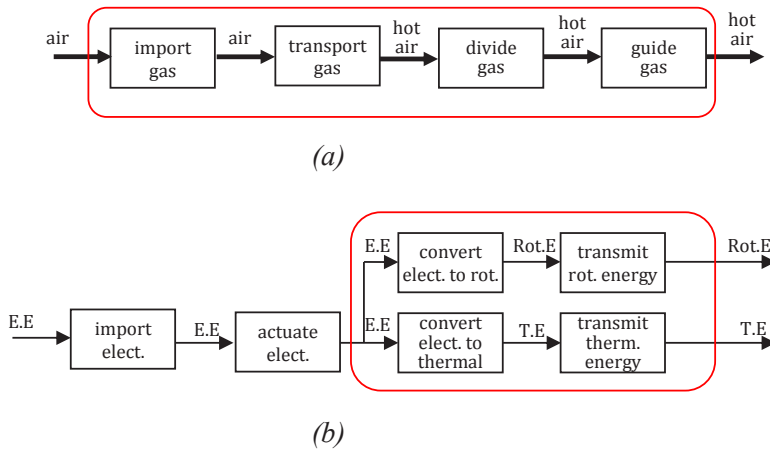


Figure 3. Functional chains of air and electricity: (a) sequential functional chain and (b) parallel functional chain

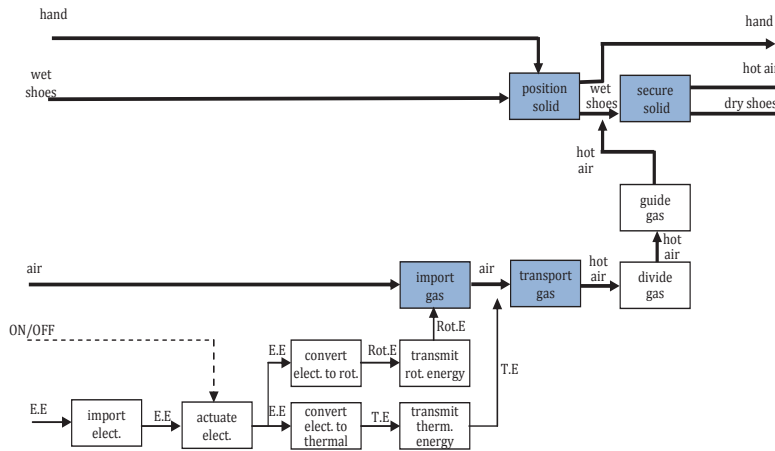


Figure 4. Functional model of an electrical shoe dryer expressed in the functional basis

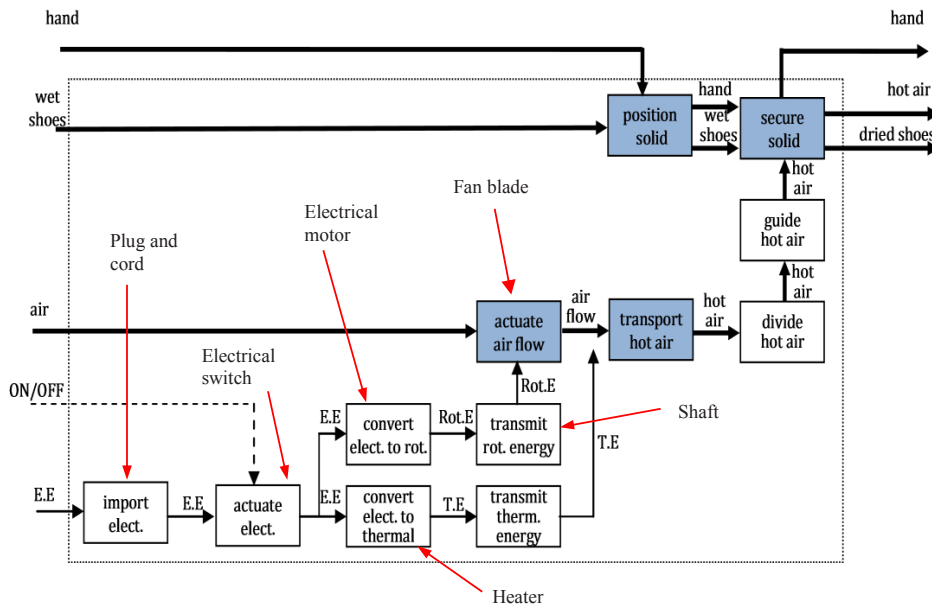


Figure 5. The standard products/components for an electrical shoe dryer

As shown in Figure 5, there are 6 standard products/components that are able to satisfy the sub-functions. For example, the sub-function to ‘convert electricity to rotational energy’ was satisfied by an electric motor and the function to ‘actuate electrical energy’ was satisfied by an electrical switch. Later on, the sketch of these products/components is drawn and the required basic properties i.e. structure,

form, material, dimensions, and surface of the product were determined to satisfy the other sub-functions. Figure 6 shows the initial concept design of an electrical shoe dryer.

Conclusions

This research aims to understand the advantages of a functional modelling approach

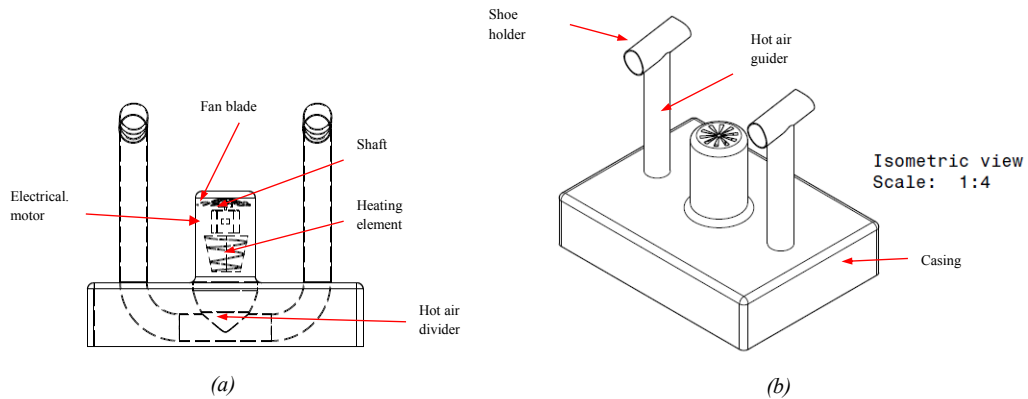


Figure 6. Initial concept design of an electrical shoe dryer: (a) 2D design and (b) 3D design

in facilitating design engineering at the conceptual design phase. The functional modelling approach of Stone and Wood (2000) was followed step by step from the development of a black box model until the aggregation of functional chains to form a functional model of the product. The functional basis of Hirtz *et al.* (2002) was employed as the design language to describe sub-functions and flows of the product. In general, the application of the functional modelling approach is able to provide design engineers with the overall image of the product without the existence of the physical entity of the product. In addition, with the help of graphical representation this approach is able to facilitate the design engineer to implement the required function into the product. It was obvious that, in the derivation of functional modelling, the experience of design engineers is influenced towards the detail of the chain of sub-functions for a flow. It was found that the approach lacks detailed procedures and rules in the aggregation of individual functional chains to form the functional model of a product and, thus, needs improvement.

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