DESIGN AND DEVELOPMENT OF A BRAKE SYSTEM USING SMART MATERIALS

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Untuk mu Aziyah…

Aku ingin engkau selalu.... hadir dan temani aku....
Di setiap langkah yang meyakini ku... .kau tercipta untuk ku.....
Meski waktu akan mampu.... memanggil seluruh ragaku.....
Ku ingin kau tahu.... ku selalu milik mu.....
Yang mencintai mu.... Sepanjang hidup ku....

Untuk mu Ibu....

Duhai apakah gerangan budi balasan....
Bagi insan melahirkan membesarkan....
Tiada bahagia jika tiada doa puja restu...
Syurga itu di telapak kaki ibu.....

Akmal 2007

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Weingarten, Germany
April 2007

Muhammmad Akmal Johar

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ABSTRACT

The research is done to fulfil the requirements of the Master of Mechatronic program at the University of Applied Sciences Ravensburg-Weingarten. This research is about designing a new concept of a brake system using smart materials. Smart materials are materials that receive, transmit or process a stimulus and respond by producing a useful effect. Smart materials have attracted researchers' attention in venturing a new technology that can improve our lives. There are a lot of materials that have been considered as smart materials. In this research a new type of material which is Ferromagnetic Shape Memory Alloy (FSMA) has been chosen. This alloy have significant advantages in term of producing a large scale of output effect and delivering fast response times compared to the other types of materials Based on these factors FSMA can be an appropriate material as an actuator for brake mechanism systems.

After the invention of FSMA in early 1990s by Dr. Kari Ullako, lots of research laboratories has set up new research groups in order to have a better understanding about this material. Up to now they are still venturing the ways to develop this material as actuators. There are a lot of potential field of application such as couplers element, vibrators element, sensor and generator element, fluidic element and positioning devices. FSMA products that have been made available in the market are linear motor and fluidic pump from Adaptamat Ltd. FSMA has a big potential to replace current mechanical actuator and machinery such as pneumatic and hydraulic.

In designing a brake system for robot applications there are several design constraints that need special attention. The design must be light and compact so that it will not become a significant additional load to the robot. In this robot application the brake system has a slightly different requirement. The brake torque is required to provide grips to the rotary shaft and not to stop the wheels. So in this application an initial braking torque is preferred.

The research also gives special attention in finding an innovative way to improve the methodology of designing and developing mechatronic products. A new approach using the UML 2.0 has been used as a modelling technique. The technique is a well proven technique in the software engineering applications and with a minimum modification it is now suitable for the mechatronic engineering. Based on the results that have been achieved in this research the integration of the UML 2.0 with the Pahl and Beitz design methodology and the V-model has been successful.

Author

LIST OF FIGURES

LIST OF TABLES

Content

CHAPTER 1
INTRODUCTION

1.1 Project Background and Motivation

A research group at the University of Applied Science Ravensburg-Weingarten is working on a development of a high dynamic chassis robot. This research group was initiated by Prof. Dr.-Ing. Ralf Stetter and Prof. Dr.-Ing. Andreas Paczynski. Figure 1.1 shows the mobile robot that has been developed and designed at the University of Applied Science Ravensburg-Weingarten.

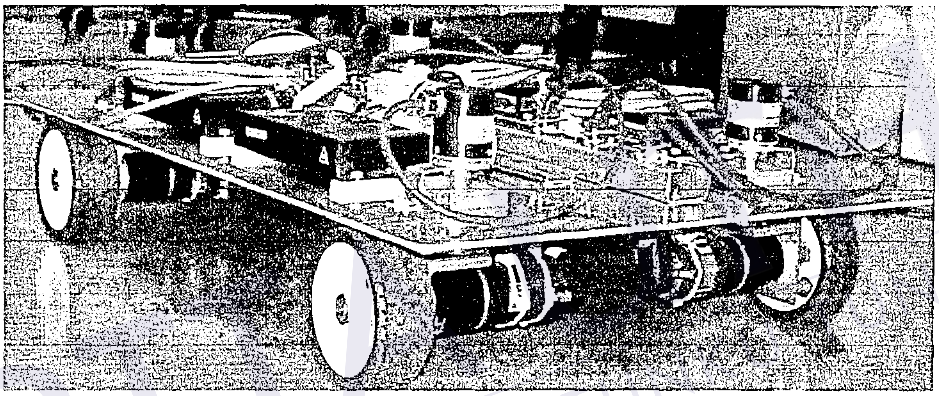

Figure 1.1: Prototype of high dynamic mobile robot.

The goal of this research is to build a robot system that has a high dynamic drive system. The drive system is built by just a drive motor and a position encoder for each wheel. The concept to steer this robot is by using the torque originally intended to drive the robot. This steering function can be achieved by controlling the amount of torque for each wheel. So it does not use any conventional steering system which is normally using a mechanical steering mechanism.

The other characteristic of this innovative drive is that each wheel can be directed into any desired position and this allows the robot to move almost in any direction without time and space consuming manoeuvres. Each of the wheels is capable to make a rotation up to 320°. This robot also has the possibility to turn around its centre. This will be an advantage if the equipment attached on this robot such as a camera that can only work at a certain orientation.

This innovative dynamic drive system not only offers the same advantage as an omni drive system but also produces a significant improvement in terms of friction reduction as well as an easier controllability.

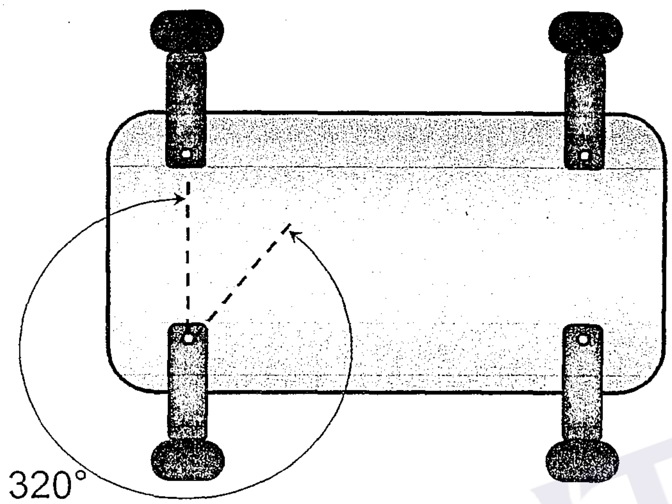

Figure 1.2: Possibility of the wheel to rotate

One important requirement of this robot is a high precision of movement. Each wheel of this robot is equipped with a motor and an encoder. When receiving a signal from the main controller, the system will provide enough electrical current to allow the motor to produce the desired torque to make a turn while the encoder is used to determine the positioning of the angle of the wheel. It is obvious that these two components alone cannot produce a high stability system. This is because even though we can control the current supplied to the motor to give the required angle, external forces such as inertia forces can cause the arm with the wheel to turn more than expected. With help of an encoder a feedback control system can be applied to turn the arm with the wheel back to the desired angle. This action needs a period of time before achieving the settlement. Therefore a braking system is desirable to minimize the settlement time and to give the mobile robot the stability and precision that it needs. An initial braking torque to the wheel axis is also required in this brake design because this initial torque will provide grip to the axis which prevent the wheels to rotate or to turn easily when moving on a rough terrain or hitting an obstacle.

1.2 Project Objective and Goals.

Exploring a new way to improve the quality of our lives and products we use is frequently the main objective when producing new concept designs. The main aim of the research describe in the thesis is to explore a new concept for a brake mechanism. In order to achieve this goal, the possibility of using smart material as a new brake actuator was exploited.

A previous attempt to design a brake system for this robot has been made by Ramhuzaini [10]. In his project he used a piezoelectric material as an actuator for his brake mechanism. The project was successful but it suffered from a few drawbacks. In his report he mentioned several rooms of improvement for his design. The fact that piezoelectric materials produce a small scale of action makes them more suitable for micro size application.

Based on previous experience it was decided to develop a new concept of a brake system using a smart material. Thus this research has a freedom in terms of choosing the right smart material that can be used as a brake actuator. This new design also must capable of producing a high efficiency and precision braking that the robot described in Section 1.1 needs.

It is intended that the outcome of this research can be used as a replacement of conventional hydraulic braking systems.

Apart from producing a new concept for a brake mechanism, this research is also looking for possibilities to improve the design methodology of a mechatronic product. Since a mechatronic product is a combination of several disciplines of engineering the necessity for generally agreed upon of a systematic approach in process design. Ramhuzaini [10] has successfully integrated two design methodologies which are the Pahl & Beitz design methodology and the V-Model design methodology during designing his piezoelectric brake system. The research presented in the thesis will ascertain if there is any room for improvement from the said combination.

The summary of the research objective, strategies and goals are as below.

Objective of the project:

1. To identify a suitable smart material that is applicable to be used in a brake system.
2. To have a new concept design of a braking system using the chosen smart material.
3. To discover innovative directions in terms of a design methodology for mechatronic products.

Strategies to achieve the objective:

1. To produce a comprehensive literature review of smart materials.
2. To generates a detail understanding about the selected smart materials.
3. To produce as many as possible new concept designs using the smart materials.
4. To produce a detail analysis for every concept design.

Goals of the project:

1. To produce a complete mechatronic system that produces a brake force by using a smart material as an actuator.

1.3 Project Timeline and Research Organisation

This project needed to be completed within 6 months. Within this short period of time an engineering design methodology which is introduced by Pahl & Beitz [1] has been used. This methodology involves several phases as follows:-

1. Planning and Task clarification phase.
2. Conceptual design phase.
3. Embodiment design phase.
4. Detail design Phase.

A Gantt chart has been developed to monitor this design activity. This chart provides a guideline of important event during the design process. The complete Gantt chart can be found in appendix A1.

The research is done by the author under the guidance from Professor Dr. Ing Ralf Stetter. However other professors from their respective field also a give significant input and guidance towards the completion of the thesis.

1.4 Thesis Organisation

This thesis is divided into six main chapters. In the first chapter an overview and background of this project is given. The initial information will certainly help the readers to have an overall idea about this project.

Chapter two will provide the reader about the background knowledge behind this research. An explanation about the research methodology can be found here. Readers can read a brief explanation of the modelling technique that has been used in this research. In this chapter readers will find facts about smart materials in general. A detailed explanation about Ferromagnetic Shape Memory Alloy will be given in this chapter because this material has been chosen as a material for this research.

In chapter three, the author will present all the concept designs that have been developed. A detail explanation of the working principle for each concept design can be read in this chapter. At the end of the chapter three there will be a discussion about the selection of the best concept design.

Chapter four will give readers a detailed description of the embodiment design. A refinement process of the selected concept design has been made. A complete detail documentation involving part design and the calculations can be found in this chapter.

In chapter five, the author will give comments about the modelling technique that has been used to model the system. The UML 2.0 is a modelling technique that is normally used in software engineering. In this research this technique has been used and the result of this attempt will be discussed in chapter five.

Finally the summary of this project will be digested in chapter six. Here the author also writes about his personal experience during executing this research. The possibilities for improvement of this project are discussed in this chapter.

CHAPTER 2
LITERATURE REVIEW

2.1 Chapter Overview

This chapter focuses on the methodology of this research. Here there will be a brief explanation on how the research is done. In this chapter readers can find an explanation about the Pahl and Beitz design methodology. It is followed by a short explanation about the new design methodology which is a combination of the Pahl and Beitz design methodology and the V-model design methodology. A short introduction of the UML 2.0 modelling technique and how it can contribute to this research is also discussed here.

This chapter will also cover a topic on smart materials. A brief explanation about smart materials and types of smart materials can be found in this chapter. There is a further discussion about Ferromagnetic Shape Memory Alloy as the chosen smart material for this research.

2.2 Pahl and Beitz Design Methodology

2.2.1 Introduction

The design methodology is a critical element in a product development. It will help the designer to work systematically and efficiently. There are a lot of design approaches available and every method has its own advantages and disadvantages.

The Pahl and Beitz design methodology is an established design methodology for mechanical products. Nowadays a solely mechanical product is hardly found. Each product available in the market is mostly a combination of more than one engineering discipline. This new engineering discipline is called as mechatronic engineering.

There is a suggestion to develop a new design methodology for developing mechatronic products. Rahman and Stetter [2] have suggested a combination of the Pahl and Beitz design methodology and the V-model based on VDI 2206 that can be used for the development of mechatronic product.

Pahl and Beitz [1] introduced four steps of design process in their design methodology. These design processes range from the beginning stage until their completion. The design steps are given as follows.

1. Planning and Task Clarification
2. Conceptual Design Phase
3. Embodiment Design Phase
4. Detail Design Phase

In the next section, a brief explanation for each design stage will be given.

2.2.2 Planning and Task Clarification Phase

In every product development the most important information for the designer is to know the design task. In the first phase of the design process, the designer must prepare an overall plan of design activities and has to clarify the main task of the design.

In this stage of design phase, the main task is collecting the required information. The designer must acquire an adequate data with regards to the objective of the project and the user requirements. This initial information is important to help the designer to identify what is the specification of the final product and what is the design constraint of this product.

Pahl and Beitz [1] suggest following working steps in the planning and task clarification phase. These working steps are shown in Figure 2.1 as a reference. At the end of this phase a document called a requirement list or a design specification will be created. This document will be the guideline for the designer to move to the next design stage which is the conceptual design phase.

2.2.3 Conceptual Design Phase

The conceptual design phase is a process where the information is extracted from the requirement list into the complete concept design. Pahl and Beitz [1] have recommended a procedure to produce a systematic concept design. Figure 2.2 shows the working steps in the conceptual design phase. In this process identifying the essential problem is required in order to produce the function structure of the product.

A function structure represents an overall relationship between the input and the output of the product. It is built on many sub-functions. All sub-functions work together to produce the required output. The designer is responsible to identify every possible working principle that can perform the function for each of the sub-function. The combination of these working principles from each sub-function will produce a concept design.

Normally the designer tries to produce as many concept designs as possible. By having many variants of concept designs, the designer will have the possibility to choose the best concept design. The selection of the best concept design is done during the evaluation stage. In order to perform the evaluation process of the concept design, the designer must identify the evaluation criteria which are based on the requirement list. The weight of the evaluation criteria need to be set to differentiate which criteria are the most important criteria compared to the others. This factor will help the designer to select the best concept design in a systematic way.

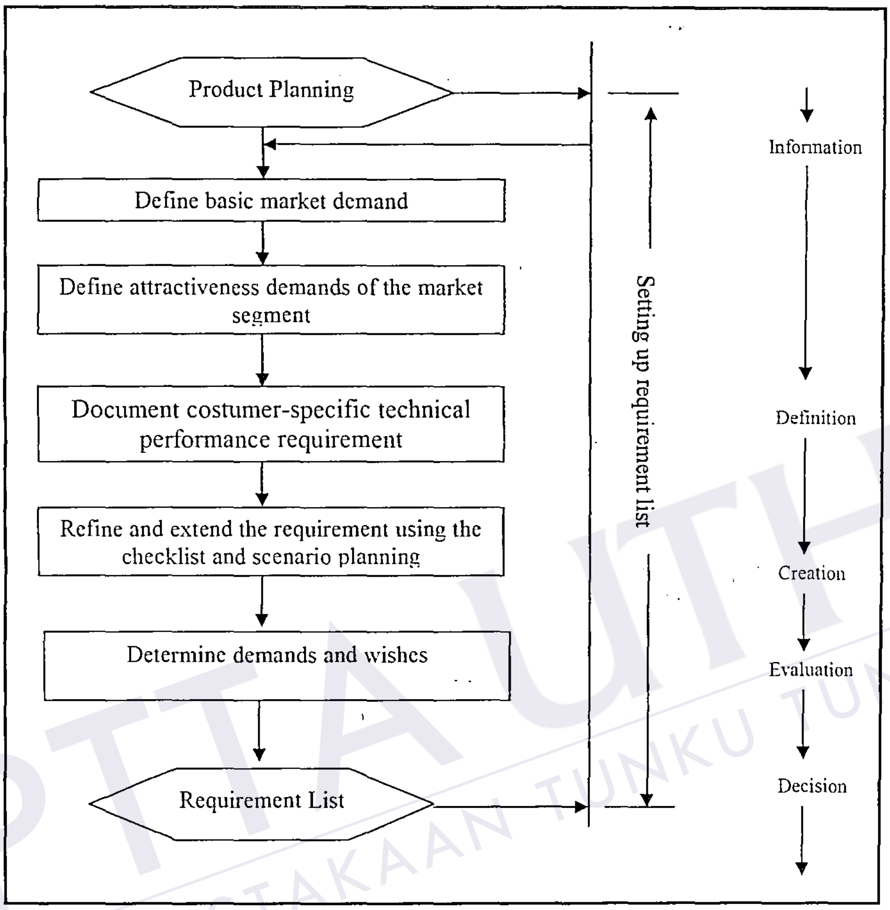

Figure 2.1: Pahl and Beitz [1] main working steps to produce a requirement list.

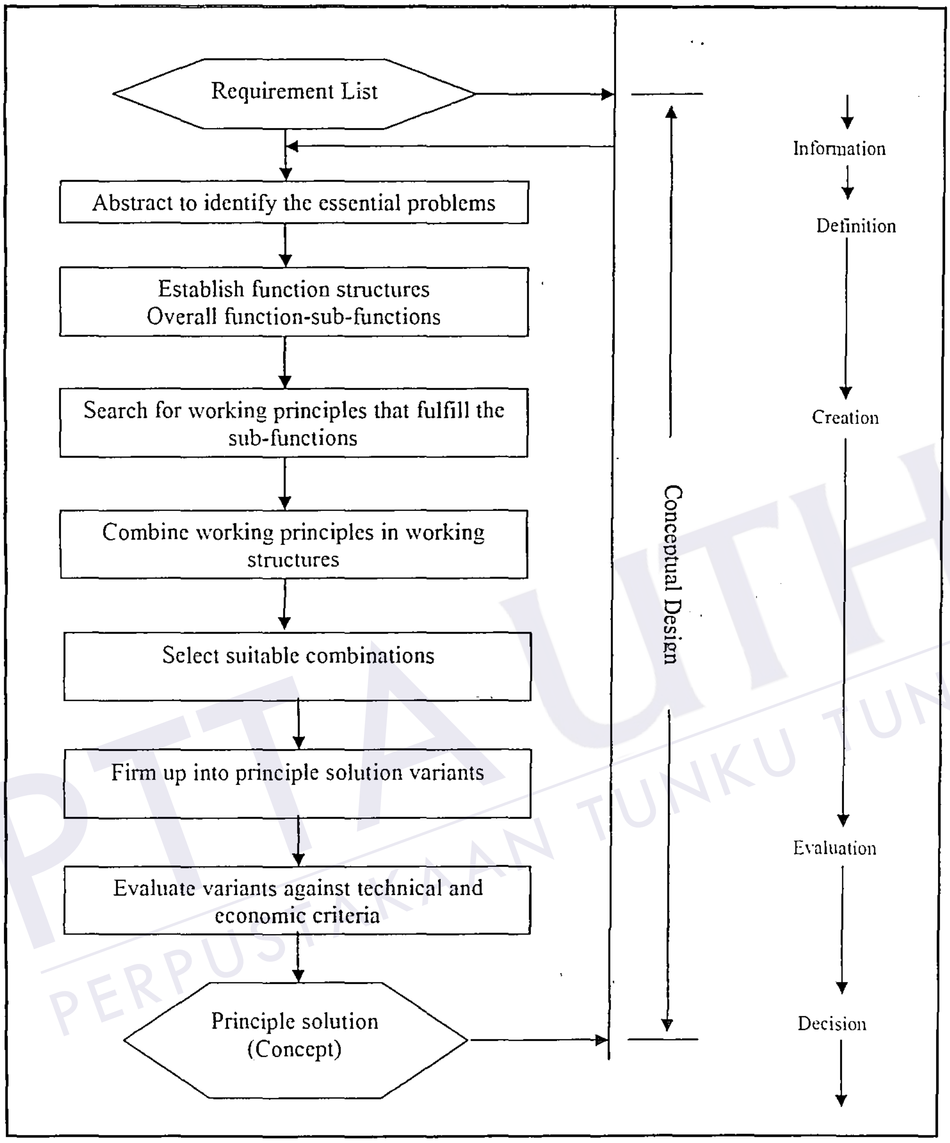

Figure 2.2: Pahl and Beitz [1] working steps of conceptual design phase.

2.2.4 Embodiment Design Phase

Embodiment design phase is a design process where a further refinement of concept design is being made. In this stage the ideas behind the concept design will be firmed up. In this process, a drawing for each involving component will be prepared. In figure 2.3 shows recommended steps in the embodiment design phase by Pahl and Beitz [1].

The embodiment process is a complex process. This is because many activities need to be done simultaneously. This process is not only one cycle of operation. Several iterations are possible due to several factors. For example if a new piece of information about the material causing the current design not applicable anymore then it may lead to an overall alteration of the design. A new additional requirement or function of the design also can be a reason for iteration in the embodiment design phase.

In the embodiment design process there are three basic rules need to apply. The basic rules are clarity, simplicity and safety in design. Clarity in design mean with the given function, every interrelationship between sub-functions must be guaranteed. For the chosen working principle every input and output of physical effect must also have a clear relationship between them. If these factors are able to be clarified then the design should have fewer problems during the integration and testing phase.

Simplicity in design is also one of the key rules during the embodiment design process. A customer will certainly prefers a simple product compared to the other complex product in the market which offers the same functions. This design rule will produce a minimum number of sub-function and working principle in the design. This will reduce the quantity of the components required and furthermore will reduce the cost of the product.

Safety is another issue in the embodiment design. Safety measurement can be classified into three types which are direct safety, indirect safety and warnings. The designer must be aware about the component and the reliability of the function that are used in the design. This will guarantee that the product has a high operational safety level.

2.2.5 Detail Design Phase

Detail design phase is the stage where all design activities is completed. At this stage the design must be ready to be manufactured. The main task in this stage design is preparing the complete specification of all component involved with the final instruction about the shapes, forms, dimensions and materials.

The designer needs to prepare the manufacturing instruction and all relevant manufacturing documents. Figure 2.4 shows Pahl and Beitz [1] suggested steps in the detail design phase. However in this research the design activities are only be done until the embodiment design phase. This is because it is required a longer time and more manpower in order to accomplish all the design activities.

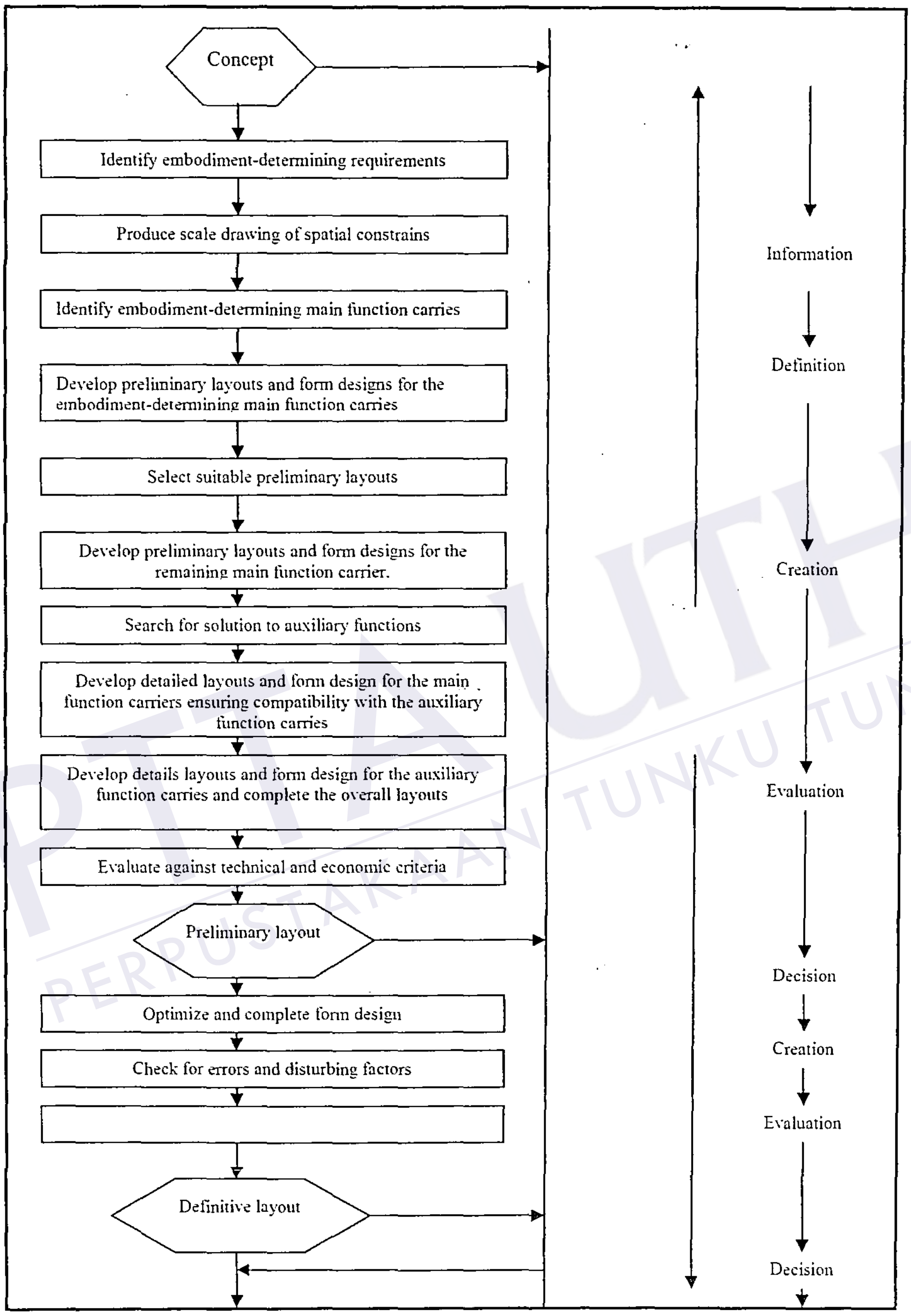

Figure 2.3: Pahl and Beitz [1] steps of embodiment design.

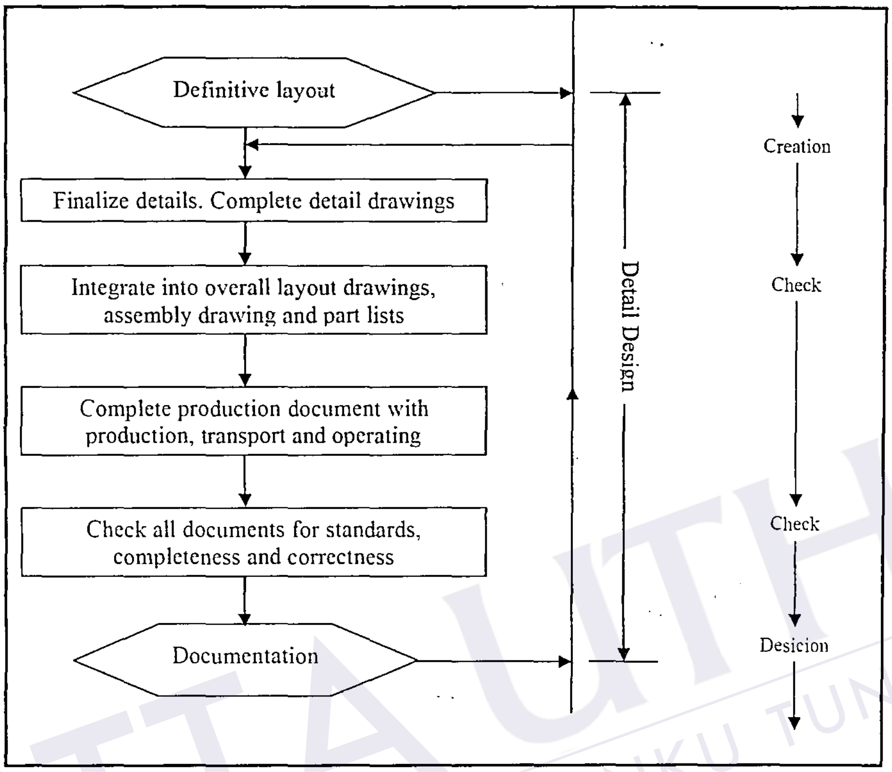

Figure 2.4: Pahl and Beitz [1] steps of detail design.

2.3 V-Model (VDI 2206: Design Methodology for mechatronical system)

As explained in the previous section, the Pahl and Beitz design methodology is a suitable design methodology for designing mechanical component. Since this research involve in designing a mechatronic product, using the Pahl and Beitz design methodology is considered as a non-ideal tool for this purpose.

However Germany federal administration has introduced a guideline for designing mechatronic products which is based on the V-model. This guideline is called "VDI 2206: Design methodology for mechatronical systems". A V-model diagram is a graphical representation of a product development cycle. It starts with the requirement list of the system. From this requirement list a cross-domain principle solution which describes the requirement is created. At this stage of development phase is called as the system design phase. In this phase, the V-model diagram will clearly show the main engineering domains that involve in the system. Each sub-function will be separated from each other based on their engineering domains. At this point each engineer from the respective field will have a clear picture regarding the task and their responsibilities.

The next design stage is called the domain-specific design. In this stage the engineer is still working separately in their own domain to find the specific solution of each task. An integration process will take place after completing the domain-specific design phase. This stage is called the system integration phase. Here the result from each domain will be integrated together to assemble as a complete product. A lot of testing and validating efforts need to be done at this stage to ensure the end product fulfils all requirements. After all testing and validating results fulfil the initial requirement list then the product development cycle is completed. Figure 2.5 shows the basic V-model diagram.

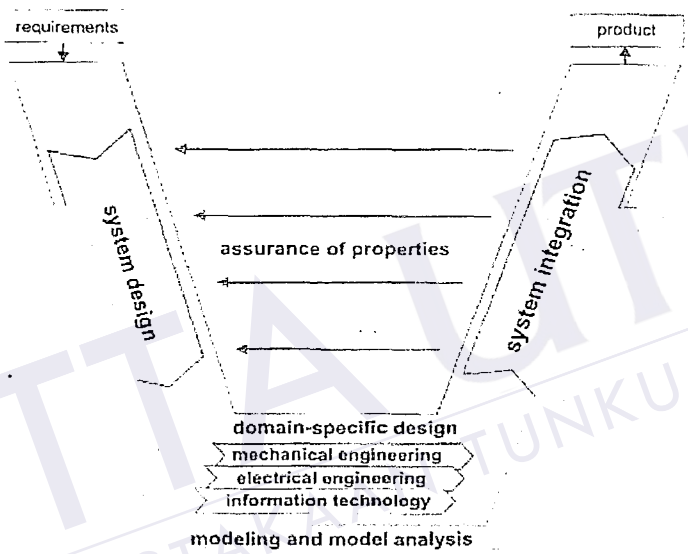

Figure 2.5: V-model (VDI-Guideline 2206)

2.4 Combining Pahl & Beitz design methodology and VDI 2206 design methodology

An effort has been made in order to improve the design methodology for mechatronic products. Mr. Ramhuzaini [10] in his thesis has shown a high degree of success in combining the Pahl and Beitz design methodology with the VDI 2206 design methodology.

In his findings, the VDI 2206 was acting as a process model since the V-model is very useful in dividing a complex development work into their respective engineering domains. This will help the design process of the Pahl and Beitz design methodology to be more organized. Therefore this combination of the two design methodologies will produce a more systematic and organized work for process development of mechatronic products [2]. Figure 2.6 shows the process model for the new design methodology.

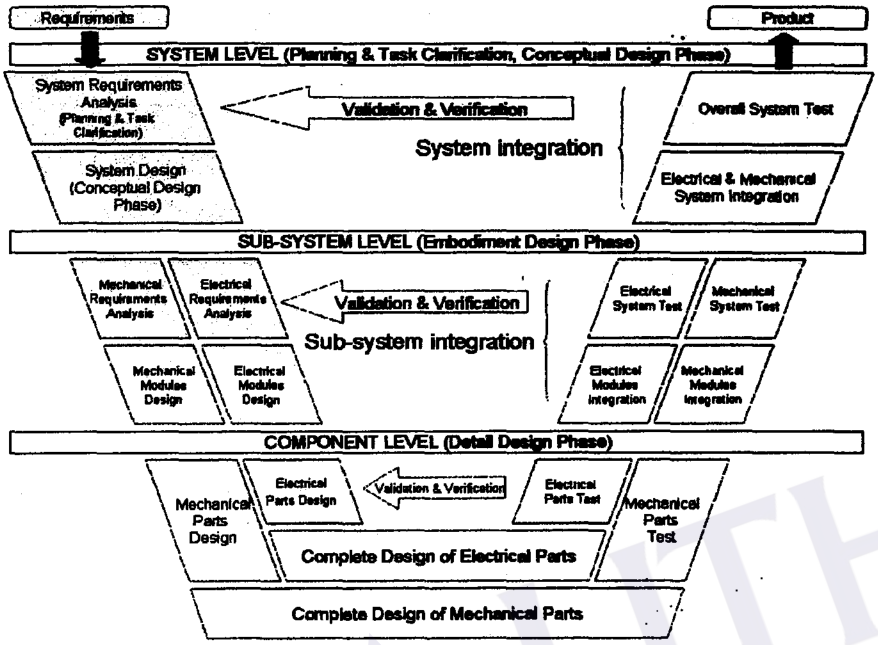

Figure 2.6: The combination of the V-model and the Pahl and Beitz Design Methodology structure.

In this new structure, the V-model diagram can be divided into three main levels which are the system level, the sub-system level and the component level. In the system level the main objective is to produce a cross-domain solution principle that describes the main characteristic of the system based on the requirement list. The main activities during this stage are the planning and task clarification phase and the conceptual design phase.

The outcome of the system level will become the input of the sub-system level. Here the main system already divided into several sub-systems with respect to their engineering domains. A further refinement of each solution principle is carried out here via an embodiment design process. The outcome of this process is a rough layout design which includes the overall arrangement of the subsystem.

The next stage is the component level stage where a detail design activities is carried out. Here the process covered the detailed design of each component, the detail calculations and analysis concerning every single parameter involved. After completing the detail design phase, all these components are being documented and are ready to be produced.

In the sub-system integration all components will be assembled to produce a complete sub-system. Here each sub-system will be tested to validate each subsystem follow all the respective requirement list.

After completing the validation process, an integration process is carried out to produce the final product. This activity is performed during the system integration phase.

APPENDIX D
REFERENCE LIST

[1] Pahl.G.;Beitz.W,;Feldhusen.J,;Grote.K.H, *Engineering Design :A systematic Approach.* Springer-Verlag, Berlin, Heidelberg, New York,Tokyo 2007 (3rd Edition)

[2] Rahman; Stetter.R; Pulm,U., *Systematic Mechatronic Design of Piezoelectrical brake.*, International Conference on Engineering Design, ICED '07.

[3] James A. Harvey, *Handbook of Material Selection.* ISBN 0-471-35924-6 John Wiley & Sons Inc New York. Pg: 401-418.

[4] Ullako K. M., *Method of producing motion and force by controlling the twin structure orientation of a material and its uses.* US Pattern No.:6 157 101.

[5] Adaptamat Ltd., *Technical Specification of MSM actuator model A5-2.* Refer from website www.adaptamat.com.

[6] O'Handley et al., *High Strain Magnetic Field-Controlled actuator materials.* US Pattern No. 5 958 154.

[7] Ohta et al. *Actuator* US. Pattern Document No.: 6 803 846.

[8] Ullako K.M, *Actuators and apparatus.* US Pattern Document No. 6 515 382 B1.

[9] Dieter M. et al.,*Rollof /Matek Machinen Elemente (Tabellen Buch).* ISBN 3-528-17028-X, Viewveg Fachbuecher der Technik. Pg: 1 Tb1.1.

[10] Rahman, R. B. A., *Systematic mechatronical design of a piezoelectrical brake*, Master Thesis, University of Ravensburg-Weingarten, 2006 (not published).

[11] Relationships Between Classes Table from www.developer.com.