國 立 交 通 大 學

機械工程學系

碩士論文

自動手煞車系統之產品設計

Product Design of Electronic Parking Brake

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碩 士 論 文

A Thesis
Submitted to Department of Mechanical Engineering
College of Engineering
National Chiao Tung University
in Partial Fulfillment of the Requirements
for the Degree of
Master
in
Mechanical Engineering

May 2006
Hsinchu, Taiwan, Republic of China

中華民國九十五年五月

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摘要

本研究是針對自動手煞車系統作產品設計。利用市場調查、品質機能展開(QFD)、機構設計、控制設計與系統整合，提供一完整的產品設計流程。

市場調查包含專利分析與市售產品調查。根據 46 篇專利分析結果顯示，自動手煞車專利篇數逐年增加，已漸漸取代傳統手煞車成為發展的主軸。另外市售產品調查也發現，此自動手煞車系統已成為許多市售車輛的基本配備，其中包含 Jaguar（XJ、S-type）、Audi（A6、A8），Renault（New Vel Satis、Scenic）、BMW（7-Series）與 Volkswagen（Passat）。因此，自動手煞車系統的發展是備受期待的。然而，此系統仍然有許多缺點有待改善，例如：複雜性、噪音、高價位與低效率等。

在對自動手煞車有了基本的瞭解之後，緊接著利用品質機能展開法，對於產品的設計發展與系統規格作評估。根據品質機能展開法的步驟，依序定義顧客需求、轉換為工程設計規格、比較現有產品與定義出目標設計值。

在機構概念設計過程中提出三個概念設計並且評估之，並對其中一個滿足最多需求功能的概念進行具體化設計（此概念可達成作動、減速、自鎖、緊急手動解除及平衡器等功能），而在具體化設計中，先進行有限元素分析，以根據分析結果選出適當的材料進行雛形機構的製作。

在結合機構與控制設計部分則是以 PC-based 的方式進行。先在電腦中以 LabVIEW 軟體架構出控制邏輯與模擬車上的控制元件（檔位、油門、煞車及速度表等），再與上述離形機構作回饋訊號的連接。最終建立一測試機台對離形機拉力及作動狀況作測試，預估出其輸入馬達扭力與輸出拉動煞車線的力關係圖，並比較本離形機與品質機能展開法所定之目標值的差異，作為日後設計的參考依據。

Product Design of Electronic Parking Brake

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ABSTRACT

This study focuses on the product design of an electronic parking brake (EPB) system. A complete product design procedure from market survey, quality function development (QFD) method, mechanical design, control design, system integration, and system test is provided.

Market survey includes commercial products review and patent analyses. The EPB patent population increases year by year after 1996. In addition, there are many brands of commercial vehicles, such as Jaguar, Audi, Renault, BMW, and Volkswagen, installing the system as an essential requirement. As a result, the EPB system is expected to be bright in the vehicle industrial. However, there are many disadvantages needed to be improved, such as complexity, noise, high cost, and low efficiency.

After the introduction and survey of EPB, design specifications of the system can be identified. The QFD method is used for the product development. QFD is used to transform the customers' requirements to the measurable engineering requirements, compare the available products, and determine the design target.

Then, three mechanism concepts are created and evaluated. The best one, including a operator, a reducer, a self-locker, a manual releaser, and a balancer, is selected to be embodied. FEA is used to help select materials and ensure the enough strength after the CAD model is developed

Finally, PC-based method is used to integrate the mechanism and electronics. The LabVIEW program controls the EPB in the virtual environment with considerations of various driving conditions. In addition, the sensor switch signals are fed back to PC to ensure the parking success. Then, testing instrumentation is built to verify the pulling force and practicability. Furthermore, the relation between the input motor torque and the output brake force is found for the application to other vehicles. Finally, the system specifications are compared with the QFD targets to be the criterion for future designs.

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NOTATIONS

F	The mechanism output force
F_x	The output force at different current
I	The motor input current
I_{Fx}	The input current when motor output force F_x
KW	The input power
n	The motor rotating speed
r	The mechanism moment arm
T	The motor output torque
V	The motor input voltage
W	The motor input power

CHAPTER 1 INTRODUCTION

1.1 Parking Brake

In the beginning of the vehicles invention, there was no parking brake system for using. At that time, the vehicles only had one brake system, named first brake system, and sometimes got failure or braked down because of the poor technique and the low efficient mechanism. However, these accident failures are a major threat to customs' lives. For this reason, the United States set up the law "vehicles should have second brake systems for emergency situations [1]". After the enforceable rule, vehicle companies started to pay attention to the importance of the second emergency brake system, which is also called parking brake system nowadays because of its parking stop function.

A traditional parking brake system has several basic functions, including parking, impermanent stop (coming cross a stop light), and gradient starting in the automatic transmission (AT) or manual transmission (MT) vehicles. When operating every function of parking brake system, the user needs to determine using the system or not by judging the outside situation. Then the user should choose an appropriate timing for operating the handbrake lever to cooperate with clutch pedal harmoniously. However, these operations require special skills and additional efforts. For instance, a user should operate the shift lever, parking pedal, and handbrake lever repeatedly at every stop. Unexpectedly pulling up the parking brake also causes emergencies in many cases. As a result, the parking brakes are still causing problems to customers.

1.2 Motivation

Generally speaking, the second emergency brake system was developed into three types, hand brakes, foot brakes and electronic brakes, according to the operation interface. From the literal meanings of these words, hand brakes and foot brakes mean that the user should put the hand stick or step on the foot pedal manually. On the contrary, the electronic brake can act automatically by actuators. It really makes driving and parking more convenient and more comfortable.

There are more and more vehicles installing the EPB system, such as the Jaguar XJ and S-type, the Audi A6 and A8, the Renault New Vel Satis and Scenic, the BMW 7-Series and the Volkswagen Passat. Market needs will strongly support the product development. Besides, the survey on the developing tendency of the parking brake system has been performed. It based on patents published in the United States Patent and Trademark Office (USPTO). The related searching key words were “electronic brake” and “brake” for vehicles Fig 1.2-1and Fig 1.2-2. According to the Fig 1.2-1, it shows that researches about the electronic parking brake system were increasing year by year after 1996. In addition, the figure (Fig 1.2-2) also indicates that the proportion of electronic parking brake (EPB) to parking brake was increasing (from 12.5% to 50.9%). With the requirement on the developing market, the EPB system will become the most attractive and expected object on the automobiles in the next decade.

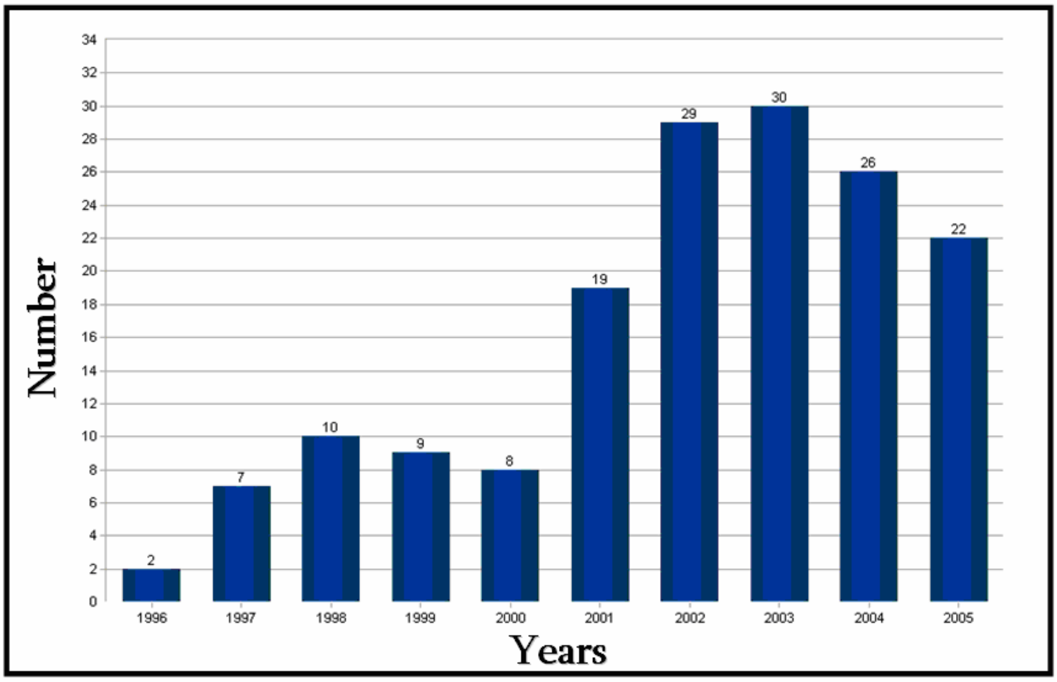


Fig 1.2-1 The Number of the EPB Patent

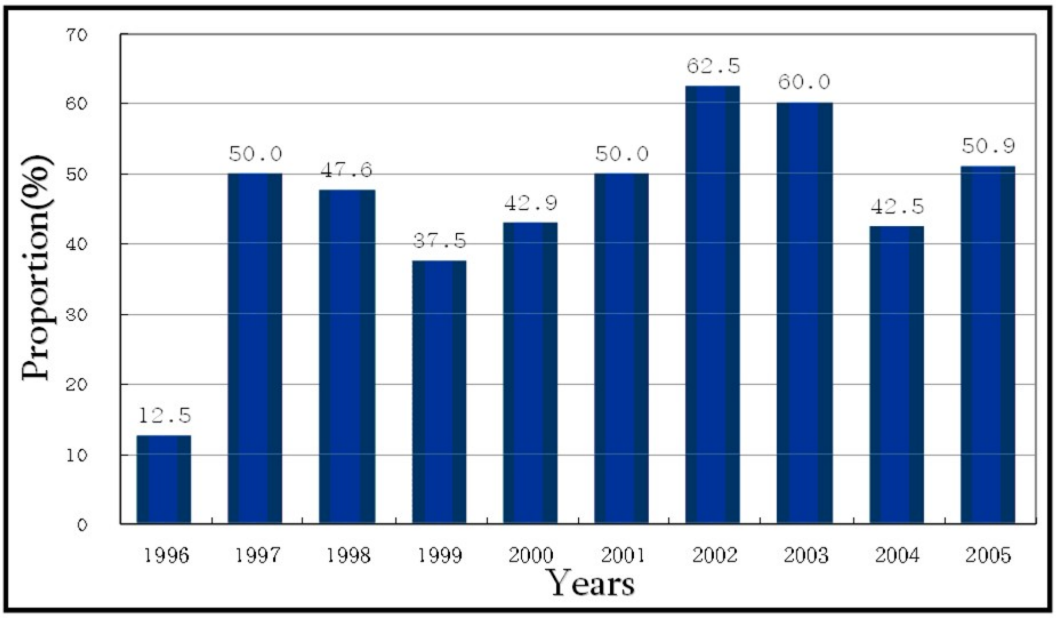


Fig 1.2-2 The Proportion of Electronic Parking Brake to Parking Brake

Although, the EPB system is more convenient and more efficient than traditional ones, it still has some problems, such as the failure of the power support, the crash of the control unit, the breakdown of the mechanism, and the failure of the lock component. There are lots of shortages needed to be improved.

1.3 Thesis Outlines

A complete product design procedure from market survey, QFD mechanical design, control design, system integrating, and prototype testing will be performed in this study. The final target of this study is to practice the process of product design by which the final EPB product is expected to be sold on market. In chapter 2, the EPB is introduced. Except the functions review, the study also focuses on the patents and market products survey. The functions of EPB, patents analyses, products comparison, and market investigations will be proposed in this chapter.

The QFD method, helping to develop a complete product, will be introduced in chapter 3. QFD is used to realize the customers' requirements, transform to the measurable engineering requirements, compare the available products, and determine the design target. Moreover, the specification target of the system is identified.

Three mechanism concepts are brought out and evaluated in chapter 4. The best design is selected to be embodied. FEA is used to help select materials and ensure the enough strength, after the CAD model is developed.

The control design, including firmware and hardware, is discussed in chapter 5. The LabVIEW control logic, controls the EPB in the virtual environment with considerations of various driving conditions is developed. In addition, the actuator and the sensors are selected thoughtfully.

The embodiment procedures, such as the prototype machining, the control interface, the system integrating, and the testing instrumentation, are completed in chapter 6. Furthermore, the system specifications are compared with the QFD targets to be the criterion for future designs. Finally, the conclusions and the future works are discussed in the last chapter

CHAPTER 2 ELECTRONIC PARKING BRAKE

2.1 Introduction

The EPB is popular in recent years. A computer-controlled unit actuates the parking brake is used. The functions for stopping brake, climbing start, and impermanent stop are all integrated in the s.

A standard EPB system includes two subsystems, the mechanism and the control. Each subsystem consists of several components (Fig 2.1-1). For example, the mechanism is comprised of an operator, a reducer, a self-locker and a manual releaser. The basic purpose of the device is to pull the brake cable smoothly and safely. On the other hand, the control part can be divided into two part: firmware and hardware. The firmware is the control logic and program written in a memory chip. Besides, the hardware part comprises actuators, sensors (speed, position, gradient, etc.), the user interface, power suppliers and emergency reminder (LED).

Sometimes, this electronic subsystem might integrate with other system, such as the anti-lock brake system (ABS), the electrical stability program (ESP), and etc. Although different products have their various structures, the basic components are similar as mentioned above.

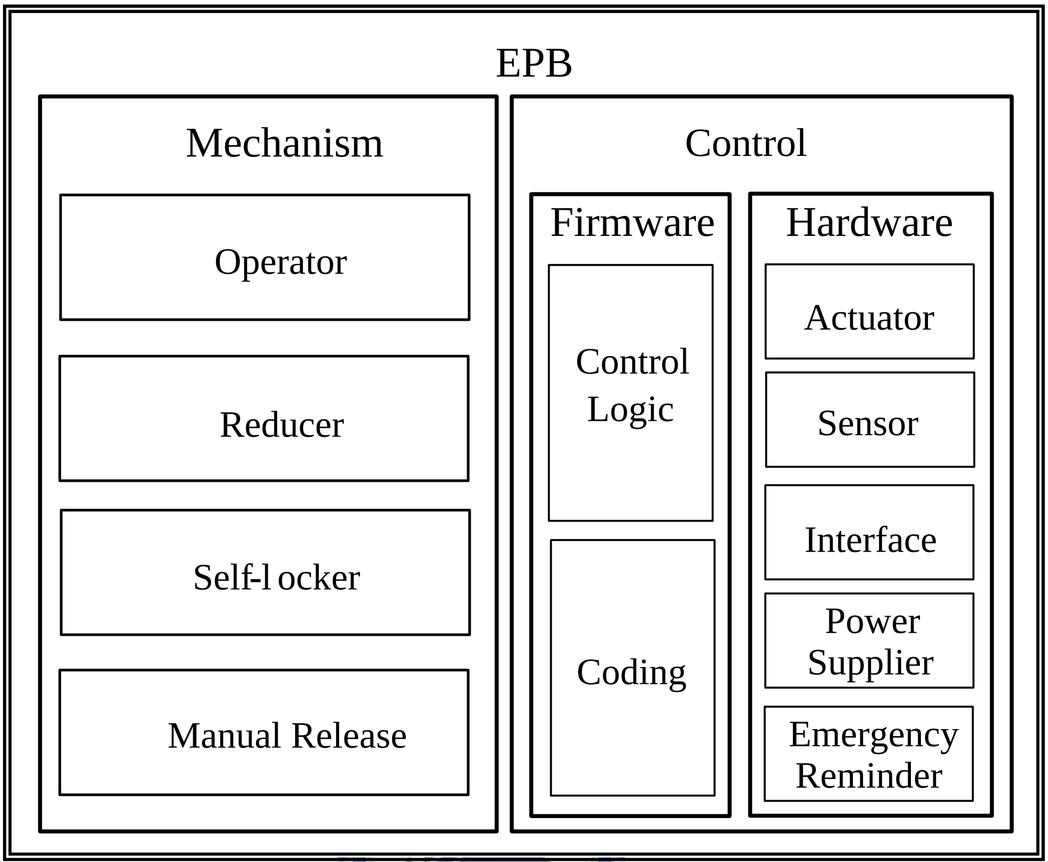


Fig 2.1-1 Structure of the EPB System

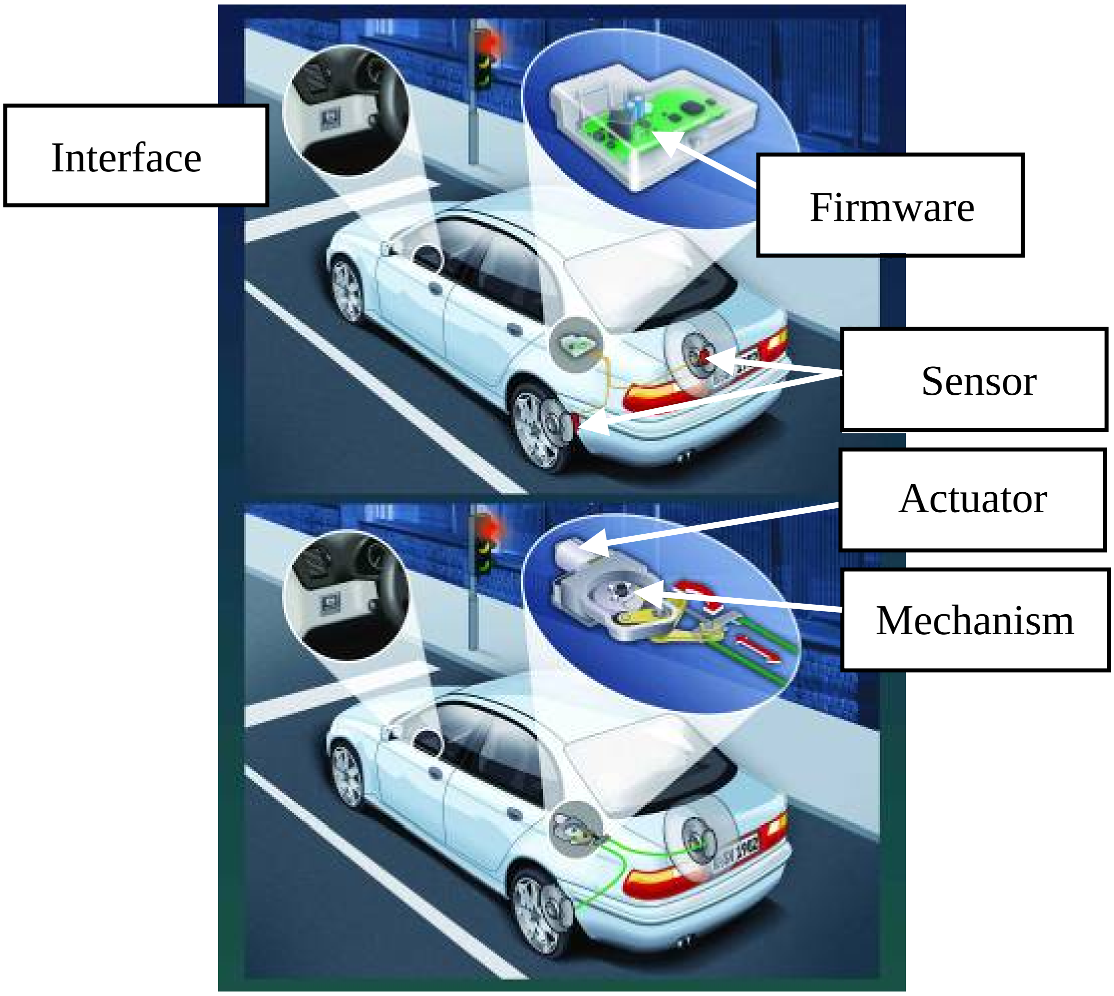


Fig 2.1-2 Overview of the EPB System(I)

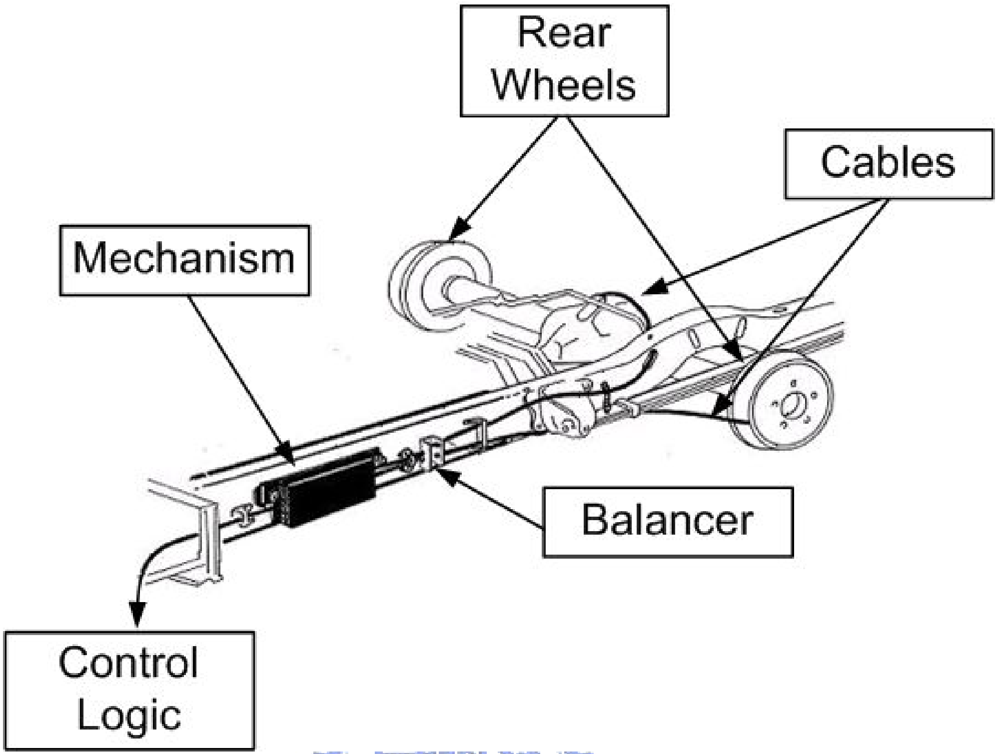


Fig 2.1-3 Overview of the EPB System (II)

2.2 Patents

Referring to the patents research, the results of analysis can be divided into three parts: the mechanism, the hardware, and the control logic of the firmware. Components and methods mentioned in patents are invented to improve the disadvantages of prior products. The disadvantages are complexity, noise, high cost and low efficiency. The design target can be defined with the analysis, such as to simplify the mechanism, to make it quiet, to work in high efficiency, and to reduce cost.

2.2.1 Mechanism

There are various components used in the mechanism of the EPB system (Table 2.2-1). The utility rate of components shows the developing tendency. For example, “electronic” might be the purpose of motor using, and the “simplification” might be the purpose of spring or sliding lump using. This table actually provides a way for the product design and the patent around. These components are separated by different functions, such as operator, self-locker, reducer and manual releaser. The specific properties of components (Table 2.2-1) are discussed in below section.

Components	Numbers	Rates (%)
Motor	35	72.9
Spring	25	52.1
Cable	23	47.9
Worm Gear	15	31.3
Sliding Lump	13	27.1
Hydraulic Valve	11	22.9
Manual Releaser	10	20.8
Wheel Sensor	10	20.8
Cam	7	14.6
Planetary Gearbox	7	14.6
Electromagnet Valve	7	14.6
Balancer	6	12.5
Ratchet	6	12.5
Ball Worn Gear	5	10.4
Gear Box	4	8.3
Wedge	1	2.1
Freewheel	1	2.1

Table 2.2-1 The Utility Rate of Components of the Patents of the EPB System

2.2.1.1 Operator

- Spring

The EPB system needs the functions of pulling the cable, and returning the cable to the original position. Therefore, the spring is a simple method to achieve this motion. The utility rate of the spring is much higher than other components (Table 2.2-1 and Table 2.2-2).

- Worm gear

Worm gears are commonly used (Table 2.2-1 and Table 2.2-2) because of its self-lock and small volume advantages. The worm gear has been developed for years, and its also available in the market. Therefore, the cost can be reduced by using the standard components.

- Cam

This devise is usually used in the EPB system because different cam profiles can change the torque when pulling the brake cable. The advantage can reduce the cost from selecting a high performance actuator (Table 2.2-2).

- Wedge

This device uses the geometric shape to achieve the acting or connecting motions. The advantage is the simple structure and easy manufacturing (Table 2.2-2).

- Freewheel

This device is not so popular in the EPB system. But, freewheels have a special property that can store the energy from actuators. This advantage can reduce the waste of energy during operating (Table 2.2-1).

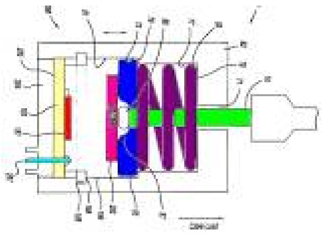
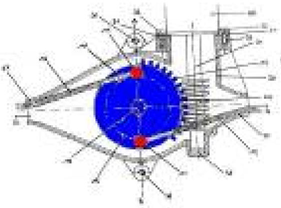
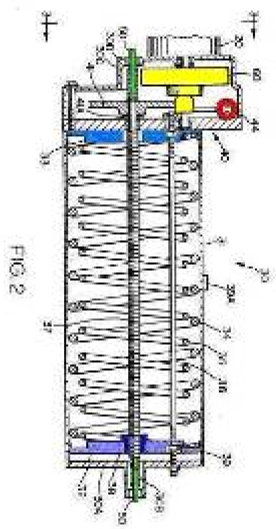
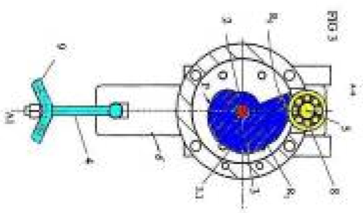
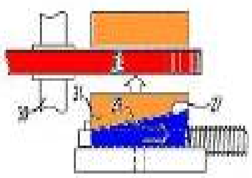
<table>
<tr><th>Spring</th><th>Worm Gear</th><th>Freewheel</th></tr>
<tr><td>
U.S. Patent
No. 6609595 [2]</td><td>
U.S. Patent
No. 6863162 [3]</td><td rowspan="3">
U.S. Patent
No. 5092432 [4]</td></tr>
<tr><th>Cam</th><th>Wedge</th></tr>
<tr><td>
U.S. Patent
No. 6851525 [5]</td><td>
U.S. Patent
No.20050034939 [6]</td></tr>
</table>

Table 2.2-2 The Operators of the EPB System

2.2.1.2 Reducer

A gear box or a planetary gearbox is used as the gear reducer that can reduce the speed and increase the torque of the actuator. Although the high price of planetary gearbox, its performance is better than others, such as lower noises, accuracy, and less vibration (Table 2.2-3).

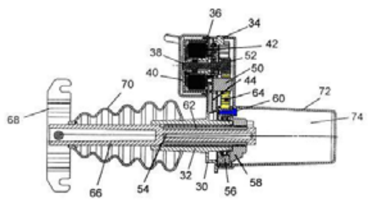
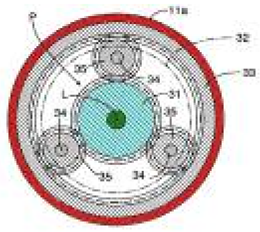
Gear Box	Planetary Gearbox
 U.S. Patent No. 6513632 [7]	 U.S. Patent No. 20050077782 [8]

Table 2.2-3 The Reducers of the EPB System

2.2.1.3 Self-Locker

In order to avoid the unexpected releasing which will cause dangers, the function of self-lock is required to support the security considerations.

- Ratchet wheel

  The ratchet wheel should work with a ratchet lever. These components also have standard products for selection. It is an original ideal to support a locking function. However, the ratchet could disengage the wheel if it suffer a force in opposite direction. As a result, it is easy to get failure when striking with accidental force (Table 2.2-4).

- Worm gear

The worn gear has not only the operator function (mentioned in section 2.2.1.1) ,but also the self-locking function. The reliability of the self-lock function of worm gears is better than ratchet wheels (Table 2.2-4).

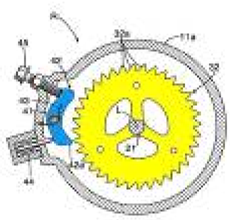
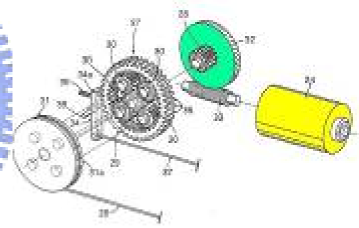
Ratchet Wheel	**Worm Gear**
 U.S. Patent No. 20050077782 [8]	 U.S. Patent No. 6905181 [9]

Table 2.2-4 The Self-lockers of the EPB System

2.2.1.4 Manual Releaser

If the system fails or locks the brake disk unexpectedly, a function to release the brake cable should be provided. It may be a manual or automatic device. For example, a manual handle or a releasing lever can be found in patents (Table 2.2-5).

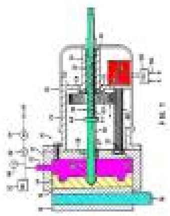
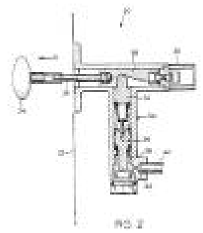
Manual Handle	
 U.S. Patent No. 5148894 [10]	 U.S. Patent No. 5704693 [11]

Table 2.2-5 The Manual Releasers of the EPB System

2.2.2 Hardware

2.2.2.1 Actuator

Actuator is the device that can actuate mechanisms. From the patent survey, the electronic motor is used in almost all concepts as the actuator (about 20%, Table 2.2-1). The advantages of the motor are convenient, fast, simple, and cheap. There are also other actuators, such as a hydraulic pump and an electromagnet valve (Table 2.2-6). The hydraulic pump can provide larger force than motors, so it is usually installed in trailers. But the delayed-action response and the complexity are the disadvantages. The electromagnet valve is a simple component compared with hydraulic pump. But, it needs to be held by a continuous current, and results in power wastes.

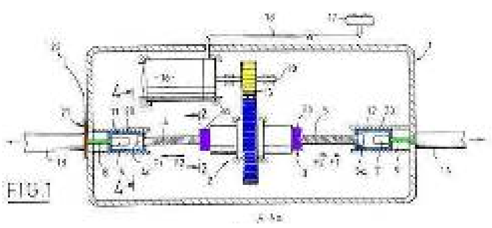
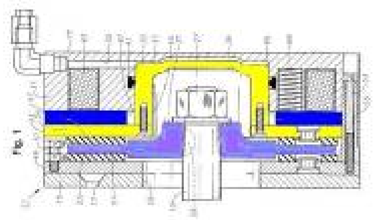
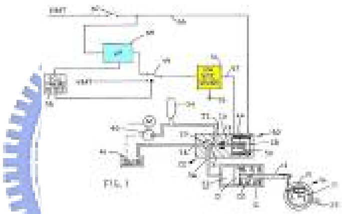
Motor	**Electromagnet Valve**
 U.S. Patent No. 5590744 [12]	 U.S. Patent No. 6543587 [13]
Hydraulic Pump	
 U.S. Patent No. 6550870 [14]	

Table 2.2-6 The Actuators of the EPB System

2.2.2.2 Sensor

- Position Sensor

The position sensor is usually installed in order to realize the device positions. For simulating the environment, it is used to sensor the situation of the shift lever or the gas pedal.

- Speed Sensor

The speed sensor is used to judge the situation of vehicles, such as stopping, accelerating, or backing.

- Gradient Sensor

The gradient sensor is used to determine the tilting angle. If the reclining angle is over the limit of safety, the sensor will recognize the danger situation and feedback the information to the controller unit.

2.2.3 Additional Functions

In the previous study, several additional functions have been added on the EPB system, such as the main brake system, the anti-lock braking system (ABS), the burglar alarm system, the re-clamp system, and the hill-holder system. Actually, these alternative functions are not new innovations. However, the inventor has tried to integrate all those functions in logic control units. This can increase the added value of the automobiles and make it difficult to connect for competitors to explain the system signals. Therefore, they can exclude other manufacturers and get the most benefits. Following functions are usually attached on the EPB system:

- Anti-Lock Braking System (ABS)

Prevent the brakes from locking and losing traction while braking.

- Electronic Stability Program (ESP)

It can sense the drive-wheel slip under acceleration. The program can individually brakes the slipping wheel or wheels, and/or reduces excess engine power until the car is in control.

- Brake Aided System (BAS)

As the sensor detects that the brake pedal was pressed quickly, the control unit will increase the brake motion completely. It creates a higher stopping force for emergencies because most drivers are unable to generate. Therefore, it can help to prevent accidents.

- Traction Control and Vehicle Stability Control Systems (TCS)

TCS uses the electro-hydraulic system to prevent loss of control when excessive throttle or steering is applied by the driver.

- Electronic Throttle Control (ETC)

The ETC computer can smooth the fuel supply during accelerating, and can help to improve fuel consumption and engine performance.

- Acceleration Slip Regulation (ASP)

Guarantee that the wheels have equal traction when the driver needs to accelerate quickly.

2.3 Products

The concept of the EPB system was supposed firstly in 1996 [15]. Several foresighted corporations started to apply for the patents of these new techniques. After developing for several years, vehicle companies and component manufacturers attempted to produce a usable commercial product. The Lincon Corp. starts to set up the EPB system in their LS type vehicles in 2003. Then, many other companies started to install the EPB system in their vehicles. (Table 2.3-1) For example, the Jaguar XJ and S-type, the Audi A6 and A8, the Renault New Vel Satis and Scenic, the BMW 7-Series and the Volkswagen Passat all have the EPB system in their vehicles from 2003 to 2005. In past, the EPB was limited to expensive vehicles. However, after the success of EPB system in these vehicles, moddle-level vehicles, such as the Ford Focus and G-Max, use the EPB system nowadays. In addition, there are at least eight types of vehicles plan to set the EPB system in 2006. As a result, more customers will anticipate using the new system after the price decreasing. It is believed that the EPB system may become a basic equipment by which the EPB market will have a bright future.

Companies	Types	Companies	Types
LINCOLN	LS	BMW	7-Series
JAGUAR	XJ and S-type	VW	New Passat
Ford	Focus and C-Max	RENAULT	Scenic and New Vel Satis
Audi	A6 and A8		

Table 2.3-1 Commercial Products of the EPB System

Besides, the EPB system is not all manufactured by the vehicle companies. Some products are cooperated by both vehicle companies and the vehicle component manufacturers. For manufacturers, they may choose to cooperate with vehicle companies or independently design the system by themselves. On the one hand, if the manufacturer chooses the former, they can get classified information and the cost of the product can be decreased efficiently. For example, the TRW corp., one famous component manufacturer in Germany, has cooperated with Renault for developing the EPB system installed in Scenic. Cooperation makes designs more transparent. Connecting attached system with the Electronic Control Unit

(ECU) of vehicles can make the cost down. Nevertheless, the market of the product will be limited to certain type of vehicles, because of the compatibility of the specification.

On the other hand, if these manufacturers choose the latter, the necessary information of researches and developments, such as the sensor signals and the control logic, will not easy to been acquired. And the functions between components can not easily be integrated. For the reason, the function of product will be restricted and the cost will increase. For instance, the microeletrical brake system (MBS) Corp., a vehicle companies in Taiwan, has invented an independent component without cooperating with any vehicle companies. The product only has some basic functions required for an EPB system, such as switch on/off. However, the market and the compatibility will be expanded because of the property of independent controlling. The list of the manufacturers of the EPB system is listed in Table 2.3-2.

Country	**Company**
US	Delphi
	Dura
	Westinghouse
Germany	TRW
	Continental Teves
	Siemens VDO
Australia	AL-KO
Taiwan	MBS

Table 2.3-2 Manufacturers of the EPB System

Although, there are two different development tendencies, the objectives are the same (Table 2.3-3), including simple mechanism, high efficiency, self-lock, adjustable force, small volume of motor, low cost, and rare failure.

Objectives	Numbers
Simple Mechanism	33
High Efficiency	16
Self-Lock	13
Adjustable Force	8
Small Volume of Motor	5
Low Cost	4
Rare Failure	3
Sliding Avoiding	2

Table 2.3-3 The Objectives of the Patents of the EPB System

Therefore, available EPBs can be divided into two types: single component and complete system (Fig 2.3-1). Single component is usually provided by small manufacturers, and their target market always concentrates on customers whose car has no EPB initially. For this reason, it must be simple, low cost, and easy installation. Conversely, the complete system is usually developed by vehicle companies. The objectives of such product are to increase the selling price and improve the performance of their vehicles. As a result, the complete system needs to be multi-functions and high qualities, and the cost of it is always higher than the single component.

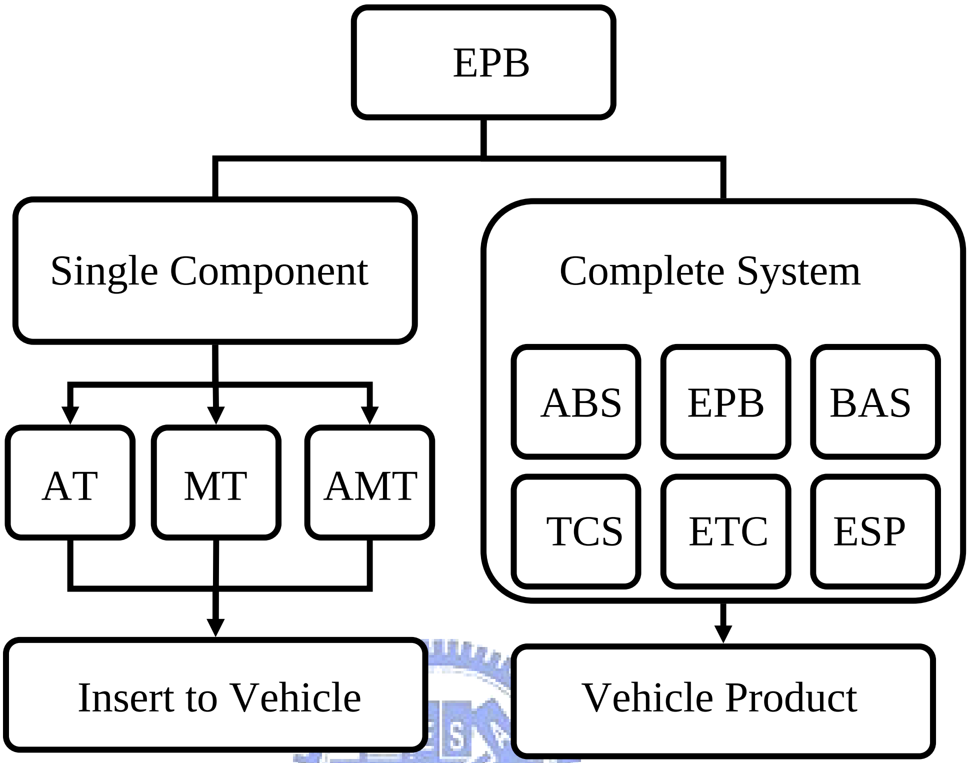


Fig 2.3-1 Tendencies of the EPB System

2.3.1 MBS

MBS Corp. is a Taiwanese company, and they don't cooperate with any vehicles company. Its target market concentrates on common users. Therefore, the product is compatible for any kind of vehicles, including AT or MT vehicles. Users can buy the product from retailers and install it by themselves. However, the more compatibility it has, the less functions it contains. Therefore, this simple product cannot meet the entire requirement for customers.

The function and the control logic of the MBS product are simple, and can be divided into two modes, automatic and manual mode (Table 2.3-4). The logic of the automatic mode are different between AT and MT vehicles. For example, for an AT vehicle, the brake will engage when the shifting lever is at N position. And the brake will disengaged when the shifting lever is at R or D position. However, for a MT vehicle, the system will engage the brake when the vehicle stop (speed is equal to zero). And the system will disengage the brake when the user steps on the gas pedal. Furthermore, if users want to actively operate the system, they can turn on/off the switch to engage/disengage the brake easily.

<table>
<tr><th>Mode</th><th>Type</th><th>Brake</th><th>Situation</th></tr>
<tr><td rowspan="4">Automatic</td><td rowspan="2">AT</td><td>Engage</td><td>Shifting lever at N position</td></tr>
<tr><td>Disengage</td><td>Shifting lever at R or D position</td></tr>
<tr><td rowspan="2">MT</td><td>Engage</td><td>Stop</td></tr>
<tr><td>Disengage</td><td>Step on the gas pedal</td></tr>
<tr><td rowspan="2">Manual</td><td colspan="2">Engage</td><td>Turn on the switch</td></tr>
<tr><td colspan="2">Disengage</td><td>Turn off the switch</td></tr>
</table>

Table 2.3-4 Logic Control of the EPB System of MBS

2.3.2 Renault Scenic

Renault’s product is designed by Renault and TRW. The functions of the product can be divided into two parts: automatic and manual mode. Each detailed operation is described in Table 2.3-5. It is suitable for use in both AT and MT vehicles (only for Renault vehicles). However, the functions mentioned below are depending on the product designed for AT vehicles (Table 2.3-5). The function and the logic control of this product are difficult than MBS. For the automatic mode, the brake will be engaged when the user turns off the ignition, and be disengaged when the user steps on the gas pedal. On the contrast, for the manual mode, the brake will be engaged when the user turns on the switch, and be disengaged when the user turns off the switch and push safety button.

Furthermore, the product comprises more safety functions, such as disengaging when driving and warming signals as components get failure. The brake force also can be adjusted if the user pushes the switch more strongly or longer. Besides, the product even provides a manual releaser installed in rear box of vehicle for emergency.

Mode	**Brake**	**Situation**
Automatic	Engage	Turn off ignition
	Disengage	Step on the gas pedal
Manual	Engage	Turn on the switch
	Disengage	Turn off the switch and Push safety button
Special Functions	1.Disengaging when driving 2.Double check (LED and button light) 3.Manual releaser when failing 4.Adjustable force	

Table 2.3-5 Logic Control of the EPB System of Renault Scenic

2.3.3 Audi A6 and A8

"Audi" is treated as a symbol of high level vehicles. The performance of product is superior, and the functions and the logic control are very complicated. It can be divided into two modes, automatic mode and manual mode (Table 2.3-6). Generally speaking, the user should always uses the manual mode to make the brake engaging, and the automatic mode to make the brake disengaging. But the system can make the brake engaging automatically to avoid the vehicle sliding down on a hill. And the user also can directly turn on the switch to make the brake disengaging.

In Audi products, hill holder is a special function that does not appear in middle-level vehicles now. The brake force can be adjusted according to the gradient automatically. In addition, the manual releaser is also an essential requirement. Furthermorer, the system applies other additional functions, including the temperature compensation and brake attrition feedback. These functions make the vehicle more convenient safer.

Mode	Brake	Situation
Automatic	Engage	On a hill
	Disengage	Step on the gas pedal and set the safety belt
Manual	Engage	Turn on the switch
	Disengage	Turn off the switch
Special Functions	1. Hill holder 2. Drum attrition feedback 3. Temperature compensation 4. Manual releaser when failing 5. Double check (LED and button light) 6. Adjective force	

Table 2.3-6 Logic Control of the EPB System of Audi A6 and A8

2.4 Remarks

After the first concept of the EPB was brought out, the later concepts was improved step by step. At first, functions of the EPB were only limited to basic requirements, such as letting electronic apparatus substitute human labor. The mechanism was large and complicated without any control logic. After years, the concepts of the patents had made a great progress in the complexity and the efficiency of mechanism. In the present, some company started to create the concept that integrated other systems with the EPB system, such as the main brake system, the anti-lock braking system (ABS), the burglar alarm system, the re-clamp system (to avoid the failure of braking when the disk temperature is too high), and the hill-holler system (to avoid sliding when stopping on a hill). The most difficult part of the complete system is to combine the respective signals and logic control unit together. By the further development, the EPB is not the system as it was originally. It has become a multi-functional system gradually.

However, the multi-functions tendency has been leaded by vehicle companies. They try to develop a complete system that combines all relative subsystems. In other words, small components manufacturers, which have specific subsystem techniques, have the opportunity to work with large vehicle companies. In Taiwan, vehicle companies have no ability to produce a complete vehicle now. And the market of vehicles is smaller than those of other countries. In order to increase the market share, these manufacturers have tried to discriminate their objectives from the vehicle companies and to reduce the cost and the redundant functions. Therefore, developing a independent product with acting alone signals and control logic is the only competitive way.

CHAPTER 3 QFD AND REQUIREMENTS

3.1 Introduction

There are many techniques used to generate engineering specifications. The best and popular one is the quality function development (QFD) [16][17]. The advantages of QFD method is that it organize the required information for understanding the problem during product development. Some objectives can be achieved as follows:

- Understand the specifications or goals for the product.
- Understand how the competition meets the goals
- Understand what is important from the customers' viewpoints
- Set numerical targets to work forward

In other words, QFD is a quality method of good knowledge or epistemology (how do we know the needs of the customer? how do we decide what features to include? and to what level of performance?). QFD supplies a process for design and ensures that the result will meet the customers' requirement. The process can be divided into four stages as follows.

- Product Planning Stage (Customers' Requirements → Design Needs)
- Product Deployment stage (Design Needs → Product Specifications)
- Process Planning Stage (Product Specifications → Manufacturing Requirement)
- Production Planning Stage (Manufacturing Requirement → Operating Illustrations)

Applying the QFD steps builds the house of quality as shown in Fig 3.1-1. This house has many parts, each contains valuable information. The numbers in the figure refer to the steps that are required to be filled by designers.

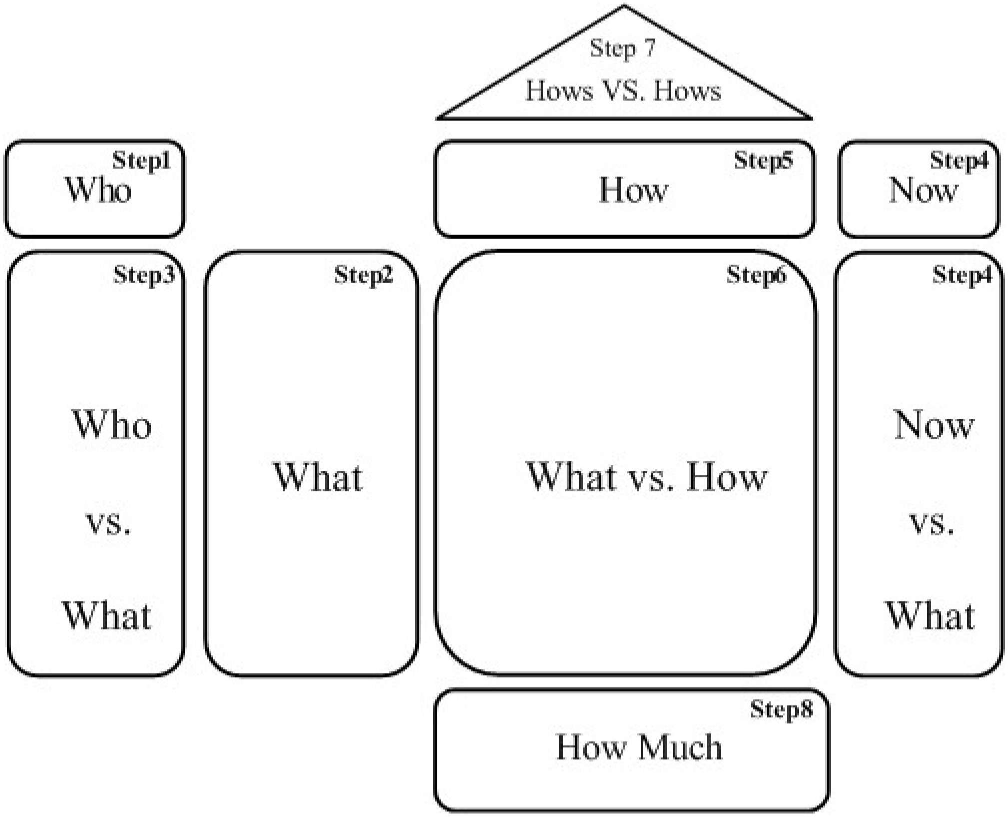


Fig 3.1-1 QFD House

3.2 QFD on EPB

After the introduction of the QFD method, it can be used on the EPB system as follows (Table 3.2-1).

- *Identify the customers (Who)*

  Customers are the people relative to this product. Users (customers), sales, and manufacturers are selected in this case.

- *Determine the customs' requirements (What)*

  After the customers have been identified, it is required to determine what is to be designd, such as performances, human factors, the environment, manufacturing and others. Parts of the requirements are provided by Essor Inc., one of the cooperative companies.

- *Determine relative importance of the requirement (Who vs. What)*

  The result of customers' needs is presented in the SUM block of Table 2.2-1. It shows that the most expected requirements are the parking confirmation, effort-saving, emergency safety function, appropriate braking force, appropriate brake speed, and adjustable braking force.

- *Identify and evaluate the competition (Now)*

In order to measure all levels of the market, the definition of competitions contains there levels, including MBS (low-level), Renault Scenic (middle-level) and Audi A8 (high-level). The results state that the Renault Scenic meets most customers' requirements (Table 3.2-1, NOW block).

- *Gernerate engineering specifications (How)*

Customers' requirements have to be transformed into measurable engineering specifications. These items are not only written by experiences, but also the information provided by patent analyses (Table 2.3-3).

- *Relate customers' requirement to engineering specifications (What vs. How)*

In this step, the relation between customers' requirements and engineering specifications will be estimated. Use the numbers (3 = strong relationship, 2 = medium relationship, 1 = weak relationship, Blank = no relationship at all) to define the relationship between items.

- *Set engineering targets (How much)*

Compare the specification of commercial products. Then, the specifications of the product target can be defined in the table (Table 3.2-1, Target block).

User	Sales	Manufecturer	SUM			EPB	HOW												NOW		
							Brake force	States of adjustable force	Assembly time	# of sensors	# of Motor	Operating time	# of component	Manual button	Releaser	Weight	CNS test	Cost	MBS	Renault Scenic	Audi A8
						Direction of Improvement	↑	↑	↓	↓	↓	↓	↓	-	-	↓	-	↓			
						Units	kg	#	hr	#	#	S	#	y/n	y/n	kg	y/n	KNT			
8	9	4	**21**	WHAT	Performance	Hill-holder	1	3		3							1	2	1	5	5
3	14	9	**26**	WHAT	Performance	Manual mode				1			2	3	2		1		1	3	3
12	14	7	**33**	WHAT	Performance	Emergency safety funciton		2		2			2		3		2		1	5	3
14	10	11	**35**	WHAT	Performance	Effort-saving	3	3			3			1					1	3	3
15	15	12	**42**	WHAT	Performance	Braking	3	3	1		1	1							3	5	5
11	11	6	**28**	WHAT	Performance	Appropriate braking speed		1				3	1						1	3	3
13	12	8	**33**	WHAT	Performance	Appropriate braking force	3	2			2						2		1	5	5
9	8	13	**30**	WHAT	Performance	Adjustable braking force	3	3			2	1		1				2	1	3	5
10	3	5	**18**	WHAT	Performance	Easy to brake	1			2		2	3	3					3	3	5
1	4	10	**15**	WHAT	Manu-fecturin	Easy to assemble			3	2	2		3			2			3	1	1
2	1	14	**17**	WHAT	Manu-fecturin	No special tools			3				2					3	3	1	1
6	5	3	**14**	WHAT	Other	Less nosie	1						3					2	3	1	3
5	6	1	**12**	WHAT	Other	Pass safety legislation	2					2			2		3		3	5	5
7	7	2	**16**	WHAT	Other	Low Cost		2		3	3		3		2	1		3	5	3	1
4	2	15	**21**	WHAT	Other	High compatibility of components			3				3					2	5	3	1
						Target	**<300**	**1**	**1.5**	**7**	**1**	**1**	**1**	**y**	**y**	**1~2**	**y**	**25**			
						MBS	300	1	1	7	1	2	3	y	y	1~2		10			
						Renault Scenic		2	1	8	1	1	1	y	y	1~2	y	40			
						Audi A8		2	1~2	7	2		3	y	y	1~2	y	37			

1

Table 3.2-1 QFD House of the EPB System

3.3 Cost Considerations

Cost is the most important factor for commercial products. How to match the requirement of customers will also influence the product selling significantly. Conventional design process focuses more on engineering capabilities and less on customer needs. They also neglect the cost problem at the beginning of the design process. When designers try to incorporate cost and customer requirements, the design process may be completed.

On the contrast, following the steps of QFD will efficiently reach the goals with lower cost and full requirements. It helps designers to consider the cost and customer needs in the whole process.

Conventional design process also considers the cost problem. The figure (Fig 3.3-1) shows that designers treat the cost problem after finishing phototypes. But the money and time have been spent and wasted on the phototype development. Because of the developed theory is impractical, the designer usually overestimate what customers need. For this reason, there are many redundant functions which were manufactured in the phototype, such as adjustable mechanisms or probable functions.

However, QFD design process estimates the cost step by step (Fig 3.3-2). It reduces the time of building theory and the cost of phototypes substantially.

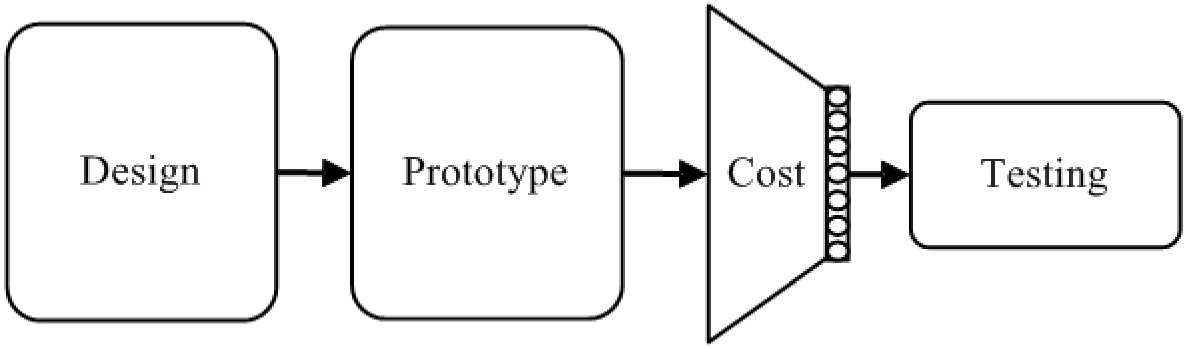


Fig 3.3-1 Conventional Design Process

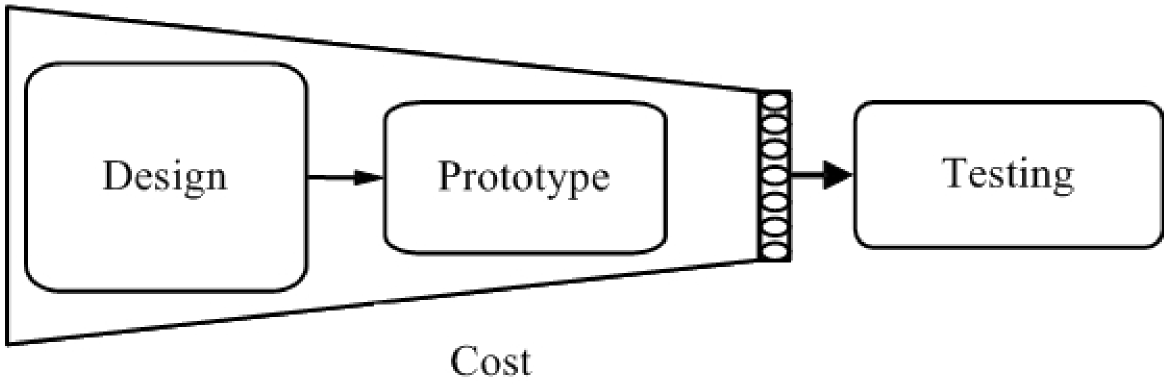


Fig 3.3-2 QFD Design Process

CHAPTER 4 MECHANISM CONCEPTUAL DESIGN

4.1 Design Method

Brainstorming is chosen as the design method for its advantage of collecting every member’s viewpoints. My laboratory members, 10 people who major in different regions of mechanical design, are the ideal resources. EPB functions knowledge is taught to member in order to make the process more efficient and successful. The background knowledge includes EPB main functions (actuator, reducer, self-locker, and releaser) and previous design introductions. There are four rules need to be kept by members in the creating process:

- Record all the ideas generated.
- Generate as many ideas as possible, and then verbalize these ideas.
- Think wild. Silly, impossible ideas sometimes lead to useful ideas.
- Do not allow evaluation of the ideas; just the generation of then.

4.2 Conceptual Designs

There were several ideals supported through the brainstorming design method. To make profound ideas of each the brainstorming ideas, these concepts were discussed individually. In the second step of brainstorming, some members can trigger ideas from the other team members. Some useful concepts were picked as followed.

4.2.1 Concept 1

Reducer function of planetary gearbox was used in this concept. Two planet gears which connect with the cables rotate along the fixed planet carrier (Fig 4.2-1). Clockwise and counterclockwise motion of planet gears will pull and release the cables separately. In addition, the releaser, the pin which connects the cables and the planet gears, can be drawn out when the devise is failed.

With the planetary gearbox, the volume of the EPB mechanism can be reduced efficiently. However, the self-locker function can't be provided directly through the design. It means that other lockers will be attached in order to make the mechanism safer. The locker will make the devise far more complex than present designs.

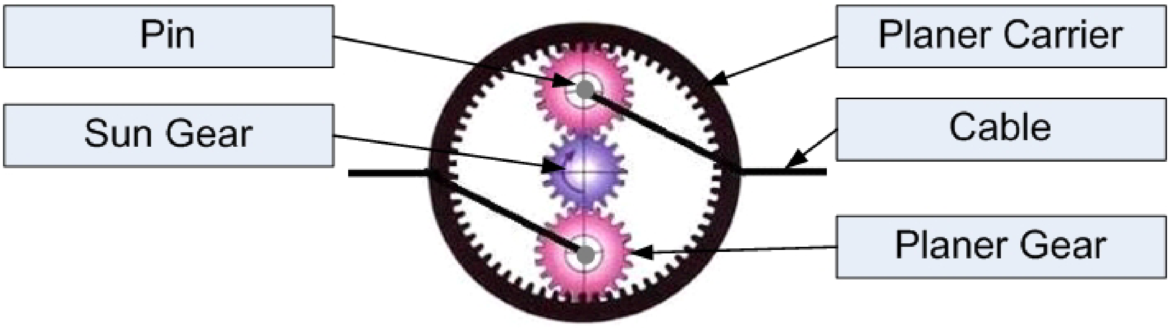


Fig 4.2-1 The Concept 1 Structure (Engaging)

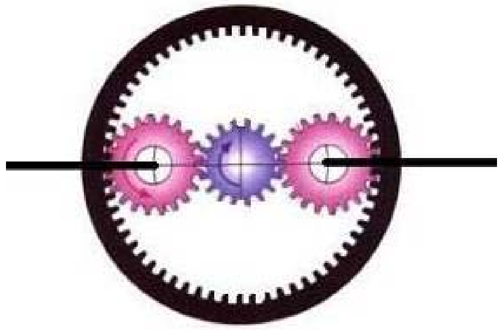


Fig 4.2-2 The Concept 1Structure (Disengaging)

4.2.2 Concept 2

This concept combines the EPB functions with the balancer function. The EPB functions include operator, reducer, self-locker, and releaser. Pull and release brake cables by a worm shaft, two links, and two plates (upper and bottom plates) (Fig 4.2-3). The vertical distance change between two plates can be transferred to horizontal motion between cables. In addition, the speed reduced ratio and the self-lock function can be provided by the worm shaft which is proposed to connect with motor axis. Furthermore, the pin (Fig 4.2-5) called as releaser can be drawn out when the devise is failed.

Beside the basic EPB functions, two springs in the button plate (Fig 4.2-6) can supply the balance function, automatically adjusting the unbalance force between two rear brakes. The redundant or insufficient force between two cables can be absorbed by the springs, until the cable force equilibrates.

The integration of the EPB system and the balancer makes the mechanism more simple and small. The assembly is easier and the compatibility is wider than prior art. However, the K value of springs is hard to define for different vehicle brake forces.

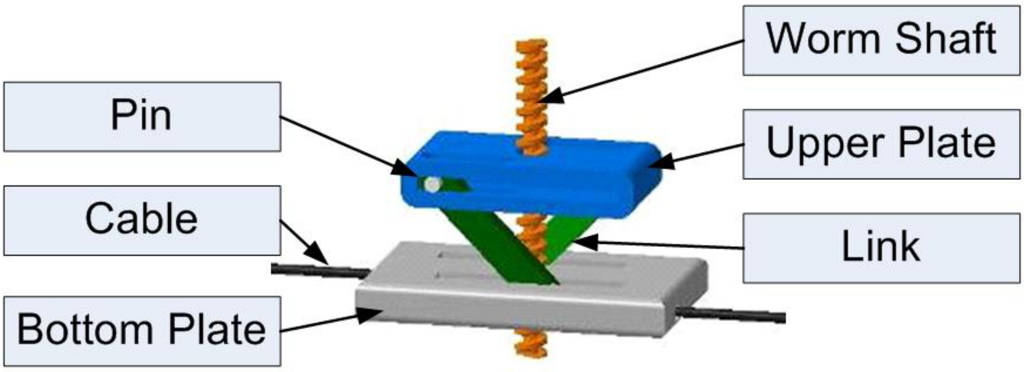


Fig 4.2-3 The Concept 2 Structure (Engaging)

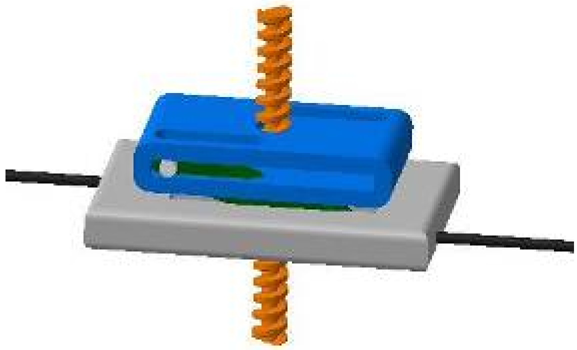


Fig 4.2-4 The Concept 2 Structure (Disengaging)

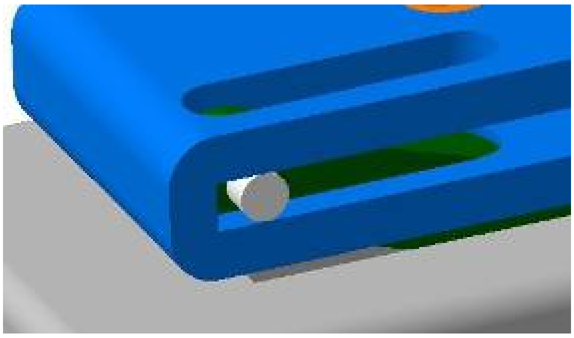


Fig 4.2-5 The Pin

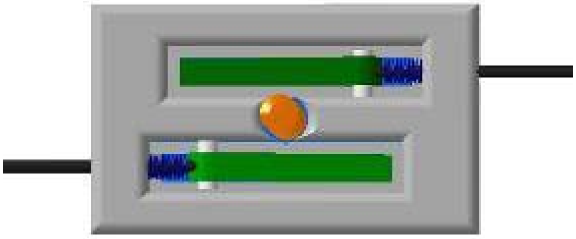


Fig 4.2-6 Springs and Bottom Plate

4.2.3 Concept 3

This concept combines the EPB functions with the balancer function. Pull and release the cables by an S plate, a worm gear, rollers and pin screws (Fig 4.2-7). The worm shaft connected with motor will actuate the worm gear to rotate. The S plate was fixed in the X direction and can slide in the Y direction. The pin screws and the rollers (Fig 4.2-9) sliding along the worm gear track which can pull or release the cables as the worm gear rotating. In addition, the speed reduced ratio and the self-lock function can be provided by the worm shaft and the worm gear. Furthermore, the pin screws called releaser can be drawn out when the devise is failed.

Beside, the balance function can be supplied by S plate's DOF (degree of freedom). The S plate can adjust the unbalance force by moving in the Y direction. For example, the S plate will move along the positive Y direction, if the A cable need greater force than B cable. The balance function is more convince and the whole EPB mechanism is smaller than prior art.

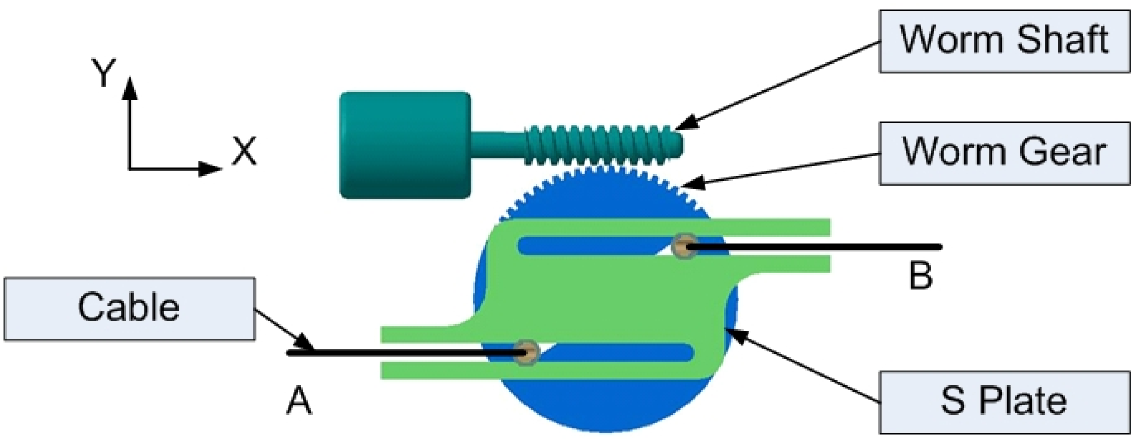


Fig 4.2-7 The Concept 3 Structure

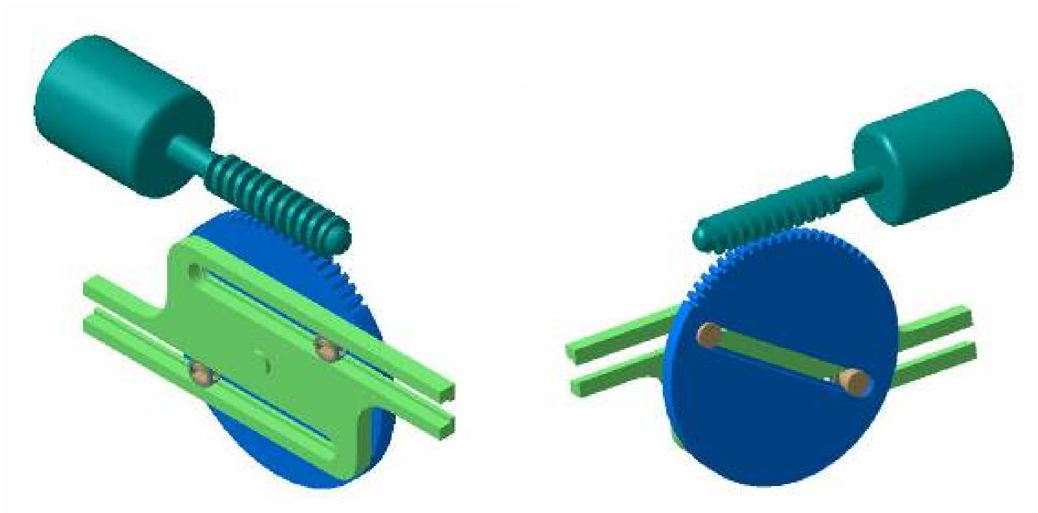


Fig 4.2-8 The Concept 3

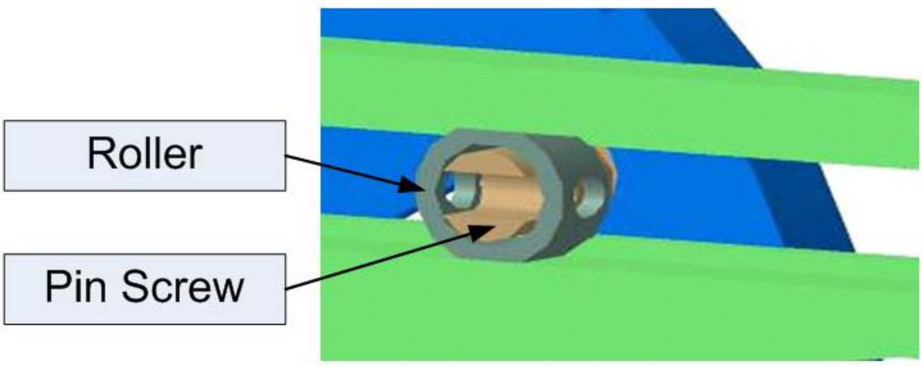


Fig 4.2-9 The Pin Screw and The Roller

4.3 Concept Evaluation

Evaluation bases on a basic decision matrix. This matrix includes several items, such as criteria (from QFD specification items), importance for each criterion, concepts, evaluation of each concept using criteria, and the final score for each concept. As the evaluation (Table 4.3-1) show, one concept, the concept 2, should be chosen as a judging datum. The “+”,”S”, and “-” symbols are used as the mark of “superior”, ”the same”, and ”inferior” separately.

Consequently, the concept 3 was presented as the best design by the evaluation of the decision matrix. The total weighted scores are 63, which are greater than other two designs, datum and -35. The results exhibit that the concept 3 is good at confirmable brake force, less assembly time, less components, and light weight.

Criteria (Specifications)			Importance	Concepts 1	Concepts 2	Concepts 3
1	Brake force	kg	17	-	Datum	+
2	States of adjustable force	#	19	+		+
3	Assembly time	hr	10	-		+
4	Number of sensors	#	13	S		S
5	Number of motor	#	13	S		S
6	Operating time	S	9	+		+
7	Number of component	#	22	-		+
8	Manual button	y/n	8	S		S
9	Releaser	y/n	9	S		S
10	Weight	kg	3	-		+
11	CNS test	y/n	9	S		S
12	Cost	KNT	14	-		-
Satisfaction		Total +		2	-	6
		Total -		5	-	1
		Overall total		-3	-	5
		Weighted total		-38	-	66

Table 4.3-1 Evaluation Table

4.4 Finite Element Analysis (FEA)

The result of the finite element analysis can make the conceptual designs, material selections, and component selections more accurate. Loading conditions, boundary constrains, materials properties, and model meshing require to be considered carefully in the FEA process. However, the cable force of the brake is considered as the most important factor to design a durable mechanism. The following discussions on the cable force are a preparing work for the FEA.

4.4.1 Cable Force

The brake force is defined by various definitions for different brake parts and purposes. For example, as the Fig 4.4-1 presents, the brake forces including gross brake force, cable force, and handbrake lever force. According to the vehicle law standards [18], the gross brake force (about 500Kgf) should be larger than 20 percentages of the gross vehicle weight rating, and the handbrake lever force should smaller than 40Kgf. The cable force is related to the handbrake lever force and the shaft lever ratio. Although this value is not defined by laws, six is the general value, with the consideration of safety factor 2.5, for sedans and SUVs. The cable force, therefore, can be calculates as 240Kgf. In addition, this force is the one to actuate the drum or disc brakes and the one EPB should generate. In other words, the EPB should generate 240Kgf to produce more than 500Kgf gross brake force, through the cables and the drums or discs, to make the cars stop.

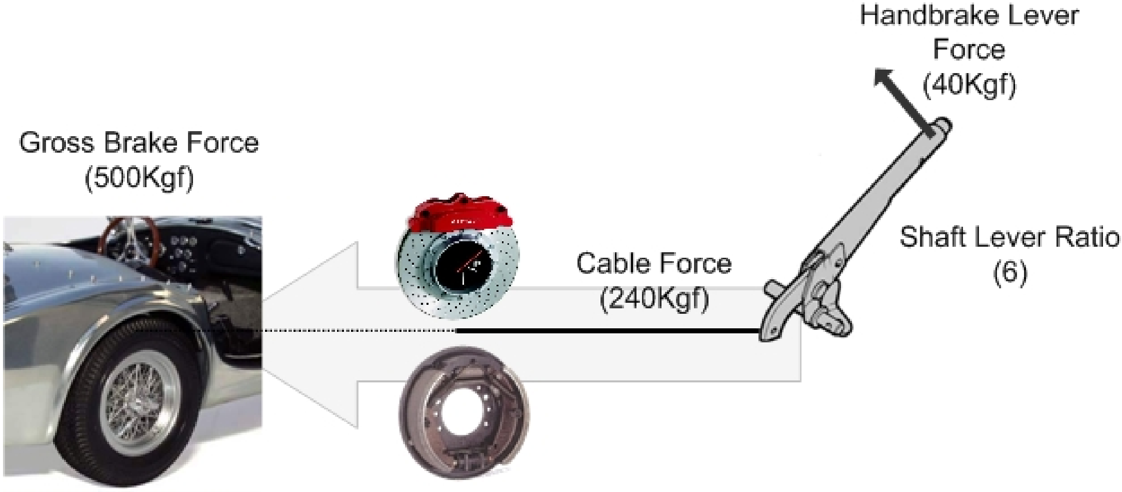


Fig 4.4-1 Cable Force

4.4.2 Analysis Conditions

The design comprises seven components: one motor (consists of worm shaft and worm gear), one axis link, one rotating plate, two couplings, one S plate, and one sliding track. To simplify the analysis, the sliding track and the motor are ignored. The simplification makes the process more efficient, but the final tendency will still be reasonable.

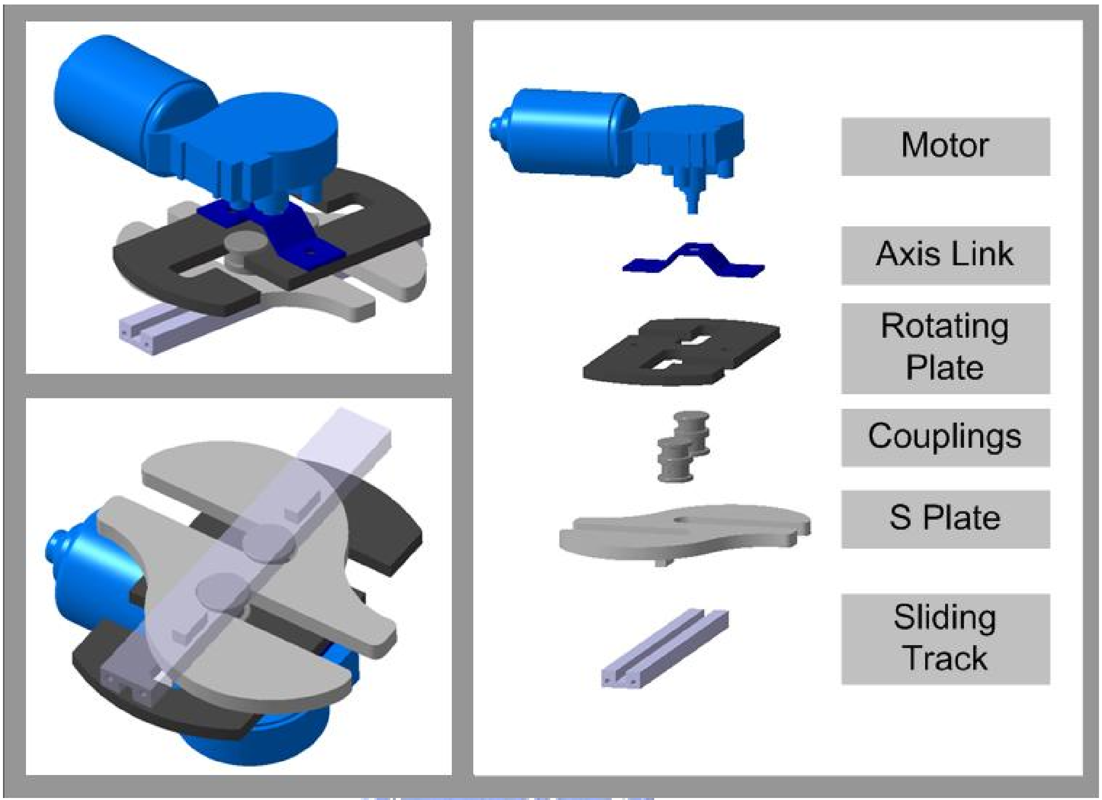


Fig 4.4-2 EPB Components

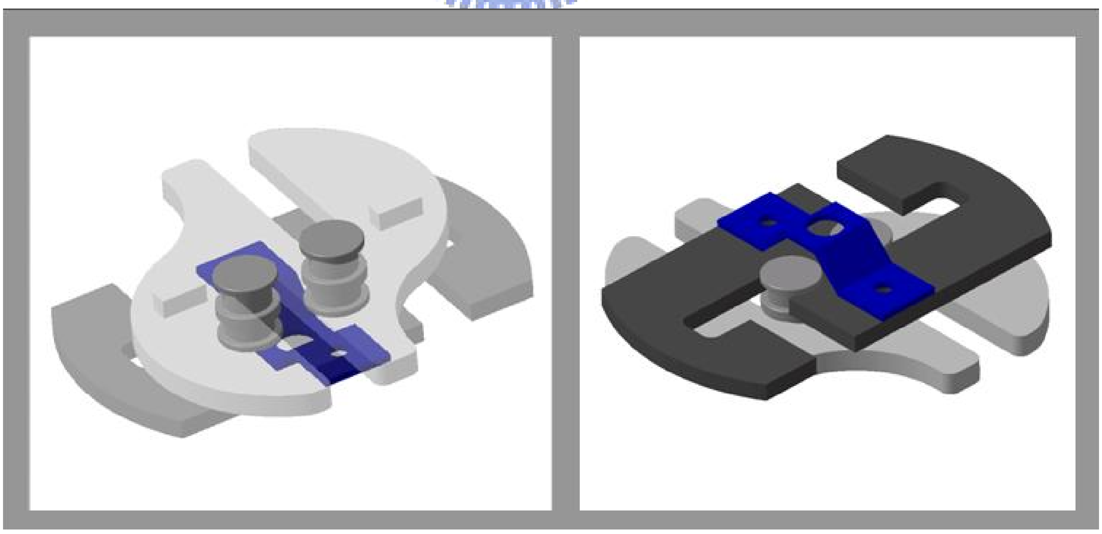


Fig 4.4-3 Simplification Model

4.4.2.1 Loads

As mentioned in section 4.4.1, the mechanism should generate 240Kgf for pulling cables. The cable force (240Kgf) is shared by two separated cables (120kgf) connected to drums or discs. As a result, the loads (120kgf) are brought to each coupling connected with separated cables.

However, the stress magnitude of components varies with different brake situations (engaging or disengaging). According the Fig 4.4-4, engaging condition (left) takes place when the cable direction is vertical with the rotating plate direction. On the contrast, those two direction isn't vertical at disengaging condition (right). Obviously, the stopping (engaging) load must be larger than the no stopping (disengaging) load for the mechanism. Therefore, the engaging situation is chosen to be the analysis model.

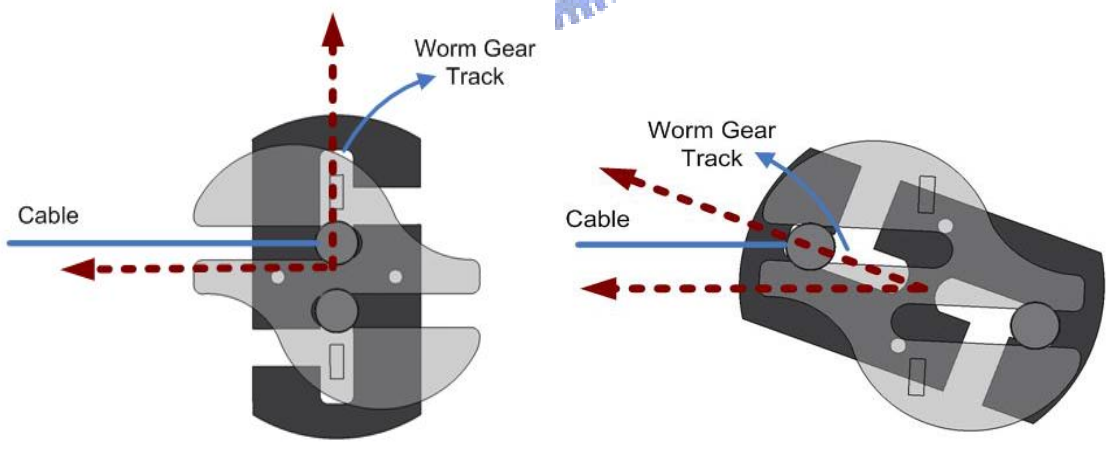


Fig 4.4-4 Engaging (Left) and Disengaging (Right) Situations

4.4.2.2 Constraints

There are five kinds of constrains defined in the analysis model showed in Fig 4.4-5. First of all, the S plate sliding surfaces contacting with sliding track are constrained to move only along the y direction. The degrees of freedom (DOF) of the S plate sliding surfaces are limited to be 1 (Fig 4.4-5, A). In addition, the second one is to fix the whole DOF of the axis link. The axis hole connected with motor output axis are assumed to completely fixed (DOF=0) (Fig 4.4-5, B).

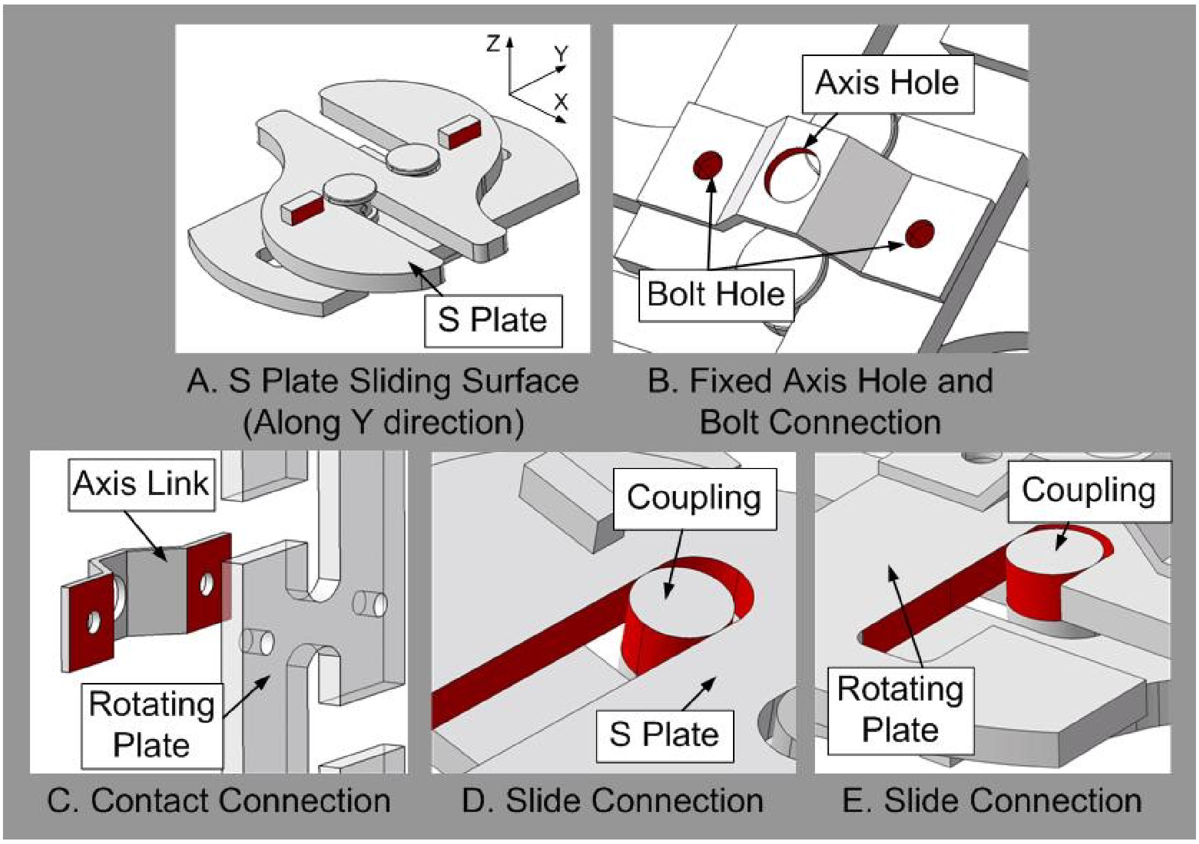


Fig 4.4-5 Constraints of the Model

At the mean time, the other connection properties between parts in this case are defined as "Bolt Connection Property", "Contact Connection Property" or "Slide Connection Property". It depends on the different contact situations between components. As Fig 4.4-5, C, D, and E show, the blot holes between the axis link and the rotating plate are bolt connection properties. The bolt pressure is set as 20 N to simulate the real connection. However, the contact surfaces between the axis link and the rotating plate are contact connection properties. They are the connection between two part bodies which are prevented from interpenetrating at their common boundary. They will behave allowably to move arbitrarily relative to each other, and contact within a user specified normal clearance. Furthermore, the relations between the couplings and the s plate, and the rotating plate are slider connection properties. They are the link between two bodies which are constrained to move together in the local normal direction at their common boundary, and will behave as if they were allowed to slide relative to each other in the local tangential plane. Since bodies can be meshed independently, the slider connection is designed to handle incompatible meshes.

4.4.2.3 Materials

The S45C was chosen to be used in prototype because of the easy manufacturing property. Its yield strength ranges from $3.1\times10^{8}\sim6\times10^{8}$ N/m2 (depended on different heat treatments) and the Poisson's ratio is 0.29. The S45C will be changed to other proper materials, if the results show that it is too weak or too strong.

4.4.3 Results

The FEA results shown in Fig 4.4-6 and Fig 4.4-7find that the maximum stress of the structure was 1.46x108 N/m2 which is smaller than the yield stress of the steel, S45C. It means that the plastic deformation will not occur if it is made by S45C. Furthermore, the safety factor 2.5 had been considered in the first step of the analysis process. As a result, the mechanism agrees with the plastic deformation limit, and also conforms to the vehicle component safety regulation.

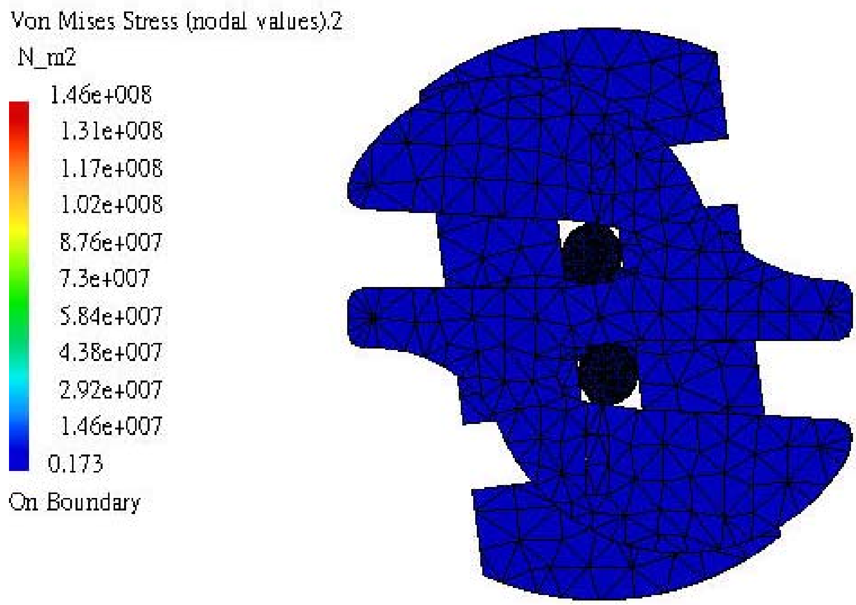


Fig 4.4-6 Von Mises Stress Distribution (Front View)

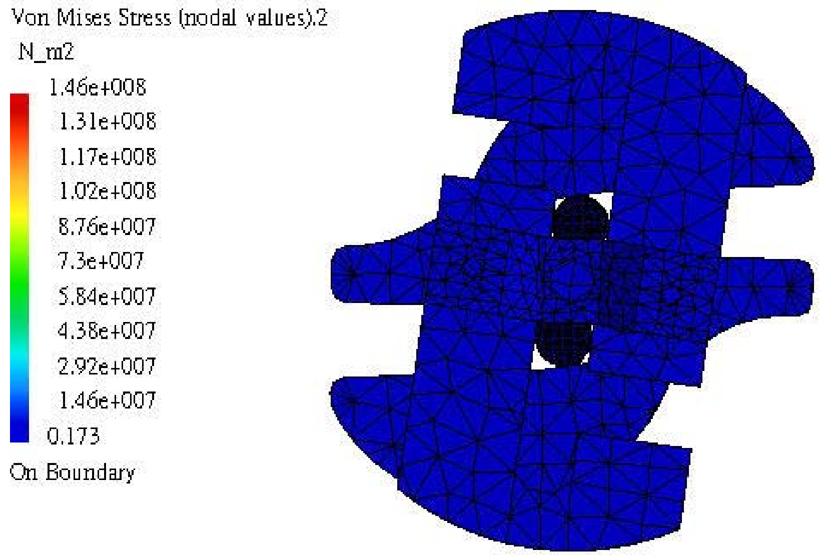


Fig 4.4-7 Von Mises Stress Distribution (Back View)

Significantly, the S45C material is overestimated and wasted. Keeping the cost down purpose, plastic materials can substitute for S45C. The tensile yield strength of plastics ranging from 3×10^7 to 7×10^7 is strong enough to be other component materials (except couplings). The Fig 4.4-8 and Fig 4.4-9 (Von Mises stress distribution of plastic (yield strength 3×107)) illustrate that the axis link, the rotating plate, and the S plate still suffer light stresses. The design might be safe and cheap if the plastic material is chosen properly (larger than 3×107).

However, the plastic material is not suitable for prototypes, but mass productions. Although the S45C is cumbersome and expansive, the easy manufacturing advantage is more important for prototype comparing to plastics. As a result, the S45C is chosen to be the material in the continuous process, manufacturing the prototype.

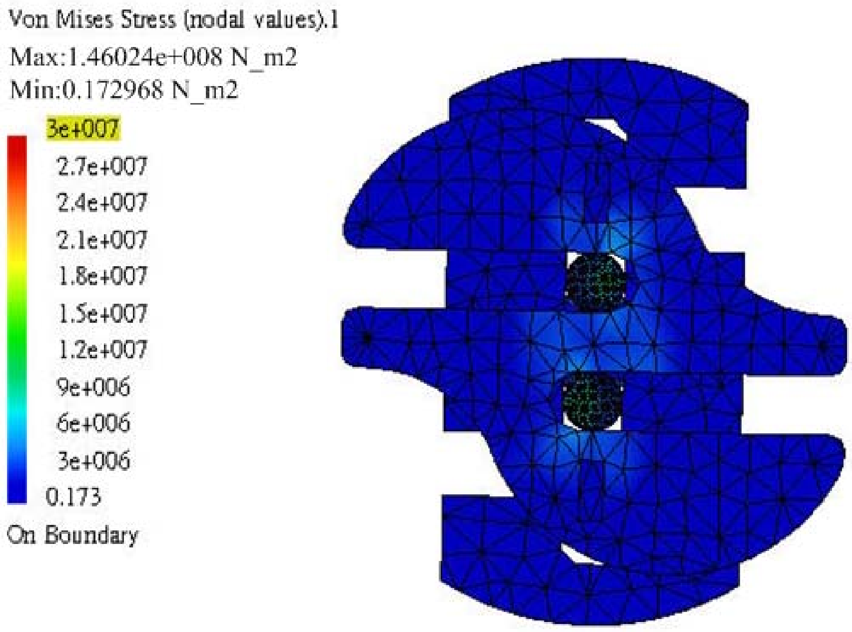


Fig 4.4-8 Von Mises Stress Distribution of Plastics (Front View)

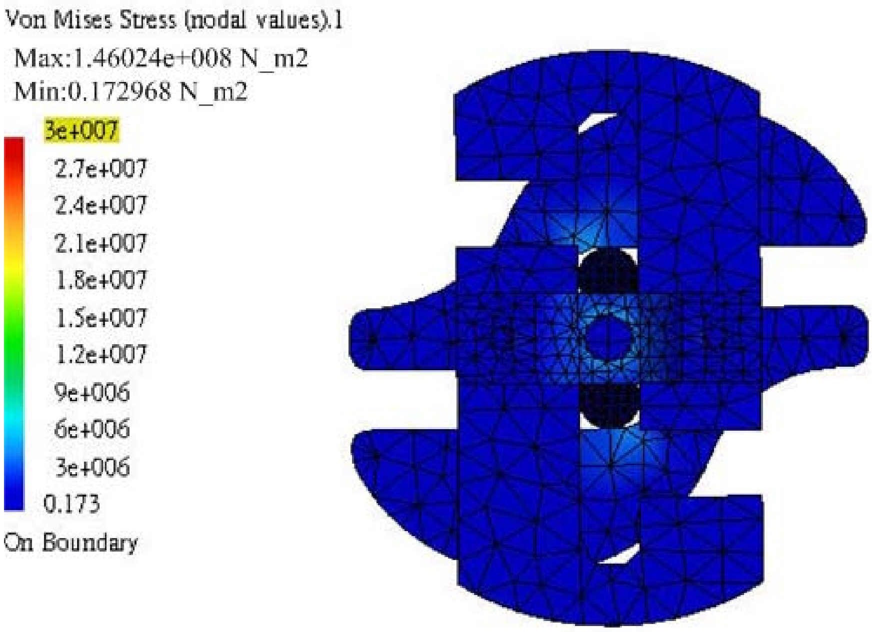


Fig 4.4-9 Von Mises Stress Distribution of Plastics (Back View)

CHAPTER 5 Control DESIGN

5.1 Firmware

5.1.1 LabVIEW

The prototype is stimulated by PC based method, and LabVIEW is selected for development software. LabVIEW, is a popular industry-leading software tool for test, measurement, and control. Its graphical development provides a superior way for engineer and scientist works, improves the product quality, shortens time to market, and enlarges engineering and manufacturing efficiency. It has the flexibility of a programming language combined with built-in tools designed specifically for test, measurement, and control. Based on these reasons, the LabVIEW is chosen to be the stimulation software for completing the system quickly and successfully. The most important reason is mentioned below.

- Graphical programming for test, measurement, and control
- Rapid application development with express virtual instruments (VIs) and easy-to-use graphical environment
- Interactive measurement assistants and powerful redesigned data acquisition (DAQ) board interface for connecting to all types of I/O

5.1.2 Control Logic

The Fig 5.1-1 shows the flow chart of the control logic. There are seven varieties of decision steps (gradient, ignition, speed, shift lever, EPB button, gas pedal, brake pedal, and cable feedback) presented as rhombuses in the flow chart. The decision tree is built orderly with these rhombus determinations. The purpose is to determine engaging or disengaging the EPB. Finally, the cable feedback signal will be used to check the completeness of the motion. There are some special functions in the flow chart described below:

- To engage the brake automatically when the shift lever was in P position. In the other words, the EPB system can substitute for pulling the handbrake lever.
- Engaging the brake suddenly will cause huge dangers as the vehicle is at high speed. To ensure the safety, the EPB button is effective only when the vehicle speed is lower than 8 km/hr. As a result, the system works safely even if someone pushes the button accidentally.
- The hill brake force will be larger than the ground one. The process boxes, “engage cable x 2 times” and “disengage cable x 2 times”, mean to enlarge cable force and to lower the releasing speed separately. However, it is only a preparing function for future product. According to the QFD targets, it will not be built in the prototype.
- Furthermore, the brake system can avoid the accident hill sliding when the vehicle is sliding to unexpected directions. For example, the backward sliding will be stopped as the shift lever is in D position. Anyway, the hill holding function will make the hill stopping safer.

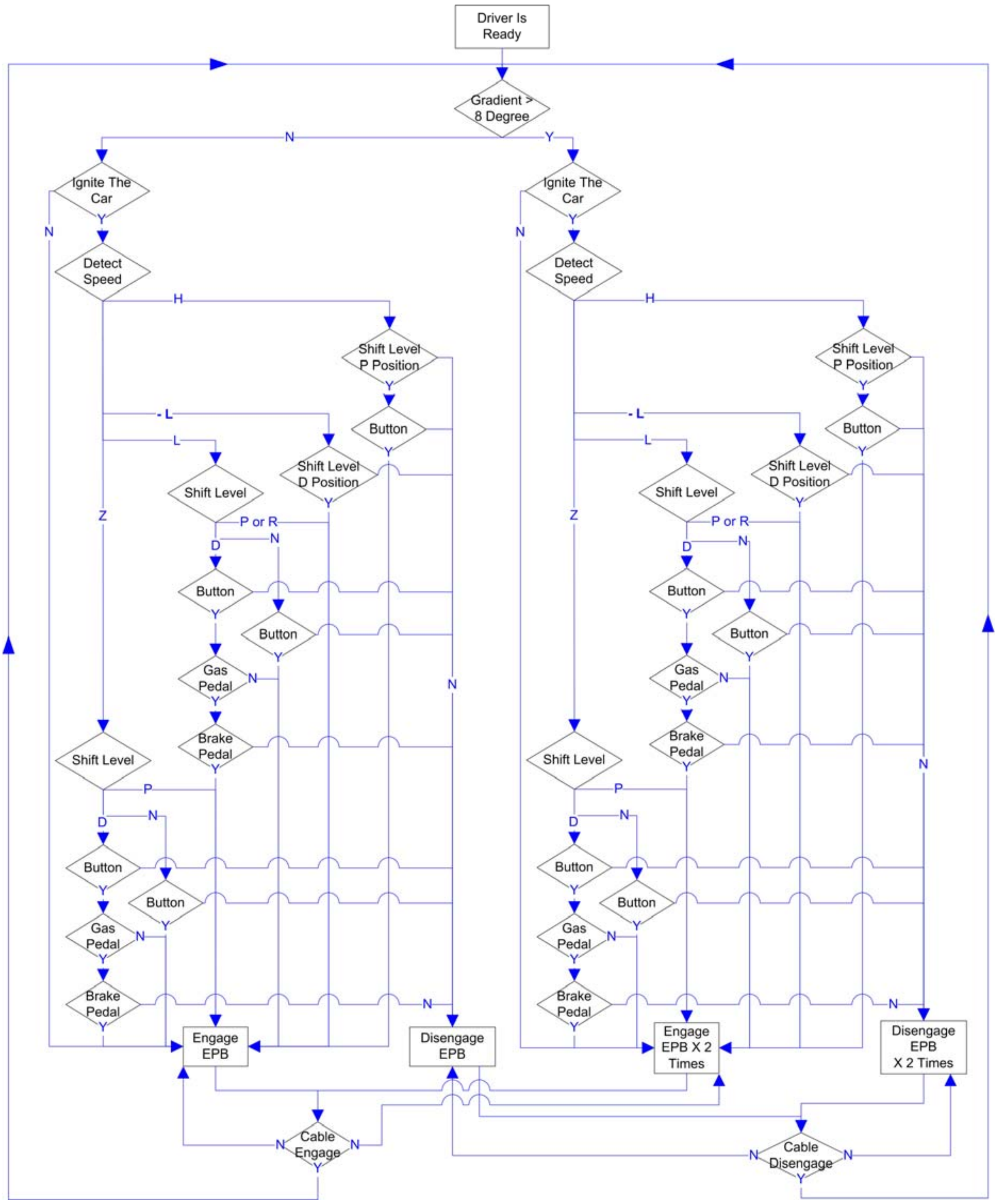


Fig 5.1-1 The Flow Chart of the Control Logic

5.2 Hardware

5.2.1 Actuator

The required working torque is about 480 kg-cm (with the required force 240 kgf and the moment arm 2 centimeters), the necessary speed is larger than 15 rpm, and the input voltage is 12 Volts. This motor specification is hardly found in commercial products. In addition, a specially made motor is too expensive to bear. Therefore, this prototype uses a smaller torque motor available in the market.

Motor, shown in Fig 5.2-1, is used to be the prototype actuator. The motor is an already commercial product for vehicle windshield wipers. Its stall torque is 380 kg-cm (Table 5.2-1), and costs only six hundreds. Although the motor's torque is barely enough for the brake load, it is large enough for testing the prototype. Moreover, with the testing result, a more proper motor will be produced for the prototype II or mass productions in the future.

A worm and a worm shaft are attached with the motor to provide the self-locker function (Fig 5.2-1-Left). There are three screw holes that can be used to fix the motor. Besides, the output axis (Fig 5.2-1-Right), manufacturing by rolled machining, requires one specially made part to collocate.

Fig 5.2-1 Motor Specification I

Items		Specifications
Volt		D.C 12V
Test Volt		D.V 13.5V(Constant)
Actuating Volt		Below D.C 8V
Volt Range		D.C 10~15V
Isolation		Above 1MΩ
Working (70Kg-cm Load)	Torque	47±4RPM
	Speed	Below 4A
Stall	Torque	380Kg-cm
	Current	Below 35A
Temp Range		-40℃ ~ 80℃
Noise		Below 58dB(A)

Table 5.2-1 Motor Specification II

5.2.2 Sensors

How to acquire the sensor signals is always a difficult subject for vehicle component manufactures. However, for modern vehicles, all sensor signals are transferred to unified digital community signals, Controller Area Network (CAN-bus). (Some of the signal codes are public, but some are private.) Then the ECU will integrate these signals and make decisions for next operations. With the progressive technique, the sensor information can be acquired by explaining the public CAN-bus codes rather than processing conventional sensor signals one by one.

However, for the prototype, the goal is to develop a model which can operate successfully and logically. Using real sensors to simulate system is necessary and uneconomical. Based on these reasons, the signal acquiring procedure, how to process every sensor signals in vehicles, is disregarded for the prototype.

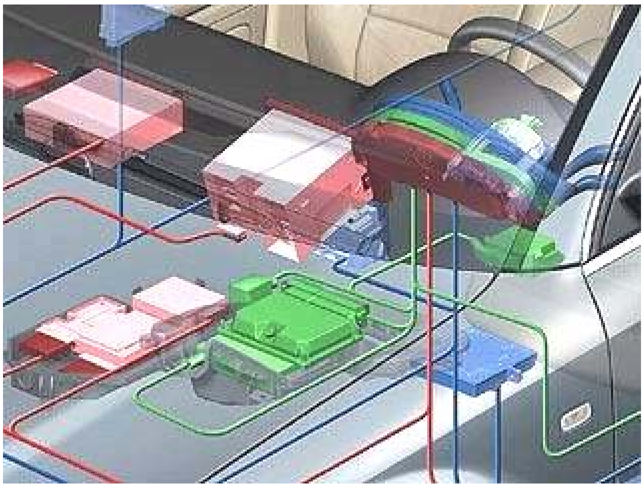
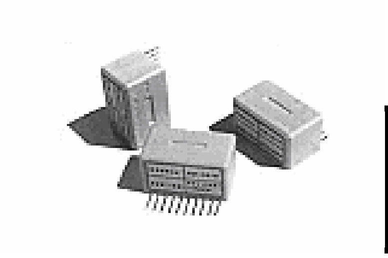


Fig 5.2-2 CAN-bus in Audi Vehicles

5.2.2.1 Gradient

The required specifications of the gradient sensor is single axis, ±20 degrees angle range, and 5 Volts voltage. The product, shown in Table 5.2-2, can be bought in the market conveniently.



Range	Output Voltage	Size(mm)	Application
±5°~±45°	±3V/±1.5V	60×40×40	Stucture and mechanism

Table 5.2-2 The Angle Sensor Specification

5.2.2.2 Speed

The speed sensor, shown in Fig 5.2-3, is a medium accuracy Hall-effect sensor. It is ideal for sensing the speed of an input or output of an automatic transmission. It is fully packaged sensor mounted to the outside of transmission, and perfectly suitable for the prototype.

Fig 5.2-3 The Hall-effect Speed Sensor

5.2.2.3 Ignition and EPB Button

The rocker switch, showed in Table 5.2-3, is chosen to be the ignition and EPB button and it has the followed advantages:

- Single-pole and double-pole configurations
- High current switching in a compact round package
- Self-locking tabs to fit industry-standard panel cut-outs

Ratings:	10A 125VAC / 8A 250 VAC 1/4 HP (UL, CSA) 10A (4) 250V ~ µ T125/55
Dielectric Strength	1000VAC for 1 minute
Insulation Resistance:	108 ohms min at 500VDC
Initial Contact Resistance:	.020 ohms max
Temperature Range:	-20°C to +85°C

Table 5.2-3 The Rocker Switch Specification

5.2.2.4 Shift Lever, Gas Pedal, Brake Pedal, and Cable Feedback

These sensors, shift lever, gas pedal, brake pedal, and cable feedback are used to be position sensors, but the limit switch is more proper for the prototype. It can be as effective as position sensors, but cheaper and more easily assembled than position sensors.

Electronic Rating:	5A, 125/250VAC 5A, 30VDC (optional)
Temperature Rating:	-40° to +85°C, +130° optional using thermoset
Case:	Thermoplastic
Actuating Button:	Thermoplastic Acetal
Terminals:	Silver-Plated Commercial Bronze
Moving Blade:	Beryllium Copper
Spring:	Stainless Steel
Auxiliary Actuator:	Cold Rolled Steel (Nickel-Plated)
Contacts:	Fine Silver (except E63 - Gold Crosspoint)

Table 5.2-4 The Limit Switch Specification

CHAPTER 6 EMBODIMENT DESIGN

6.1 Mechanism Prototype

6.1.1 Tolerance

Tolerance design is required for manufacturing compatible components. Proper precision can provide a balance between cost and efficiency. Moreover, the tolerance comprises the bilateral tolerance, and the unilateral tolerance. For general manufacture, the tolerance is arranged as normal tolerance (bilateral tolerance). On the contrast, for specific fits, the tolerance is arranged as unilateral tolerance. The normal tolerance of assemble components is listed in Table 6.1-1. Besides, the assemble drawings was showed in Fig 6.1-1

Size(mm)	0.5~6	6~30	30~120	120~315	Angle
Precision	±0.1	±0.2	±0.3	±0.5	±0.2°

Table 6.1-1 Normal Tolerance for the Components

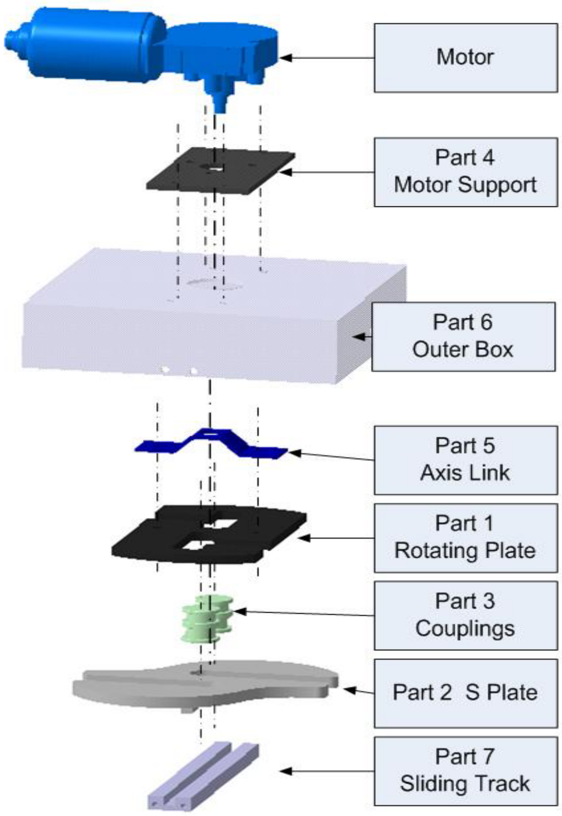


Fig 6.1-1 Assemble Draft

6.1.2 Machining

The machining cost varies according to the material amount and machining methods. Furthermore, the stock size and the waster deserve more consideration for the component geometry properties. For some specific circumstances, the design should be modified to match proper materials or machining. The suitable machining is defined after continual conversations with mechanics. The detail machining of each component is listed in Table 6.1-2.

Part NO.	Name	Manufacture	Material	Prices(NT)
1	Worm	Wire Cutting	S45C	3600
2	S Plate		S45C	5000
3	Coupling	Lathe	S45C	600
4	Motor Support		S45C	900
5	Axis Link	Laser Beam Cutting Sheetmetal Welding	S45C	1100
6	Outer Box		Stainless Steel	2500
7	Sliding Track	Lathe and Miller	Aluminum Alloy	900

Table 6.1-2 Components Manufacturing

6.1.3 Release Function

The embodiment of the release function was presented as Fig 6.1-2. There is an additional wrench to which the inner clutch and the outer clutch adhere. In emergency condition, the wrench can substitute for original actuator, the motor. The first step is to cover the axis link outer clutch and to turn counterclockwise. Then, lock the wrench by covering the wrench outer clutch with outer box inner clutch. Finally, the brake will be engaged and locked.

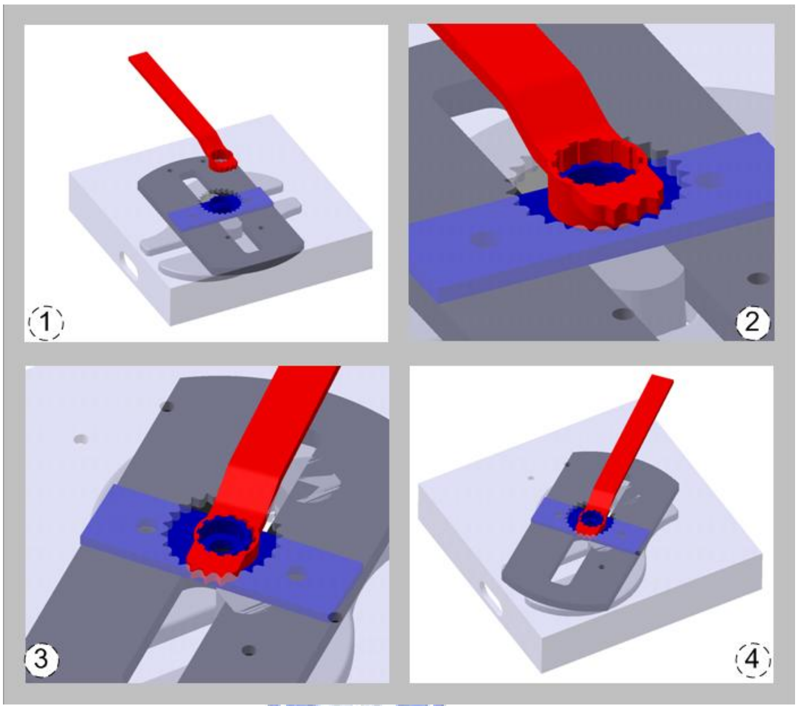


Fig 6.1-2 The Release Wrench

6.1.4 Prototype

The prototype is manufactured and assembled as Fig 6.1-3 showed. It weights 7kg. There are three parts modified to match acting objectives as presented in Fig 6.1-4. Welding machining constraints are the reason for the first modification (Fig 6.1-4-A). The original plate thickness was 5 mm which is too thick to be bent to 45 degree curvature. Thin plate (3 mm) and the axis cylinder are used to modify the machining problem. In addition, the track holder is designed to prevent the couplings from failing off rotating plate gaps (Fig 6.1-4-B). Moreover, the sliding track is thinned out to avoid the contact with couplings (Fig 6.1-4-C). Finally, except these modifications, the quality oils lubricate the prototype to make it act more smoothly.

Fig 6.1-3 The Assembled Prototype

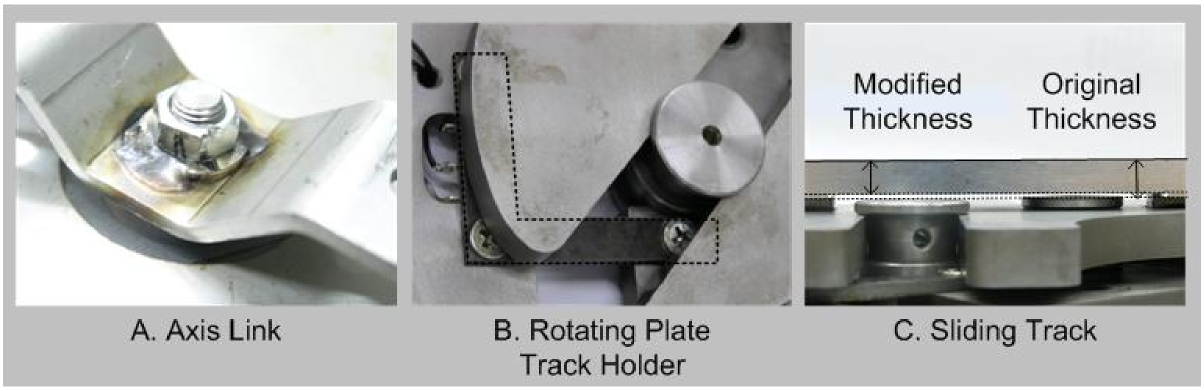


Fig 6.1-4 Modified Parts

The power supply can supply the voltage, 12 volt, to start the prototype. The opposite motions, engaging and disengaging movements, can act successfully and smoothly as expectancy. In addition, the couplings position feedback sensors, limit switches, are built in the both end sides of the sliding track as showed in Fig 6.1-6. The digital signal will pass a shut instruction to stop the actuator.

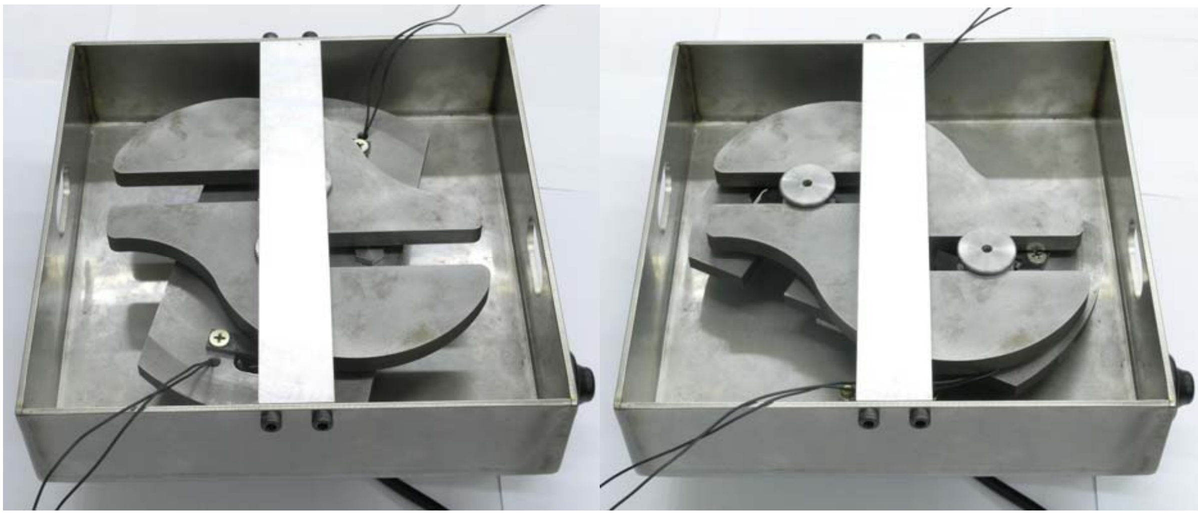


Fig 6.1-5 The Engaging (Left) and Disengaging (Right) Situations

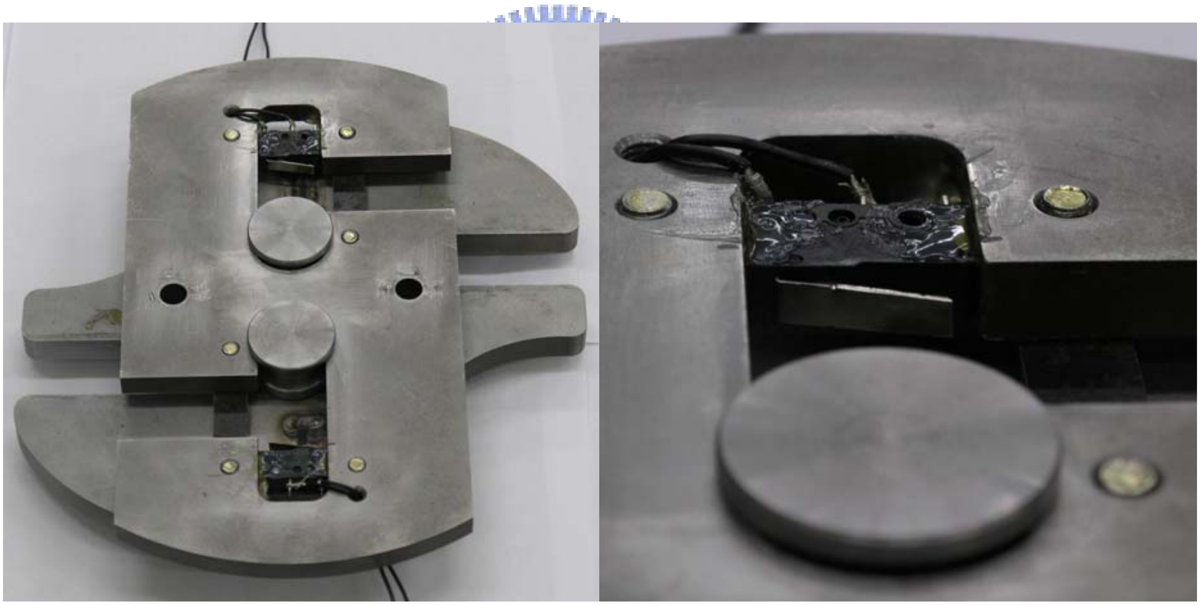


Fig 6.1-6 Limit Switch Sensors

6.2 Control Prototype

6.2.1 Interface

The LabVIEW user interface is a simulation of real driving user interface. There are three parts in the interface, consisted of the feedback, the control and the motor control. For example, sensors situations are returned to the feedback zone (Fig 6.2-1). Besides, a speedometer, an EPB LED, a hand brake button, an ignition button, a brake pedal, a gas pedal, and a shift lever are built in the control zone (Fig 6.2-3). Furthermore, what actions the motor will behave, delaying for certain seconds, turning clockwise or counterclockwise, after receiving logic orders is defined in motor control zone (Fig 6.2-3). The coupling position signals are pass back to check the successful parking. Four limit switch signals are presented in Fig 6.2-3-Signal 1 to Signal 4.

Fig 6.2-1 Feedback Zone

Fig 6.2-2 Control Zone

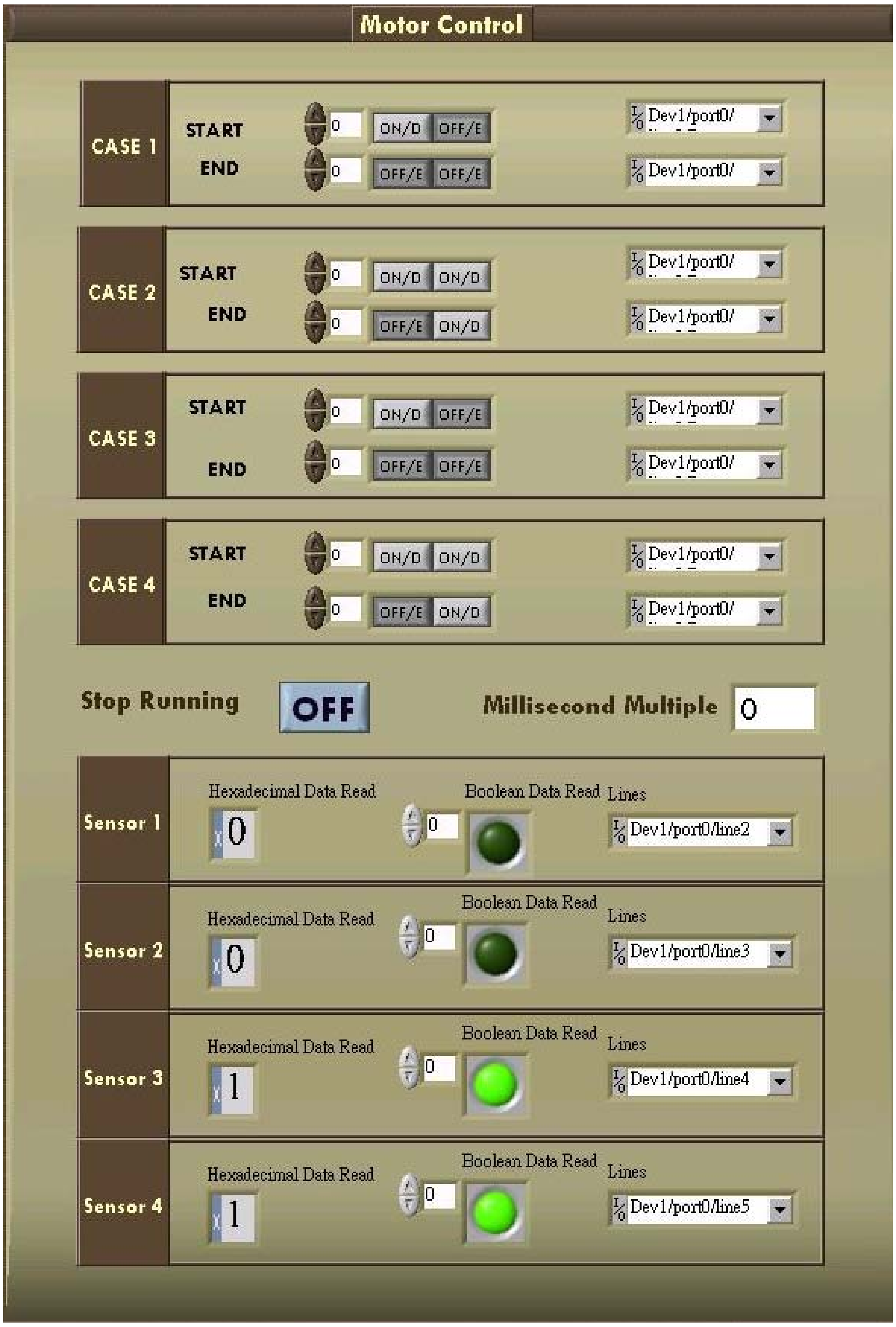


Fig 6.2-3 Motor Control Zone

6.2.2 Motor Driving Circuit

The motor driving circuit is designed by three digital relays, two 5V relays and one 12V relay. The relay is the electrical devise which can employ a solenoid to provide mechanical action to move a varying number of electrical contacts back and forth or on and off. In the circuit, one 5V relay controls the motor power switching on and off. Another 5V relay and one 12V relay control the motor counterclockwise or clockwise rotating. The control circuit and the load circuit are showed in Fig 6.2-4 and Fig 6.2-5. The R1, R2,and R3 are three relay contacts separately. When the R3 contacts A point, the current Line A will actuate motor to rotate clockwise. On the contrast, when the R3 contacts B point, the current Line B will actuate motor to rotate counterclockwise. The power supplier 12V is controlled by the button 1. It can actuate or stop the motor. However, the detail connect are present in Fig 6.2-6. The Relay C composes of the R1 and the R2 relay contacts. The Relay B substitutes the R3 and Relay A substitutes the button 1.

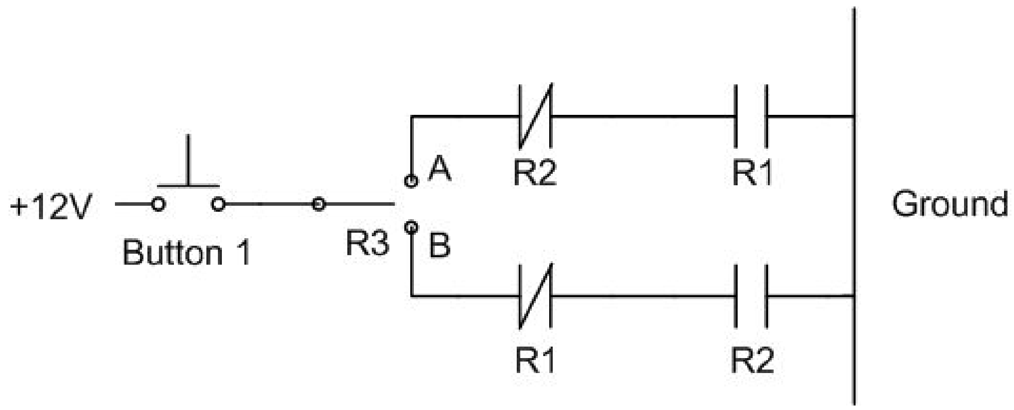


Fig 6.2-4 The Motor Driving Control Circuit

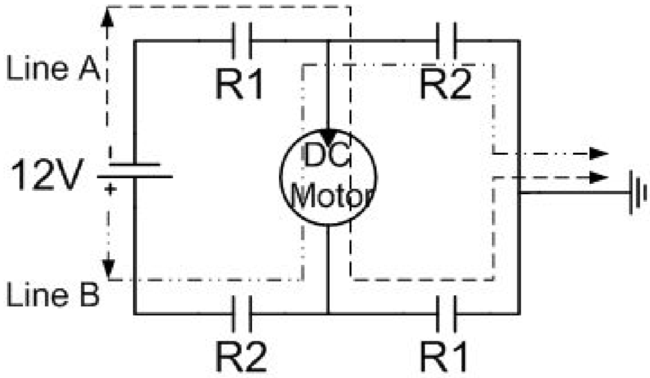


Fig 6.2-5 The Motor Driving Load Circuit

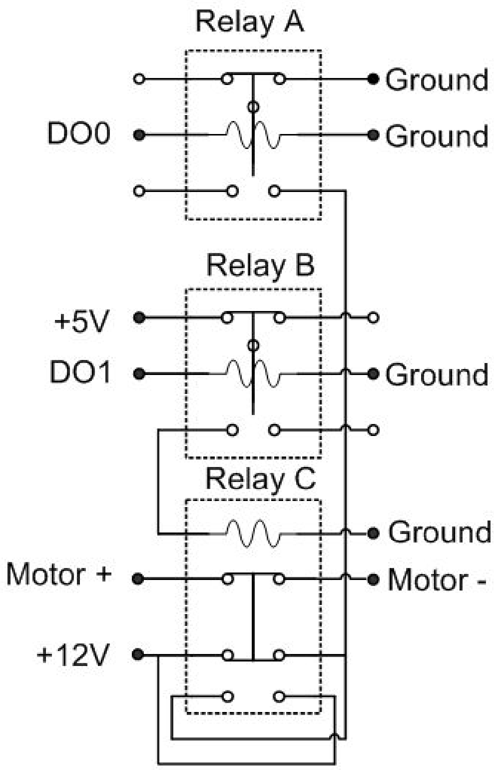


Fig 6.2-6 The Motor Driving Circuit Connection

6.3 Integration System

The final system, including a computer, a date acquisition (DAQ) card, a terminal, a motor driving circuit, a power supplier, and a mechanism prototype, is showed in (Fig 6.3-1). The control logic and the user interface are programmed by LabVIEW in the computer. It will pass instructs or receive feedback signals through the DAQ card and the terminal. Then through the driving circuit, the motor will be controlled to rotate clockwise or counterclockwise. Moreover, the mechanism prototype will pass feedback signals to the PC through the DAQ card and terminal to ensure the successful motion. However, the power supplier provides the power of motor (12V) and the motor rotating circuit (5V and 12V).

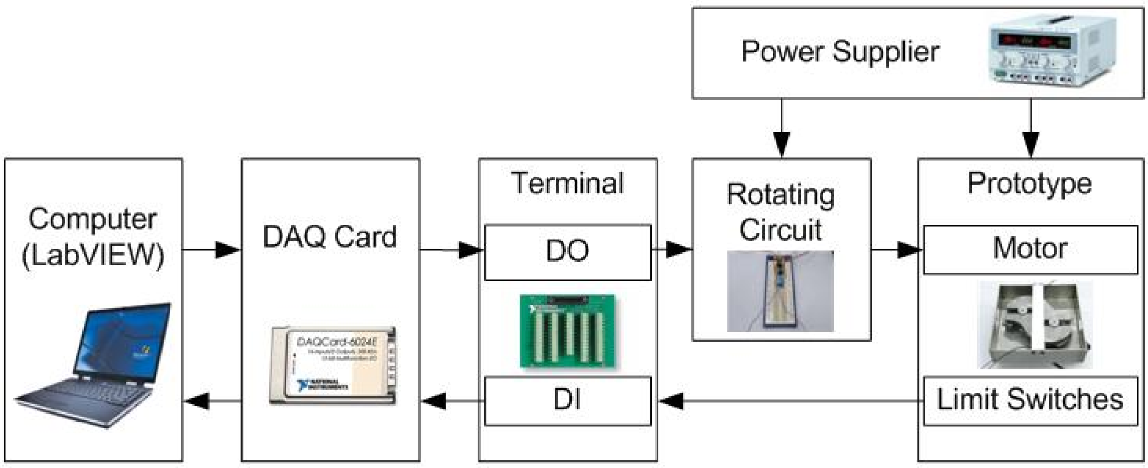


Fig 6.3-1 The Integrated System

6.4 Test Instrumentation

The output force of the prototype is measured by the test instrumentation (Fig 6.4-1). The relation between cable positions and the force, and the maximum force are the objectives of the measurement. Moreover, the result will illustrate the proper engaging distance and required input volt and current.

The cable distances are recorded by nicking the load cell position in graduation. The distance is equal to the cable pulled. For example, the 0 cm position means that the prototype starts to pull the cable. Furthermore, the 3 cm position means that the prototype has pulled the cable for 3 cm (Fig 6.4-2).

The load cell (for maximum load 50 Kg) can measure the prototype force and show in the signal indicator. The signal indicator is an amplifier that can magnify the slight variations of load cell. After repeated counterpoise adjustment, the indicator can read the tensile and the pressure forces with precision 0.01 Kg. In addition, the power supplier actuates the motor by 12 volts and 1~3 amp currents.

Fig 6.4-1 The Force Test Instrumentation

The force related to the cable position is showed in Fig 6.4-2. The maximum force occurs when the cable is in 3 cm position even if the current is different. This position is also the engaging situation which requires larger force to pull the cable. Therefore, the maximum force is suitable for providing the larger pull force for the engaging situation.

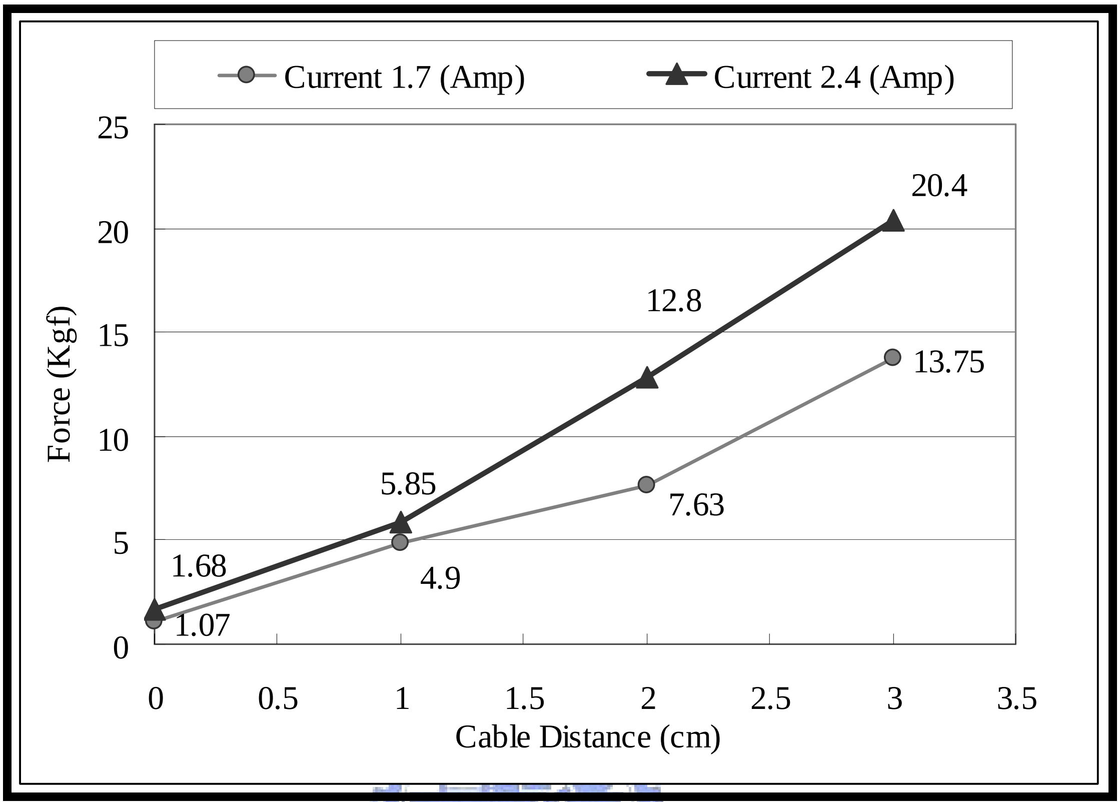


Fig 6.4-2 The Relation between the Force and the Cable Distance (12Vlots)

However, the force is far from the require force, 120 Kg, for each cable proven in section 4.4.1. If the power supplier could provide higher current, the output force might reach the required force, 120 Kg. According to the formula below, the output force is in direct ratio to the input current when the input voltage, rotating plate radius, and rotating speed are stable. For the prototype, the input power can be written as:

$$W = V \times I \tag{6.4-1}$$

where W is the input power (watt), V is the input voltage (volt), and the I is the input current (ampere). In addition, the input power can also be written as follows:

$$KW = T \times n / 974 \tag{6.4-2}$$

and

$$T = F \times r \tag{6.4-3}$$

where KW is the input power(K watts), the T is the motor output torque (kg-cm), n is the motor rotating speed (R.P.M), the F is the mechanism output force, and the r is the mechanism moment arm. By rearrangement of Eq.(6.4-1), Eq.(6.4-2), and Eq.(6.4-3),

$$F = \frac{974 \times V}{1000 \times r \times n} \times I \tag{6.4-4}$$

When V, n, and r are constant,

$$F \propto I \tag{6.4-5}$$

The current for output force 120kg can be estimated by the extrapolation. The current should be 11.39 (Amp) for prototype to reach the 120 Kg output force. The calculation is presented as below.

$$\frac{F_2 - F_1}{I_{F2} - I_{F1}} = \frac{F_x - F_1}{I_{Fx} - I_{F1}} \tag{6.4-6}$$

where I_{F1} is the motor input current when the motor output force is F_1, I_{F2} is the motor input current when the motor output force is F_2, and I_{Fx} is assumed to be the input current when output force is equal to $F_x = 120$ kgf. The value of I_{120} is gotten by other known factors:

$$\frac{20.4-13.75}{2.4-1.8}=\frac{120-13.75}{I_{Fx}-1.8} \tag{6.4-7}$$

$$I_{Fx}=11.39 \tag{6.4-8}$$

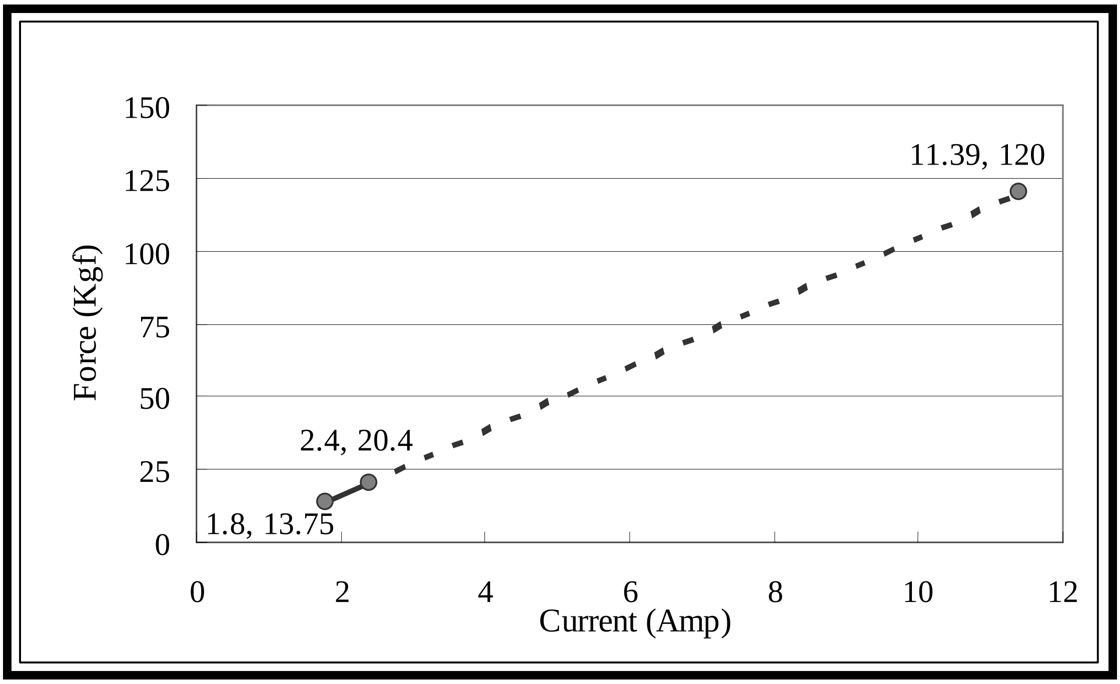


Fig 6.4-3 The Relation between the Force and the Current (12Vlots)

The current 11.39 Amp is hardly supplied by normal power suppliers. The specific power supplier which can supply higher currents will be too expansive to bear. Moreover, the current 11.39 Amp must can be offered by vehicle batteries (50~70 Amp). As a result, the prototype output force is believed to conform with the required force if the sufficient current is offered.

The prototype output mentioned above is designed only for sedans and SUVs. In addition, a trailer or a truck can set this product if the motor torque is changed. For general use, the relation between the motor torque and the prototype output force should be illustrated. As the Fig 6.4-4 shows, the motor torque (T) is equal to output force cross radius ($F \times r$). The mechanism frictions are assumed to be ignored. However, for the prototype, the r is a constant, 2 cm. Therefore, the relation between motor torque (T) and the prototype output force (F) is presented as Fig 6.4-5. The Curve can help the designer to modifying the mechanism for more kinds of vehicles.

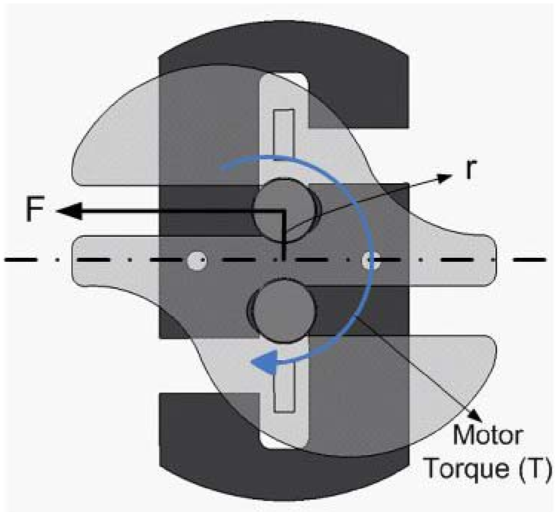


Fig 6.4-4 The Geometry Relations

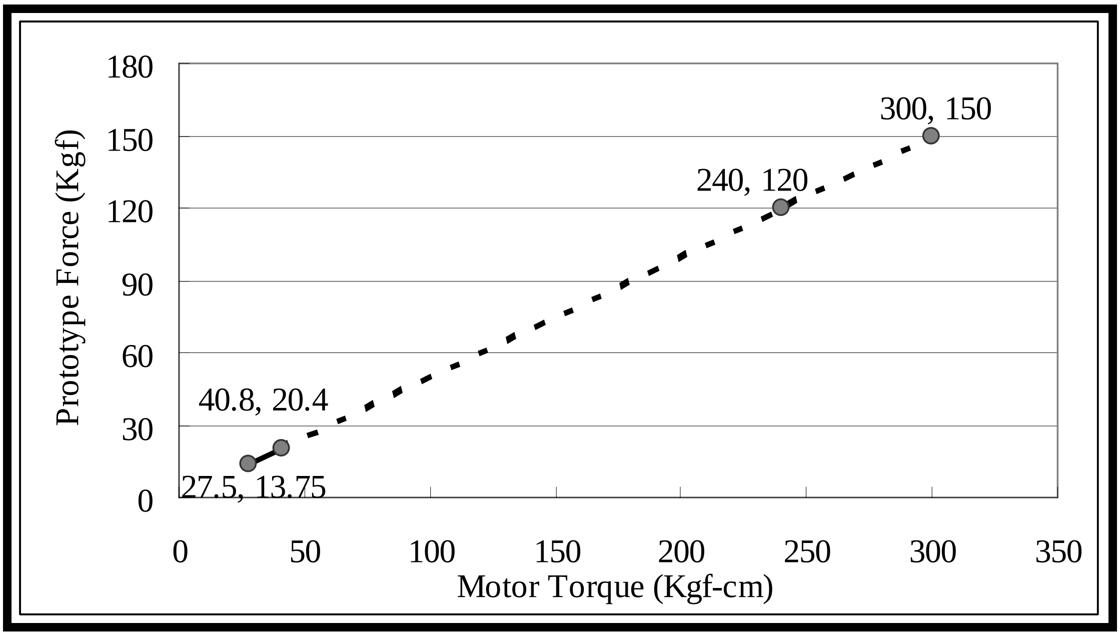


Fig 6.4-5 The Relation between Motor Torque and Prototype Force

6.5 Comparisons

The system is integrated by mechanism and electronics completely. Then, the system specifications should be compared with the QFD targets, discussed in section 3.2. The QFD targets are defined considerately by the patent analysis and the market survey. An estimative criterion for future design will be build by the comparison. As Table 6.5-1 shows, the QFD target is presented in the “Target-QFD” column, and the system specification is showed in the “Target Achieved” column. In addition, the specifications of other competitive brand products are listed in “MBS”, ”Renault scenic”, and “Audi A8” columns.

Obviously, the performance of the system has achieved several targets. Especially, the acts of operating time and the cost are better than the QFD targets. However, the releaser function, the weight, and the CNS test are worse or uncompleted. The release function concept has been introduced in section 6.1.3, and required to be modified and machined. Moreover, the reason for the bulky weight has been discussed in section 4.4.2.3 and 4.4.3. For the explanation, plastics can substitute the S45C to reduce weight in mass production. Finally, the product is proposed to have the CNS test as a quality proof.

Specifications / Brands		Brake force	States of adjustable force	Assembly time	Sensor amount	Motor amount	Operating time	Component amount	Manual button	Releaser	Weight	CNS test	Cost
		kg	#	hr	#	#	S	#	y/n	y/n	kg	y/n	KNT
MBS		300	1	1	7	1	2	3	y	y	1~2		10
Renault Scenic			2	1	8	1	1	1	y	y	1~2	y	40
Audi A8			2	1~2	7	2		3	y	y	1~2	y	37
Target	**QFD**	**<300**	**1**	**1.5**	**7**	**1**	**1.2**	**1**	**y**	**y**	**1~2**	**y**	**25**
	Achieved	**240 (Estimated)**	**1**	**1.5**	**7**	**1**	**1**	**1**	**y**	**n**	**7**	**n**	**16**
	Notices	○	○	○	○	○	◎	○	○	×	×	×	◎

Table 6.5-1 The Comparison between the QFD Target and the Achieved Target

CHAPTER 7 CONCLUSIONS AND FUTURE WORKS

7.1 Conclusions

The EPB study provides a complete procedure of product design from patent analysis, the market survey, QFD method, mechanical design, electronic design, and system integration.

The patent analyses and the commercial products surveys bring out the product potential tendency, the function comparisons of commercial products, and the patent technique matrixes. In addition, the QFD method clarifies the customer requirements, the commercial product specifications and then defines the target specifications for designing a competitive product.

The new EPB system is developed and embodied. The mechanism combines the balancer with the original EPB, providing operator, reducer, self-locker, releaser, and balancer functions. Moreover, the PC-based method is used to integrate the mechanism and electronics. LabVIEW program is used to control the EPB in the virtual environment with considerations of various driving conditions. The program provides a convenient manner to modify the control algorithm in the future.

Finally, the test instrumentation for the EPB system is developed. The relation between the input motor torque and the output brake force is recorded as the recommend for the application to other vehicles. In addition, the comparison between QFD targets and the system specification can be the criterion for future modifications.

7.2 Future Works

- The releasing function concept is too complex to be machined and should be modified.
- The materials strength (S45C) is not suitable for a commercial product. It is overestimated and makes the total weight heavier than other product. The material, plastics, is more proper for mass producing, discussed in Section 4.4.2.
- The pulling distance is overestimated, and the volume is larger than other commercial products. Modifying the distance and the size of mechanism will be needed to minimize the prototype volume.
- The self-locker torque of the selected motor is not enough for the load condition. The exact load condition should be defined after the testing vehicle is chosen. Then, the motor torque can be more appropriate for the vehicle brake system.
- The asymmetry arrangement of mechanism caused by balancer function will produce a banding load for the motor axis. The load affection to the mechanism needed to be deliberated.
- The real vehicle sensors should pass signals to the PC for testing. Furthermore, the control logic should be modified to suit to both automatic transmission (AT) and manual transmission (MT) vehicles.
- The CNS testing is required to have a quality proof for commercial productions.

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