OPTIMAL ANTI LOCK BRAKING SYSTEM WITH REGENERATIVE BRAKING IN HYBRID ELECTRIC VEHICLE

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To my beloved parents and brothers

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ABSTRACT

Hybrid electric vehicle is an electric drive vehicle which is powered by internal combustion engines (ICE) and an electric motor. However, this vehicle has some problems such as driving range, recharge time and battery cost. On the other hand, one advantage of HEV is able to recover energy during the brake by converting kinetic energy into electric energy and use it immediately or stored when it is required. This process is called regenerative braking. Anti-lock-braking system (ABS) is a safety system which allows the wheels to maintain the friction between the tires and prevent the car from skidding especially on dry and slippery road surfaces. Change in vehicle weight, friction coefficient of the road and road inclination can affect the behavior of the braking system. Therefore, optimization of the ABS system is necessary. In this study, optimal anti-lock-braking system (ABS) with regenerative braking in a hybrid electric vehicle is surveyed. The methodology consists of the mathematical model of the vehicle, ICE and electric motor, control design for ABS system and simulation. Besides, MATLAB software is used for the simulation model.

ABSTRAK

Hibrid kenderaan elektrik adalah memandu kenderaan elektrik yang dikuasakan oleh enjin pembakaran dalaman (ICE) dan motor elektrik. Walau bagaimanapun , kenderaan ini mempunyai beberapa masalah seperti pelbagai memandu , masa aliran masuk dan kos bateri. Sebaliknya , satu kelebihan HEV adalah keupayaan untuk mendapatkan semula tenaga semasa brek dengan menukar tenaga kinetik kepada tenaga elektrik dan menggunakannya dengan serta-merta atau disimpan apabila ia diperlukan. Proses ini dipanggil brek regeneratif. Sistem anti -kunci brek - (ABS) adalah sistem keselamatan yang membolehkan roda untuk mengekalkan geseran antara tayar dan menghalang kereta dari tergelincir terutamanya pada permukaan jalan kering dan licin. Perubahan berat kenderaan , pekali geseran jalan dan kecenderungan jalan boleh memberi kesan kepada tingkah laku sistem brek. Oleh itu , pengoptimuman sistem ABS itu perlu. Dalam kajian ini, sistem anti -kunci brek - optimum (ABS) dengan brek regeneratif di dalam kenderaan elektrik hibrid yang dikaji. Metodologi ini terdiri daripada model matematik kenderaan, ICE dan motor elektrik , reka bentuk kawalan sistem ABS dan simulasi. Selain itu, perisian MATLAB digunakan untuk model penyelakuan.

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LIST OF ABBREVIATIONS

ICE	-	Internal Combustion Engine
DoT	-	Department of Transportation
ABS	-	Anti-locking Brake System
AC	-	Alternative Voltage
ECU	-	Electric Control Unit
HEV	-	Complementary Metal Oxide Semiconductor
e-CVT	-	electric-Continuously Variable Transmission
CVT	-	Continuously Variable Transmission
PHEV	-	Parallel Hybrid Electric Vehicle
CBCS	-	Combined Braking Control Strategy
AFPM	-	Axial Flux Permanent Magnet
EMF	-	Electro Magnetic Field
PID	-	Proportional Integral Derivative

CHAPTER 1

INTRODUCTION

1.1 Hybrid Electric Vehicle

Hybrid electric vehicle is a kind of vehicle that consists of two major parts. These two parts are internal combustion engine (ICE) and motor. An internal combustion engine is an engine which operates by burning its fuel within the engine. The most usual internal combustion engine type is gasoline powered. A motor is a machine that converts electrical energy into mechanical energy. This is done by applying the force to a coil that is located in a magnetic field. There are three kinds of hybrid electric vehicle. These types are series hybrid electric vehicle, parallel hybrid electric vehicle and through-the-road hybrid electric vehicle. Each of them are explained in following.

1.1.1 Series Hybrid Electric Vehicle

In a series hybrid electric vehicle, the combustion engine drives an electric generator instead of driving the wheels directly. The generator charges a battery and powers an electric motor. When large amounts of power are needed, the motor draws electricity from both the batteries and the generator (Ursan, Vremeră et al.). Following picture shows the connections of battery, inverter, motor, engine and generator .

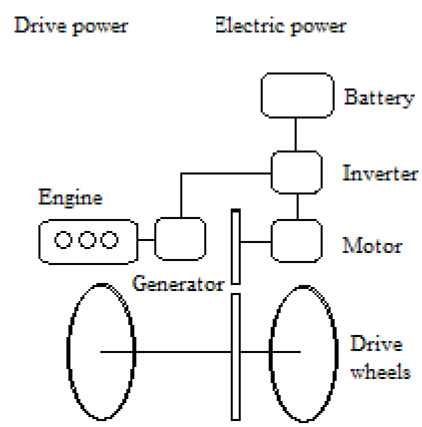

Figure 1.1 Structure of a series hybrid vehicle

Series hybrid electric vehicles can be boosted with the help of ultracapacitor, which can improve the efficiency by minimizing the losses in the battery. They provide most amount of energy during acceleration and take regenerative energy during braking. A complex transmission between motor and wheel is not necessary. If the motors are attached to the vehicle body, flexible couplings are required. Some vehicle designs have separate electric motors for each wheel. In some configurations, individual wheel motors are used. Also in this research four in wheel motor are used.

1.1.2 Parallel Hybrid Electric Vehicle

Parallel hybrid systems are composed of both an internal combustion engine (ICE) and an electric motor that are connected to a mechanical transmission in parallel.

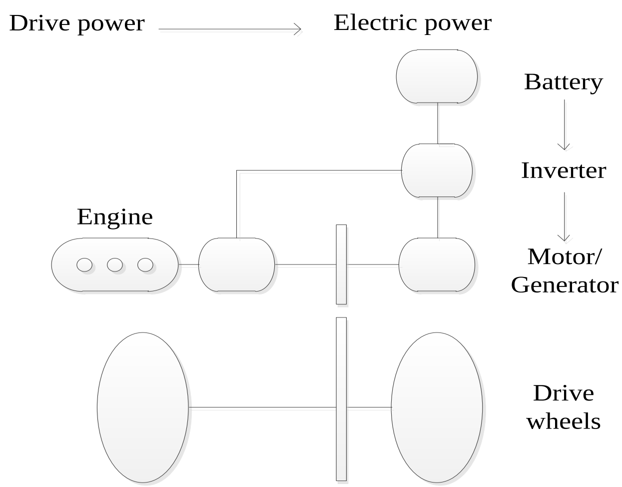

Figure 1.2 Structure of a parallel hybrid electric vehicle

As it is shown in the above picture, in most designs motor and electrical generator are combined together and placed in one unit. Sometimes conventional starter motor and the alternator are replaced between the combustion engine and the transmission. The battery recharges during regenerative breaking and does not charge when the car is not moving

1.1.3 Through-The-Road Hybrid Electric Vehicle

Through-the-road hybrid electric vehicle consists of two sources of traction drive that make up the hybrid system; these two sources are Internal Combustion Engine (ICE) and electric motor. The following picture shows different parts of through-the-road hybrid electric vehicle. As it is seen motor and engine in this type of hybrid electric vehicle does not any connection together.

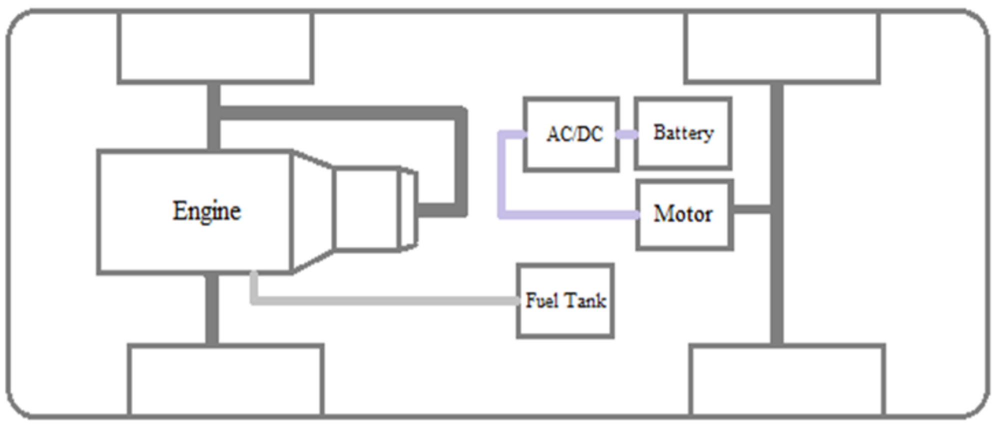

Figure 1.3 Through The Road Hybrid Electric Vehicle

This research is focused on Trough The Road hybrid electric vehicle.

1.2 Brake

Brake is a device for slowing or stop motion. The typical brake system consists of disk brakes in front and disk or drum brakes in the rear connected by a system of tubes and hoses that link the brake at each wheel to the master cylinder. Other systems that are connected with the brake system include the parking brakes, power brake booster and the anti-lock system. When the driver pushes the brake pedal, pressure transmits to the master cylinder and forces hydraulic oil through a series of pipes and reaches to each wheel. It is very important that the fluid is pure liquid and there are no air bubbles in it. Air can compress, which causes severely reduced braking efficiency.

On a disk brake, the fluid from the master cylinder is forced into a caliper where it presses against a piston. Pads are attached to the wheels and push it to slow down or stop the motion. This process is similar to a bicycle brake where two rubber pads rub against the wheel. With drum brakes, fluid is forced into the wheel cylinder which pushes the brake shoes out so that the friction linings are pressed against the drum that is attached to the wheel and cause to stope the wheel. In other case, the friction surfaces of the pads on a disk brake system or the shoes on a drum brake convert the forward motion of the vehicle into heat. Heat is what causes the friction surfaces of the pads and shoes to eventually wear out and require replacement.

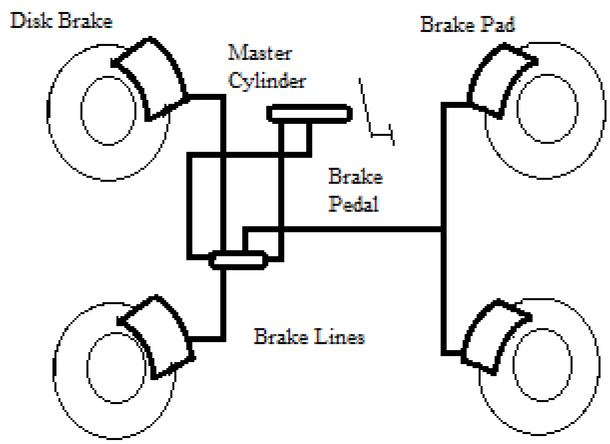

Figure 1.4 components of brake system

In the next sections, several parts of brake system will be explaine

1.2.1 Master Cylinder

Master cylinder is located in the engine compartment, in front of the driver's seat. A typical master cylinder consists of two complete separate master cylinders, each handling two wheels. If one side fails, the driver will still be able to stop the car. The brake warning light that is located on the dash will light if either side fails. Master cylinders are very reliable and rarely malfunction; although, the most common problem of them is an internal leak. If this problem happens, the brake pedal sinks to the floor slowly when driver's foot applies steady pressure.

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1.2.2 Brake Fluid

Brake fluid is special oil and has specific properties. It is designed to be resistant against very high and very low temperature. Brake fluid must meet standards that are set by the Department of Transportation (DoT). The current standard is DOT-3 which has a boiling point of 460º F. The brake fluid storage is on top of the master cylinder. The brake fluid level a little will be reduce to wear the brake pads. This is a normal condition and no cause for concern. If the level drops significantly during a short period of time or goes down to about two-thirds of full amount, brakes need to check as soon as possible.

1.2.3 Brake Lines

The brake fluid goes to the wheels through a series of steel pipes and reinforced rubber hoses from the master cylinder. Rubber hoses only use in places that flexibility is needed, for example at the front wheels, which move up and down same as steer. The rest of the system uses non-corrosive seamless steel tubing with special fittings at all attachment points. If a steel line needs to fix, the best way is to replace the whole of line.

1.2.4 Disk Brakes

The disk brake is the best brake that is funded until now. Disk brakes are used to stop motion. Disk brakes are less affected by water, are self-adjusting and self-cleaning. The main components of a disk brake are the Brake Pads, Rotor, Caliper and Caliper Support.

1.2.5 Brake Pads

There are two brake pads on each caliper. They are constructed of a metal shoe that is the lining riveted or bonded to it. The pads are installed in the caliper and there is one pad on each side of rotor. Because of some properties such as heat absorbing and quiet operation, brake linings are made from asbestos; but, because of health problems, asbestos has been illegal, so nowadays new materials are being used. Brake pads should be changed periodically. Many models of pads with various qualities are available. The differences are related to brake life and its noise. In heavy use, harder linings produce better stop but during apply they produce irritating squeal.

When the lining connects to the metal brake shoe, metal to metal condition happened and the shoe rub damages the brake also the braking efficiency will be decreased, so brake pads have to be checked regularly. Some brake pads are equipped with a warning sensor that will send out a voice noise when the pads are worn to a point where they have to be changed. Whenever this noise is heard that means brake need to be checked.

1.3 Regenerative Braking System

Regenerative braking is an effective approach for electric vehicles that extend driving range of the vehicles. The control strategy of regenerative braking plays an important role in maintaining the vehicle's stability and recovering energy (Guo, Wang et al. 2009). Regenerative is a braking system used in hybrid vehicles. During the braking kinetic energy convert to some un-useful energy like heat, but in the car with regenerative braking, this energy converts to some useful energy like electricity and saves in battery and does not waste the energy.

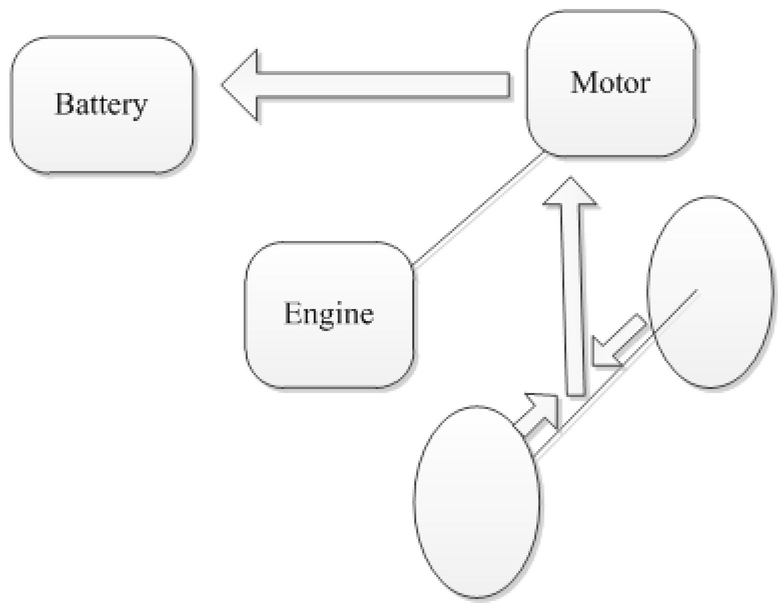

Figure 1.5 Regenerative braking system

1.4 Anti-Lock Braking System (ABS)

Anti-locking brake systems (ABS) are well established in the automotive industry to improve safety feature. ABS generally provide a hihgh level of safety for vehicle by limiting the longitudinal wheel slip in a braking event with deep slip condition (Anwar 2004). An ABS improves vehicle control and decreases stopping distances especially on dry and slippery surfaces; however, on slippery surfaces like snowing road, an ABS can significantly increase braking distance, although still improve the vehicle control is necessary. ABS consists of three major parts. They are wheel speed sensor, electric control unit and hydraulic pressure modulator.

1.4.1 Wheel Speed Sensor

Wheel speed sensors are sensors to detect the rotational speed of each wheel. In most vehicles, these sensors are the permanent magnet type. A permanent magnet sensor includes a coil of wire that is wounded around a magnet core.

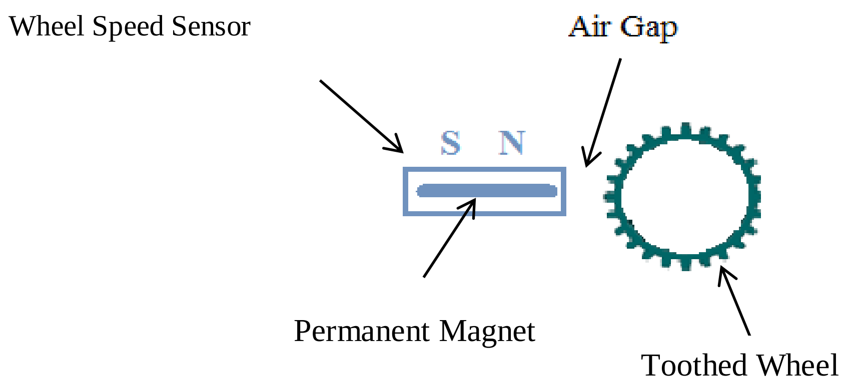

Figure 1.6 Wheel speed sensor

Every wheel has a speed sensor and informs the control unit of the wheel speed. These sensors are located on the steering knuckle of front wheel drive vehicles and the axle housing of the rears. The ABS control unit receives lower AC voltage from these sensors which increases with wheel speed. Then, the values of these signals are compared to the values of the other wheels and these information stores in memory.

1.4.2 Electric Control Unit (ECU)

Commands are sent in the form of electrical signals to the hydraulic control unit by the ABS Control Module or ECU. This unit executes the commands by using three solenoid valves connected in series with the master cylinder and the brake circuits. In normal condition, brake pedal force is transmitted to the master cylinder, then through the solenoid valve goes to brake pads and arrives to the wheel. When the signals from the wheel speed sensor does not show a tendency for the wheel, the ECU does not send any control current to the solenoid coil, so The solenoid valve is not energized, and the hydraulic pressure that's is produce from the master cylinder is supplied to the brake unit. When the control unit detects any lock-up tendency, a command current is sent to the solenoid coil. Then, the armature and valve move up, and separate the brake circuit from the master cylinder. The pressure between the solenoid and the brake circuit is kept constant.

If the sensor signal shows the decrease of acceleration continuously, the Control Module sends a larger current to the solenoid valve. The braking pressure decreases by moving the armature. If the sensors detect the normal speed then the wheel has allowed speeding up, the ECU stops all command current, which decreases the energy of the solenoid valve. The pressure increases, and the wheel are again slowed down.

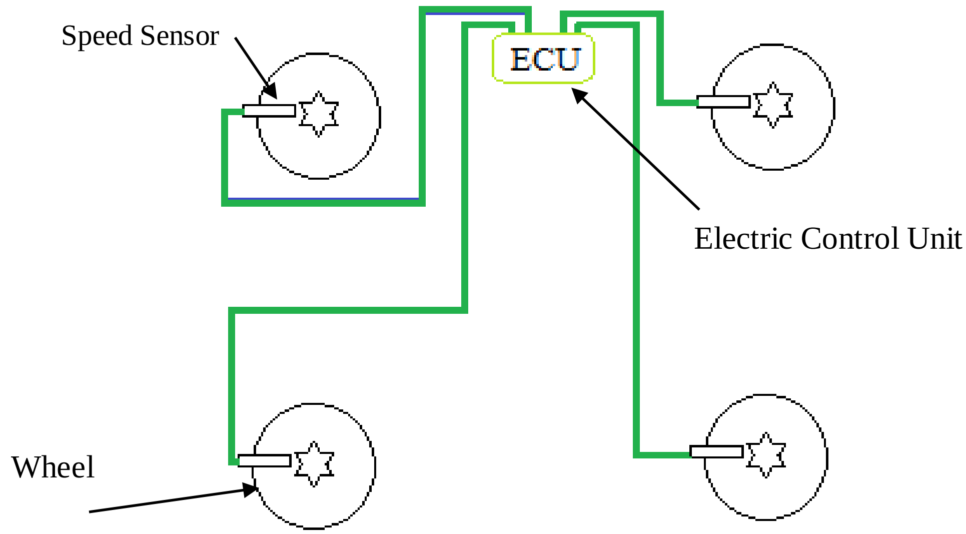

Figure 1.7 Electric control unit

1.4.3 Hydraulic Pressure Modulator

When operating in normal conditions, the outlet valve (C) of the hydraulic modulator is closed and the inlet valve (A) stays open until the pressure reaches the desired value. Then inlet and outlet valves remain closed to keep this pressure and provide adequate brake torque for wheel brake cylinders. Once the control unit shows any excessive wheel slip, the related outlet valve is opened to decrease the pressure in the accumulator (D) and avoid wheel from lockup. The excess brake fluid is returned to the master cylinder during the return pump (E). After the wheel slip returns to normal, the energy of valve solenoids will be reduced and the hydraulic modulator resumes the regular braking process.

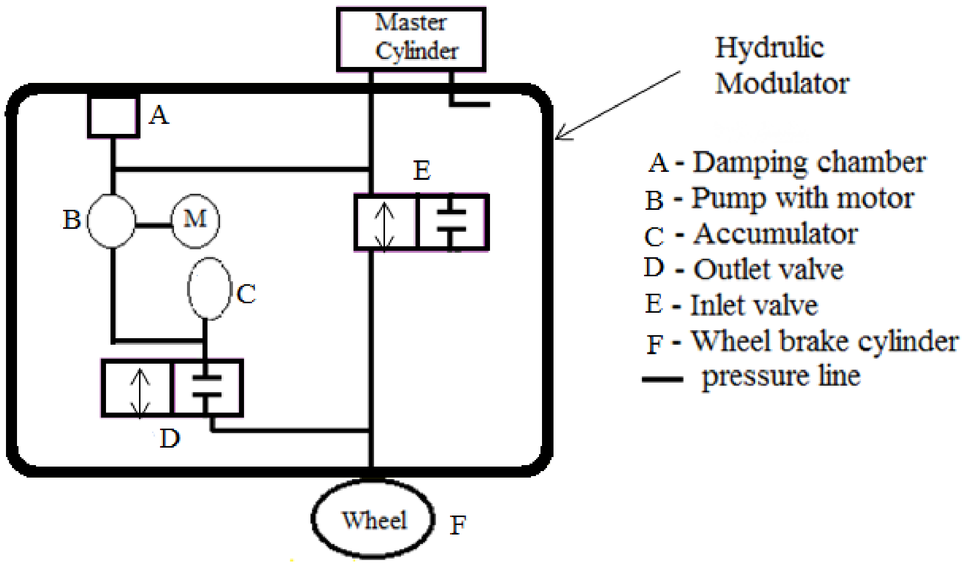

Figure 1.8 Hydraulic pressure modulator

1.5 Problem Statement

In articles that are studied, focus is on control with one variable control but in this research two control variable are used.

1.6 Project Objective

The Objectives of this research are divided into three parts:

1. To develop a mathematical model Hybrid Electric Vehicle (HEV).
2. To design a controller for an optimal braking of a Hybrid Electric Vehicle (HEV).
3. To simulate and validate the controller design.

1.7 Project Scope

This project involves a hybrid electric vehicle (HEV). Furthermore, only simulation will be carried out to achieve a desired slip ratio.

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