Faculty of Mechanical Engineering

REGENERATIVE BRAKING EFFECTS ON ISOTHERMAL AND ADIABATIC ENERGY STORAGE OF HYDRO-PNEUMATIC DRIVELINE

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SUPERVISOR'S DECLARATION

I declare that this thesis entitled "Regenerative Braking Effects On Isothermal And Adiabatic Energy Storage Of Hydro-Pneumatic Driveline" is the result of my research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :.....

Name of Supervisor: FAIZIL BIN WASBARI

Date :.....

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion, this dissertation/report is sufficient regarding scope and quality as partial fulfillment of Bachelor Degree of Mechanical Engineering with Honor.

Signature : .....

Name : .....

Date : .....

DEDICATION

To my beloved mother and father

ABSTRACT

The regenerative braking system is a process whereby the motor is reversed during the deceleration or stopping of a vehicle. Nowadays, there are various types of storage used to capture energy such as electrical, hydraulic, compress and kinetic. Hydrostatic regenerative braking system (HRB) was first retrofitted on a refuse truck. In order to apply HRB in the vehicle, research towards hydraulic energy storage performance will be needed. The hydraulic energy storage also known as an accumulator and the selection of the accumulator is based on their performance. The performance of each process will produce a different result. Thus, this research seeks to simulate regenerative breaking performance for adiabatic and isothermal processes**.** The result of regenerative braking performance for adiabatic and isothermal processes was obtained from simulation and needed to be compared based on the efficiency. The software used to conduct the simulation is Automation Studio. The result shows that isothermal process gives higher volume effectiveness and energy efficiency which is 13.55% and 17% compared to adiabatic process. However, when it comes to charging process (filling time), the adiabatic process gives higher result which is 18.31% compared to isothermal process. Adiabatic process only takes 112.37 s to reach 200 bar while isothermal process took 126.27 s to reach 200 bar. For the best case, a combination of both processes will be suitable to apply to the accumulator.

ABSTRAK

Sistem brek jenaan semula adalah satu proses di mana motor diundurkan semasa kenderaan bergerak perlahan atau kenderaan berhenti. Pada masa kini, Terdapat pelbagai jenis storan yang digunakan untuk menyimpan tenaga seperti elektrik, hidraulik, mampat dan kinetik. Permulaan sistem brek regeneratif hidrostatik (HRB) telah digunakan oleh lori sampah. Untuk menggunakan HRB dalam kenderaan, kajian terhadap prestasi simpanan tenaga hidraulik akan diperlukan. Storan tenaga hidraulik juga dikenali sebagai pemumpuk dan pemilihan pemumpuk tersebut adalah berdasarkan prestasi mereka. Prestasi setiap proses akan menghasilkan keputusan yang berbeza. Oleh itu, kajian ini bertujuan untuk melihat prestasi adibatik proses dan proses sesuhu di dalam storan tenaga di pemumpuk. Hasil daripada prestasi brek rjenaan semula proses adibatik dan proses sesuhu telah diperolehi daripada simulasi dan perlu dibandingkan berdasarkan efisyen masing-masing. Perisian yang digunakan untuk menjalankan simulasi ini adalah Automasi Studio. Hasil menunjukkan bahawa sesuhu proses memberikan lebih tinggi isipadu keberkesanan iaitu 13.55% dan keberkesanan tenaga iaitu 17% berbanding adibatik proses. Tetapi apabila ia disabitkan dengan mengecas p proses adibatik (penuhi masa) memberikan hasil yang lebih tinggi berbanding dengan sesuhu proses iaitu dengan 18.31% . Bagi kes terbaik, gabungan kedua-dua proses akan sesuai dipakai di pemumpuk itu.

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LIST OF ABBREVIATIONS

HRB	Hydrostatic Regenerative Braking
CVT	Continuous Variable Transmission
EPS	Expended Polystyrene
XPS	Extruded polystyrene
PUR	Polyurethane
VIP	Vacuum Insulation Panel
GFP	Gas Filled Panel
PCM	Phase Change Material
ICE	Internal Combustion Engine
DCV	Directional Control Valve
FCV	Flow Control Valve
HEV	Hydraulic Electric Vehicle
HHV	Hydraulic Hybrid Vehicle
ICE	Internal Combustion Engine
MIG	Metal Inert Gases

CH4	Methane
MG	Motor Generator
N2	Nitrogen
PHEV	Parallel Hybrid Electric Vehicle
PHHV	Parallel Hydraulic Hybrid Vehicle
PRV	Pressure Relieve Valve
SHHV	Series Hydraulic Hybrid Vehicle
SUV	Sports Utility Vehicle
SOP	Standard Operating Procedure

LIST OF SYMBOLS

C = Displacement (m^3/rad)

E = energy storage of the accumulator (Joule)

K_i = Correction factor

η_M = Mechanical efficiency

$\eta_{overall}$ = Overall efficiency

η_v = Volumetric efficiency

Δp = Pressure different (N/m^2)

P_{gh} = Gas pressure (Pascal)

P_{op} = Pressure of the oil (Pascal)

p_{in} = Pump input pressure (N/m^2)

p_{out} = Pump output pressure (N/m^2)

P_P = Pump power (Watt)

P_S = Shaft power (Watt)

Q_i = Flow rate (m^3/s)

Q_{out} = Pump output flow rate (m^3/s)

Q_{out} = Pump output flow rate (m^3/s)

t_i = Filling time (s)

T = Torque (Nm)

V_1 = Volume before compression (liter)

V_2 = Volume after compression (liter)

V_{gh} = Gas volume (m^3)

ΔV_{ideal} = Effective volume (liter)

ΔV_{ideal} = Ideal volume under isothermal (liter)

ω = Nominal speed (rad/s)

CHAPTER 1

INTRODUCTION

1.1 Background

The regenerative braking system is a process whereby the motor is reversed during the deceleration or stopping of a vehicle. The regenerative braking system functions by capturing kinetic energy which it will later store and reuse the energy during the acceleration of the vehicle. There are various types of storage used to capture energy such as electrical, hydraulic, compress and kinetic. For example, in an electric hybrid vehicle, the energy of a moving car is captured and stored in the battery or an ultra-capacitor. If the energy is to be stored in a battery, it will be stored chemically. On the other hand, in ultra-capacitor energy is stored through charge separation. While, in a kinetic hybrid, energy is stored by transferring energy to and from the flywheel and the drivetrain in the form of kinetic energy. Alternatively, hydraulic hybrids store energy in accumulators in the form of compressed gas where the gas and fluid are usually separated by a piston or a bladder (Midgley and Cebon, 2012).

Hydrostatic regenerative braking system (HRB) was first retrofitted on a refuse truck made by a company named Bosch Rexroth in January 2011 to ensure that the trucks are environmentally friendly as it can reduce the consumption of fuel. As it is a fact that the Fairfax

Truck stops and start almost 800 times a day to collect trash. Currently, this is the type of braking system has only been retrofitted in heavy load vehicles such as a Refuse Truck (Paul Heney,2011).

The increase of the use of the regenerative braking system has become famous for several reasons such as environmentally friendly, reduce fuel consumption, avert the loss of useful energy and increase work efficiency. Currently, many types of research concentrate more on the simulation consumption of fuel in hybrid-system rather than the subsystem itself (Wasbari *et al.*, 2014).

However, there is a limited study which focuses on the performance of energy storage under different thermal process mainly for passenger automotive hybrid section. The importance of this study is to examine the temperature effect on the performance of energy storage and come up with the most suitable solution to control the compression process in the system. This is because when a pedal break in a vehicle is pressed on, due to the process of compression, the temperature of the system will consequently increase. The increase in temperature of the system will affect the volume change accordingly as a result of the thermal expansion. Therefore, to obtain the optimal operation energy storage, the compression process must be controlled. As such, the isothermal and adiabatic process will be used for this research to achieve the optimal energy storage (Wasbari *et al.*, 2017).

1.2 Objective

The primary objectives of this project are: -

1) To design the charging system of regenerative breaking.
2) To simulate regenerative breaking performance for adiabatic and isothermal processes.
3) To validate the result of simulation.

1.3 Scope

The central subject matter of this research is the hydro-pneumatic driveline sub-system which is a form of a regenerative braking system. This type of braking system will be able to convert kinetic energy into compression energy. This research will be simulated using a software known as Automation Studio tools. Basically, the typical process assumed in the accumulator is isothermal, adiabatic and polytropic. Unfortunately, this research will only cover the effect of the isothermal and adiabatic process in the accumulator and focus on fluid power performance such as flow rate, Q, velocity, V, power, P, and efficiency.

1.4 Problem Statement

In a standard internal combustion engine, the peak efficiency of a vehicle would be around 30% to 40% (Fyffe, 2014). The loss of work efficiency is due to several reasons as the vehicle operates in a wide range of condition such as idling, acceleration, deceleration, stopping and cruising. In other words, the loss is due to combustion loss, heat loss, exhaust loss and mechanical loss. This reason causes the engine to operate away from its efficiency point. Thus, the work efficiency of the car is only 20% due to these losses (Fyffe, 2014). Unlike Hybrid vehicles, the electric power motor helps to accelerate the vehicle when a car requires more power than the internal combustion could produce and in contrary generate the electric motor in reverse to optimize the work efficiency when too much power is available during maximum efficiency point. Furthermore, in the automotive industry, no one researches the adiabatic and isothermal effect on energy storage which is an accumulator. Therefore, this research seeks to know which

effect is the best performance adiabatic or isothermal in energy storage which is in the accumulator.

Withal, to set up the energy stored in a car, the size and the specific pressure must be counted on to make it compatible and convenient for a auto. As this type of system has only been installed in heavy load vehicles because the heavy vehicle has adequate blank to put in such a scheme as compared to cars with limited space.

1.5 Hypothesis

This research is expected to get a higher work efficiency than an average car. Other than that, regarding volume and capacity in the energy storage which is an accumulator, this research will be expected that isothermal process is better than adiabatic process.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

For the literature review, the structuring of the chapter includes the regenerative braking which covers the literature regarding electrical, hydraulic and mechanical hybrid system and its energy storage. Other than that, this chapter also includes regenerative braking background which describes the history of the regenerative braking. Next, it also includes the regenerative braking in a vehicle which describes the application of regenerative braking in the vehicle. Besides, the efficiency of regenerative braking, component and its energy storage also will be included in this chapter.

2.2 Hybrid System

Hybrid can be defined as having two components. While automobile is a vehicle which gains its energy from two or more different sources for propulsion. In previous years electric hybrid cars are known to be most efficient in fuel consumption compared to other types of hybrid