Faculty of Mechanical Engineering

MODELLING AND SIMULATION OF WATER-BASED HYDRAULIC HYBRID DRIVELINE

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MODELLING AND SIMULATION OF WATER-BASED HYDRAULIC HYBRID DRIVELINE

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DECLARATION

I declare that this thesis entitled "Modelling And Simulation of Water-Based Hydraulic Hybrid 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.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality as a partial fulfillment of Master of Science in Mechanical Engineering

Signature	:	
Supervisor Name	:	DR. AHMAD ANAS BIN YUSOF
Date	:	

DEDICATION

This thesis is dedicated to my family. Thank you for your continuous support during my important educational years. Without their patience, understanding and most of all love, the completion of this work would not have been possible.

To my beloved father, mother, and wife

Sabaruddin b Manja, Najima bte Abd Shukoor & Ahliah Saiful

ABSTRACT

Typical hydraulic hybrid system vehicles depend on oil-based hydraulic fluid. Due to the natural concerns of environment and safety, promote the uses of the water-based hydraulic hybrid system. The main focus of this thesis is to investigate the potential of using water-based hydraulic technology instead of the current oil-based hydraulic technology. The main subject of this technology is in heavy commercial vehicles that frequently in a stop and go modes such as garbage trucks or delivery trucks that produce an immense amount of energy in a moment. The hydraulic hybrid driveline presented in this research is a series type, and the output of the driveline is connected to a Mitsubishi Fuso 6D34-0AT2 as a load to the system. In addition, the driveline is contained of hydraulic component (accumulator, hydraulic pump/motor) which serves to store and distribute power. HyspinAWS68 (mineral oil) was used as a pressure medium to create a comparison with water. This research includes an extensive study on the component modeling and simulation by using Matlab/Simulink and mainly based on the platform of Simhydraulics for the hydraulic flow and Simdriveline for the mechanical line. The focus part of modeling is primarily at 4 parts of the driveline which is system pressure, volumetric displacement, total accumulator volume, high-pressure accumulator pre-charge pressure. Based on the simulation, several data were collected such as time taken to fully charged, pressure, volumetric flow rate, torque, power, vehicle speed and also efficiency. The simulation result indicates that as one might expect that HyspinAWS68 has a higher performance of hydraulic hybrid driveline compared to water. This is due to the weakness of water properties as a pressure medium in terms of the density, viscosity, bulk modulus that causes a significant effect on the efficiency and performance of the hydraulic hybrid driveline. Several serious issues faced by water are internal leakage, pressure drop and also the capability to be compressed. In spite of this, the implementation of water hydraulic a potential response that required a depth study in terms of the properties and the component parameter to achieve the optimum performance of water-based hydraulic hybrid driveline. In future, experimental research on the performance of water-based hydraulic hybrid is required.

ABSTRAK

Kebiasaan kenderaan hibrid hidraulik bergantung kepada cecair hidraulik berasaskan minyak. Oleh itu, kebimbangan alam sekitar dan keselamatan mencetuskan penggunaan sistem hibrid hidraulik berasaskan air. Fokus utama kajian ini adalah untuk mengkaji kemungkinan menggunakan teknologi hidraulik berasaskan air berbanding teknologi hidraulik berasaskan minyak. Subjek utama teknologi ini adalah kepada kenderaan komersil berat yang kerap dalam mod berhenti dan gerak seperti trak sampah atau trak penghantaran yang mampu menghasilkan jumlah tenaga yang besar dalam seketika. Hibrid hidraulik yang diperkenalkan dalam penyelidikan ini adalah jenis siri dan disambungkan kepada Mitsubishi Fuso 6D34-0AT2 sebagai beban kepada sistem. Di samping itu, sistem ini mengandungi komponen hidraulik (penumpuk, pam/motor hidraulik) yang berfungsi untuk menyimpan dan mengedarkan kuasa. Selain itu, hyspinAWS68 (minyak mineral) digunakan sebagai medium tekanan untuk perbandingan dengan air. Kajian ini merangkumi kajian menyeluruh mengenai pemodelan dan simulasi komponen dengan menggunakan Matlab / Simulink berdasarkan perisian Simhydraulics untuk aliran hidraulik dan Simdriveline untuk aliran mekanikal. Tumpuan pemodelan adalah pada 4 bahagian iaitu tekanan sistem, anjakan volumetrik, isipadu penumpuk, tekanan awal di penumpuk tekanan tinggi. Berdasarkan simulasi, beberapa data dijana seperti masa yang diambil untuk dicas sepenuhnya, tekanan, kadar aliran volumetrik, tork, kuasa, kelajuan kenderaan dan juga kecekapan. Hasil simulasi menunjukkan bahawa HyspinAWS68 mempunyai prestasi yang lebih baik berbanding dengan air. Ini adalah disebabkan kelemahan sifat-sifat air sebagai medium tekanan iaitu dari segi ketumpatan, kelikatan, modulus pukal yang menyebabkan kesan yang jelas ke atas kecekapan dan prestasi hidraulik hibrid sistem. Sehubungan itu, beberapa isu serius yang dihadapi oleh air adalah kebocoran dalaman, penurunan tekanan dan juga keupayaan untuk dimampatkan. Walau bagaimanapun, pelaksanaan hidraulik air masih memberi tindak balas yang positif. Oleh itu, sistem ini memerlukan kajian mendalam dari segi sifat dan parameter komponen untuk mencapai prestasi optimum hibrid hidraulik berasaskan air. Pada masa akan datang, perlunya kajian eksperimen mengenai prestasi hibrid hidraulik berasaskan air.

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ρ	-	Density
M	-	Mass
V	-	Volume
v	-	Kinematic viscosity
υ	-	Dynamic viscosity
HP	-	Hydraulic pump
HM	-	Hydraulic motor
HPAcc	-	High-pressure accumulator
LPAcc	-	Low-pressure accumulator
CV	-	Charge valve
DV	-	Discharge valve
PRV	-	Pressure relief valve
t	-	Time
$P_{in\ HP}$	-	Power input hydraulic pump
$P_{out\ HP}$	-	Power output hydraulic pump
T_{HP}	-	Torque hydraulic pump
n_{HP}	-	Shaft speed hydraulic pump
D_{HP}	-	Volumetric displacement hydraulic pump
Δp_{HP}	-	Pressure difference hydraulic pump

q_{HP}	-	Volumetric flow rate hydraulic pump
$\eta_{v\ HP}$	-	Volumetric efficiency hydraulic pump
$\eta_{m\ HP}$	-	Mechanical efficiency hydraulic pump
$\eta_{t\ HP}$	-	Total efficiency hydraulic pump
$P_{in\ HM}$	-	Power input hydraulic motor
$P_{out\ HM}$	-	Power output hydraulic motor
$P_{lo\ HM}$	-	Power losses hydraulic motor
T_{HM}	-	Torque hydraulic motor
n_{HM}	-	Shaft speed hydraulic motor
D_{HM}	-	Volumetric displacement hydraulic motor
Δp_{HM}	-	Pressure difference hydraulic motor
q_{HM}	-	Volumetric flow rate hydraulic motor
$\eta_{v\ HM}$	-	Volumetric efficiency hydraulic motor
$\eta_{m\ HM}$	-	Mechanical efficiency hydraulic motor
$\eta_{t\ HM}$	-	Total efficiency hydraulic motor
K_{poi}	-	Hagen-Poiseuille coefficient
$T_{friction\ HM}$	-	Torque friction
T_0	-	No-load torque parameter
K_{TP}	-	Friction torque vs pressure gain coefficient
ρ_{nom}	-	Nominal density
v_{nom}	-	Nominal kinematic viscosity
n_{nom}	-	Nominal shaft speed
Δp_{nom}	-	Nominal pressure
$\eta_{v\ nom}$	-	Nominal volumetric viscosity
V_T	-	Total accumulator volume

V_F	-	Volume of fluid chamber
V_C	-	Effective volume
V_{dead}	-	Min gas volume
V_{init}	-	Initial fluid volume
k	-	Specific heat ratio (adiabatic index)
q	-	Volumetric flowrate
q_F	-	Fluid volumetric flowrate
p_o	-	Pre-charge pressure
p_{atm}	-	Atmospheric pressure (101325 Pa)
p_{hs}	-	Hard-stop contact pressure
p_G	-	Gas pressure
$p_{G\ min}$	-	Minimum gas pressure
$p_{G\ max}$	-	Maximum gas pressure
E_{HPAcc}	-	Energy stored in HPAcc
$E_{d\ HPAcc}$	-	Energy density in HPAcc
GVM	-	Gross Vehicle Mass
GCM	-	Gross Combination Mass
SG1	-	Simple Gear 1
SG2	-	Simple Gear 2
V	-	Vehicle speed
C	-	Correction factor

LIST OF PUBLICATIONS

1. Saiful Akmal, S., Yusof, A.A., Noor, M., Saadun, A. and Ghazali, R., 2017. Application of water as pressure medium in hydraulic hybrid system. *ARPN Journal of Engineering and Applied Sciences*, 12(16), pp.4824–4830.

2. Yusof, A.A., Saiful Akmal, S., Saadun, M.N.A. and Wasbari, F., 2018. Volume displacement simulation impact on the water hydraulic hybrid driveline performance. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 43(1), pp.20–36.

CHAPTER 1

INTRODUCTION

1.1 Hydraulic Hybrid Vehicle

Heavy commercial vehicles that frequently in a stop and go modes such as garbage trucks or delivery trucks produce an immense amount of energy in a moment (Lindzus and Ag, 2008). This energy which is generated from a high load of the engine is converted to waste heat energy that released to the airstream. Precisely, when a conventional vehicle slows down or decelerates, the friction of brake pads and wheels produce heat that is converted from the kinetic energy. This heat is dissipated into the air that causes an effective wasted energy up to 30% of the vehicle's generated power (Valente and Ferreira, 2012).

Hydraulic hybrid system or hydraulic regenerative braking system is a mechanism that stored a portion of the kinetic energy from the braking momentum as potential energy in the form of pressurized liquid. Figure 1.1 shows the hydraulic hybrid system develop by the United States Environmental Protection Agency's (EPA). The pressurized liquid is compressed by a hydraulic pump to occupy the high-pressure accumulator as an energy storage. The energy is kept up until it is required by the vehicle, by which the pressurized liquid is released from the accumulator as the vehicle accelerates. The pressurized liquid generates the drive shaft while the engine remains idle. As the vehicle achieve the desired speed or the accumulator is emptied, the engine is taking over to continue the process that is beyond the capability of the accumulator (Kumar, 2012; Clegg, 1996; Lindzus and Ag, 2008; Valente and Ferreira, 2012).

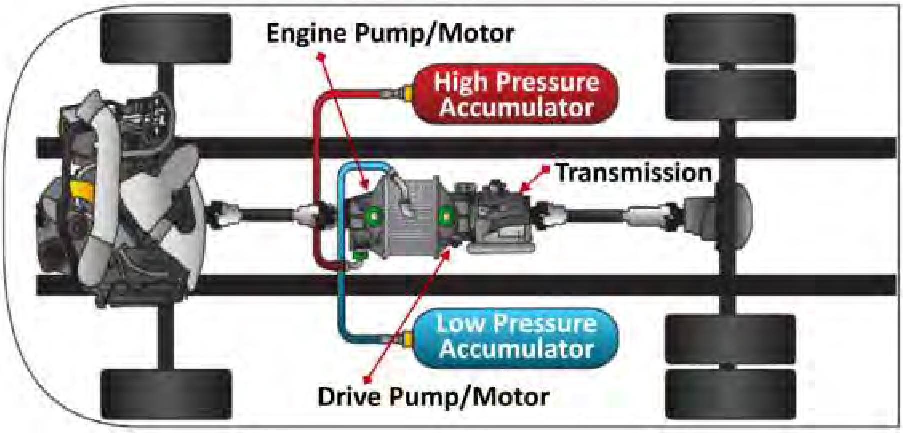

Figure 1.1: The basic mechanism of a hydraulic hybrid system configured by the United States Environmental Protection Agency's (EPA) (Kargul et al., 2015)

1.2 Problem Statement

Typical hydraulic hybrid vehicles depend on petroleum-based hydraulic fluid. Essential concerns of fire and safety in hydraulic systems promote the use of the water-based hydraulic system. Mineral oil used in hydraulic oil equipment poses a fire hazard in the event of a spillage or leakage. This is especially critical in vehicle accident scenarios where the oil spillage might trigger fire mishaps (Lim, Chua and YB He, 2003; Yusof, Mat and Din, 2013; Yusof, Wasbari and Ibrahim, 2013; Yusof et al., 2013; Zaili et al., 2014; Yusof et al., 2014). Through the usage of water hydraulics, problems related to safety and contamination of oil hydraulics in conventional hydraulic hybrid technology can be avoided.

Water hydraulics can be simplified as a fluid power system which is using water as a medium transmission of energy and power (New Hampshire Department of Environmental Services, 2014). The application of water as the transmission medium is a new concept in the industry as commonly mineral oils or other fluids are more familiar with