# DESIGN OF DIRECT DRIVE ELECTROHYDRAULIC ACTUATOR WITH SENSORS TECHNOLOGY

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**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

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# DESIGN OF DIRECT DRIVE ELECTROHYDRAULIC ACTUATOR WITH SENSORS TECHNOLOGY

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**A report submitted in partial fulfilment of the requirements for the degree of electrical engineering.**



**Faculty of Electrical Engineering**

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**2021**

# DECLARATION

I declare that this thesis entitled "DESIGN OF DIRECT DRIVE ELECTROHYDRAULIC ACTUATOR WITH SENSORS TECHNOLOGY" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

| | | |
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| Date | : | 4/7/2021 |

# APPROVAL

I hereby declare that I have checked this report entitled "DESIGN OF DIRECT DRIVE ELECTROHYDRAULIC ACTUATOR WITH SENSORS TECHNOLOGY" and in my opinion, this thesis it complies the partial fulfilment for awarding the award of the degree of Bachelor of Electrical Engineering with honours.

Signature : ..............................................

Name : ASSOCIATE PROFESSOR DR. ROZAIMI BIN GHAZALI

Date : 5/7/2021

# DEDICATIONS

To my beloved mother and father, Norhayati binti Isa and Fazli bin Chik Mat.

# ACKNOWLEDGEMENT

The purpose of this final year project is to provide students an opportunity to demonstrate all they have learned, their intellectual abilities and practical skills to solving real life engineering problems. Besides, final year project is one of the most crucial components of undergraduate studies.

This final year project report is about the student research on a topic of their choice which is "Design of Direct Drive Electrohydraulic Actuator With Sensors Technology", engaging with the scholarly debates in the relevant disciplines, and with a supervisor's guidance. Throughout this final year project, I have a chance to demonstrate all things that have learnt throughout my studies and has acquired invaluable skills and knowledge. This final year project gives an opportunity for me to develop a deeper understanding of the topic that interest to me. During this final year project, I can gain confidence and to be more sure to myself as I get a chance to interact with industries concerning their topic for data collection.

I would like to express my sincere thanks to my supervisor, Assoc. Prof. Dr. Rozaimi bin Ghazali for his guidance, understanding, patience and most importantly, positive encouragement and warm spirit to complete this thesis. Having him as my supervisor was a great pleasure and honor.



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I also would like to express my thanks to all my colleagues who have helped me in completing this final year project.

# ABSTRACT

Hydraulic actuator is one of the actuators that widely utilized due to its powerful advantages such as high force and has been implemented in heavy engineering applications. However, hydraulic systems suffer from parameters changes effect such as pressure drop, temperature effect on oil viscosity and inconsistent flow in pipeline. Due to lack of sensor monitoring for these parameters, optimum performance of the hydraulics cannot be achieved. Electro-hydraulic actuators are linear or quarter-turn actuators equipped with an integral hydraulic power system. The electro-hydraulic actuator operates on a pump-and-bleed principle wherein a motorized oil pump provides hydraulic pressure in one direction and the spring-return in the opposite (bleed) direction. The oil flow to the actuator is controlled by electric solenoid valves and can provide both open and close or modulating operation in response to a control signal. With any of these designs, the actuator can cause the valve to fail in the open, close or last (current) position, loss of electrical power because there are no device additional to sense if the system have some failure. In this project, the model of direct drive hydraulic system had been developed. Then, the close loop hydraulic model is integrated with the sensor monitoring system which including the dashboard. Finally, the performance of the parameters is presented in dashboard through graphical user interface or known as AppDesigner. The result shows that parameters such as pressure, position and flow rate are important to be monitored and considered in the controller design. The maximum value of pressure is 350 Bar, temperature is fluctuated about 50% during the operation and flow is saturated at 12L/min. In conclusion, the monitored parameters can be included in controller design and to achieve optimum performance.

# ABSTRAK

Penggerak hidraulik adalah salah satu penggerak yang digunakan secara meluas kerana kelebihannya yang kuat seperti daya tinggi dan telah dilaksanakan dalam aplikasi kejuruteraan berat. Walau bagaimanapun, sistem hidraulik mengalami perubahan kesan parameter seperti penurunan tekanan, kesan suhu pada kelikatan minyak dan aliran tidak konsisten dalam saluran paip. Kerana kekurangan pemantauan sensor untuk parameter ini, prestasi optimum hidraulik tidak dapat dicapai. Penggerak elektro-hidraulik adalah penggerak lurus atau pusingan seperempat yang dilengkapi dengan sistem kuasa hidraulik terpadu. Penggerak elektro-hidraulik beroperasi berdasarkan prinsip pam dan pendarahan di mana pam minyak bermotor memberikan tekanan hidraulik dalam satu arah dan spring-return pada arah yang bertentangan (pendarahan). Aliran minyak ke penggerak dikendalikan oleh injap solenoid elektrik dan dapat memberikan operasi terbuka dan tutup atau modulasi sebagai tindak balas kepada isyarat kawalan. Dengan mana-mana reka bentuk ini, penggerak boleh menyebabkan injap gagal pada kedudukan terbuka, tutup atau terakhir (semasa), kehilangan kuasa elektrik kerana tidak ada alat tambahan yang dapat dirasakan jika sistem mengalami beberapa kegagalan. Dalam projek ini, model sistem hidraulik pemacu langsung telah dikembangkan. Kemudian, model hidraulik loop rapat disatukan dengan sistem pemantauan sensor yang merangkumi papan pemuka. Akhirnya, prestasi parameter ditunjukkan dalam papan pemuka melalui antara muka pengguna grafik atau dikenali sebagai AppDesigner. Hasilnya menunjukkan bahawa parameter seperti tekanan, kedudukan dan kadar aliran penting untuk dipantau dan dipertimbangkan dalam reka bentuk pengawal. Nilai tekanan maksimum ialah 350 Bar, suhu berfluktuasi sekitar 50% semasa operasi dan aliran jenuh pada 12L / min. Kesimpulannya, parameter yang dipantau dapat dimasukkan dalam reka bentuk pengawal dan untuk mencapai prestasi yang optimum.

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# LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| EHA | - Electro-Hydraulic Actuator |
| A | - Cross sectional area |
| V | - Average flow velocity |
| $C_d$ | - Flow coefficient |
| $d_h$ | - Hydraulic diameter |
| $y$ | - Numerator |
| $u$ | - Denominator |
| *IoT* | - Internet of Things |
| *MAE* | - Mean Absolute Error |
| *RMSE* | - Root Mean Square Error |

# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

This chapter provides the introduction of project background, including motivation, problem statement, objective, scopes and outlines how the overall chapter is organized in this project report.

## 1.2 Project Background

Hydraulic actuators demand has been decreasing because of the noise problem, hardly to control and high cost of maintenance. It also fallen due to some limitation such as degree of compliance in comparison to electrical actuators and has low energy efficiency in order to maintain a constant supply pressure in a continuous mode [1]. The presence of electro-hydraulic actuator technology has been driving the hydraulic actuators market growth. The integration of the technology has lead to high accuracy, improved the ease of controlling, enhanced functionality and controlled performance. In developing the actuators with low cost, this integration still retaining quality and maintaining it standards.

The direct drive electro-hydraulic actuator is a new type of hydraulic transmission. It is well established in some sectors of industry. This type of actuator principle is based on closed circuit hydrostatic transmission. As opposed to the conventional open-circuit hydraulics, the main component of the actuators is a bi-directional pump that rotates with a variable speed in the direction of joint movement. The result shows the supply pressure is variable and there are no requirements for oil reservoirs or electrohydraulic servo-valves.

The direct drive electro-hydraulic actuator is directly uses motor to control the metering pump and changes the pump flow by controlling the motor's speed. The motor controls the speed, position of the hydraulic cylinder, controls the fluid pressure, flow and other parameters of pipelines. Valve actuator is an important safeguard for stable production and life since the power generation and water production are closely related to consumer and social production.

The EHA system is widely used in heavy engineering applications such as aerospace, marine engineering, and robust robotics systems. It combines the advantages of hydraulic systems and direct-drive electrical actuators [2]. Different with others electric drive system, this electrohydraulic design offers spacious power and torque reserves because of the addition of the hydraulics. It is also powerful, long lasting and has a low power input. This long lasting results in minimised maintenance as compared to conventional hydraulic valve actuators. However, basic valve actuator control mostly does not have network function, cannot be monitored and remotely controlled. It has low energy efficiency due to maintain a constant supply pressure. By all the defects of existing products, this project aiming to design the electro-hydraulic actuator based on sensor technologies where the actuator can sense the parameter changing which able to control the valve opening automatically, allows engineers real-time monitoring through PC that have been designed through MATLAB AppDesigner Dashboard in order to diagnosis device operation, upgrading the basic electrohydraulic actuators, thus maintaining the safe and stable operation of major projects.

## 1.3 Motivation

Electro-hydraulic actuators have been known for their good positioning and force feedback abilities in various system and application such as aerospace, machine tools, in marine, and industrial robots [3]. Since hydraulic actuation demand is decreasing, it is necessary to develop a well-designed system by upgrading the previous system with adding the sensors technologies. However, it still has a few number of useful characteristics and benefits such as the actuator size is small and more decoupled dynamic characteristics in a multi input and multi output configuration than their electrical counter-part [4-5]. Electro-hydraulic actuator system inherently suffers from uncertainties, nonlinearities and time-varying in its model parameters which makes the modelling and the controller designs are more complicated. The combination between electrical and hydraulic devices makes the EHA system be more flexible in implementing to real application with advanced control strategies. By applying appropriate sensor technologies for monitoring to the system, the constant failure such as fail in the valve opening and close or last (current) position, on loss of electrical power can be tackle. This will help in increasing the efficiency and productivity of the system. Moreover, this EHA need to develop to adapt to the changing world and market, which has been become more adaptable in a new world and powerful.

## 1.4 Problem statement

Nowadays, hydraulic actuator demand is decreasing and has significantly fallen due to some problems occur such as noise and internal breakdown [1]. The noises in hydraulic systems is usually caused by aeration or cavitation. Air in the fluid of hydraulic when it is being compresses and decompresses makes a knocking noise as the air circulates in the system and aeration will occurred when air tarnish the hydraulic fluid. For cavitation phenomenon occur when the volume of fluid by any part in the system exceeded the volume of the fluid being supplied and causes its normal pressure in that part of the system to fall below the vapor pressure of the hydraulic fluid. Then the formation of vapor cavities between the fluid, which will burst when compressed and causing the knocking noise to produce.

It is also have some limitation where the network function is not available that engineers unable to monitored and remotely controlled the actuator [1]. The engineers need to monitor and manually controlled the actuator themselves. They need to go to the site to take the readings of the actuator, analysing the data of the actuator in site and manually open and close the valve if any problem occurred. This will make the work complicated and troublesome.



Moreover, the hydraulic actuator also has low energy efficiency [1]. The need of continuous mode in running a hydraulic pump makes the energy efficiency of hydraulic actuator becoming low. It is due to maintain a constant supply pressure in the system. Energy efficiency means that the hardware is using less energy to provide the same service. Furthermore, it is also difficult to detect if any fault happened with the hydraulic components which will give low efficiency, affecting the speed of the maintenance and the performance of the system [13]. This project will design an effective way to remotely monitor the system, so that the engineers can locate the position of failure in time.

## 1.5 Objective

The objectives of this project are;

i) To develop direct drive electro-hydraulic actuator with sensors technology.

ii) To design closed loop controller for electro-hydraulic actuator system.

iii) To evaluate performance through sensor monitoring.

## 1.6 Scopes

This project mainly focuses on;

i) The algorithm is design by using Simscape Hydraulic model.

ii) The closed structure of EHA system will be executed using MATLAB.

iii) Pressure sensor, position sensor and volumetric flow rate sensor to detect the changing of the parameters in the system.

iv) The investigation performance of hydraulic sensors technology.

## 1.7 Project Outline

In the next following chapter, the report is organized as follows;

**Chapter 2:** Provides the overview of Eletro-Hydraulic Actuator in previous research studies. Chapter 2 also covers the design of the system, hydraulic sensors which are flow rate sensor, position sensor and pressure sensor. Chapter 2 are briefly explain about the sensor technology architecture, data measurement, dashboard display for monitoring and data acquisition technologies.

**Chapter 3:** Provide the details how the method chosen to carried out the project in order to achieve the objective. It includes, determine a suitable variable, arrangement, and integration of sensors technology and EHA system software.

**Chapter 4:** Provides the results and discussion of the EHA system model Simulink. It also includes the results by the end of the experiments based on the literature review outline in Chapter 2.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

In this chapter, the key studies related to this research are reviewed. It includes the studies on the difference of the design system, hydraulic sensors, type of communication mode, technology architecture, data measurement, dashboard display and monitoring and data analysis with references from the previous researches. Literature on electro-hydraulic actuator (EHA) design approach is explaining thoroughly with references from the previous researches focusing more on analysing the direct drive electro-hydraulic actuator with sensors technology.

## 2.2 History of Electro-Hydraulic Actuator (EHA)

Electro-hydraulic actuators (EHAs) replace hydraulic systems with self-contained actuators operated by electrical power itself. EHAs are by simplifying system architectures which it eliminates the need for separating hydraulic pumps and tubing, and improving safety and reliability. This technology basically was developed for the aerospace industry but it has expanded into many other industries where hydraulic power is needed.

Electrohydraulic drives are primarily used whenever a high power, compact size or large forces are required for individual applications. These drives are often used together with electric drive technology in machines. Nowadays, electrohydraulic drives, in terms of automation, unlike electric drives are still largely connected via analog interfaces and centralized closed control loops.

From the historical point of view, electro-hydraulic solutions have existed since 1940s. To generate a cylinder position loop, the electrical and mechanical signal will be used. The signal will be sent to the coil and controls the correction flow [6]. The first electro-hydraulic solutions obviously almost completely focus on the valve management, especially in the immediate post-war period. In the post-war period, the first two-stage valves with current feedback were developed in 1957 [7]. From that time, several attempts of matching power management units (hydraulic) were made with electric/electronic type management systems, carving out a space for a mainly controlling task for the latter. In their early incarnations in 1940s, hydraulic pumps attached to the engines fed high-pressure oil through tubes to the various control surfaces. The small valves were attached to the original control cables, controlling the flow of oil into an associated actuator connected to the control surfaces.

In the aeronautical application, the use of electro-hydraulic solutions has been used in several years. The reasons for this phenomenon are well understandable with capacities of the electric part in the information management and transmission while the power conversion and transmission is left to the hydraulic part. Power was generated, managed, transmitted and converted again only through hydraulic components such as pumps, valves and actuators, and this has happened for decades. The electric/electronic interface was just useful to manage the information and to transmit it to the operator. This solution has granted for years both the adequate management of the information flow and the necessary user-friendliness, sturdiness and reliability.

### 2.3 System Design

System design is a base of a complete system. It is a process of designing the elements of system consisting the architecture, components, verification and the data that goes through the system. A complete functional system needs an algorithm to give the instruction to the whole system. If there is no algorithm that gives the instructions in the system design, means that the whole systems are not complete and cannot functioning well as the system desired. A well explained, consistent, solid and thought out system will create a design that are systematic and not complicated. Therefore, hardware and software are essential in developing a system.

The algorithm of the system will be design by using many types of software such as MATLAB software, IAR Embedded Workbench, Programmable Logic Control (PLC) and any other suitable software that have been used in previous study. Different type of software has different algorithm. There are many ways to build the design system. Building guideline help engineers in creating the algorithm of the system design. For example, we need to consider the problem that we want to solve. By emphasize the problem will help guide future decisions on building the system. In developing the technology architecture and the design system should be in sync [8]. A task for design system is not simply to set the rules to the existing elements. Rather, it is to give the guidelines to the new elements to be generated. After analysing the problem, the development of system should follow design-development-testing-deployment cycle as in Figure 2.1 [9].

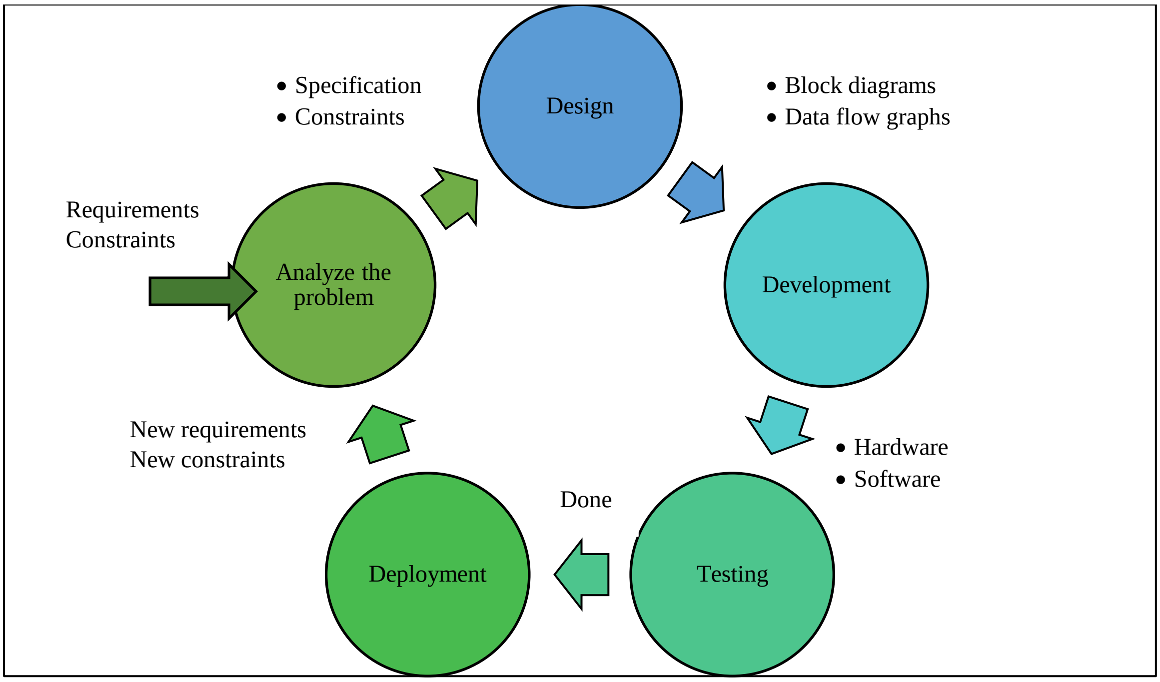


Figure 2.1: Complete life cycle of a software/hardware design system [9]

In beginning of the design phase, build a conceptual model of the hardware and software system is the first step. During this phase, engineers will estimate the expected performance of the systems. The design includes the basic input and output signals, data structures and overall software scheme. In this stage, software and hardware will be in sync. The next phase is development. It is efficient to implement the software and hardware using simulation. Simulation is easy to implement a system in a simulator rather than construct a physical device out of actual components. After developing an implementation, the system will be tested to evaluate the performance of the system. Once the system is complete and tested, it defines the overall system specifications [9]. When the system design achieving its desired process, the system will be deployed.

There are many advantages of algorithms in design system and it is in the development of the procedure itself. Developing the algorithm allows identification of the process systems and decision points to break down the problem into smaller pieces of steps and this will make the algorithm system more manageable [10]. The use of algorithm will make the system to be more efficient and more consistent. Reduction of a task of the algorithm to specified steps is an important part of analysis, control and evaluation.