



BACHELOR THESIS (ME 141502)

DEVELOPMENT OF A SIMULINK MODEL TO INVESTIGATE CONTROL STRUCTURE, SAFETY, AND STABILITY OF A WATER BRAKE SYSTEM AT MAIN ENGINE IN HOUSE 5 LABORATORY

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DOUBLE DEGREE PROGRAM OF
MARINE ENGINEERING DEPARTMENT
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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2017

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SKRIPSI (ME 141502)

PENGEMBANGAN SIMULINK MODEL UNTUK INVESTIGASI KONTROL STRUKTUR, KESELAMATAN, DAN STABILITAS SISTEM PENEREMAN AIR PADA MESIN INDUK DI LABORATORIUM 5

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SURABAYA
2017

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APPROVAL FORM

Development of a Simulink Model to Investigate Control Structure, Safety, and Stability of a Water Brake System at Main Engine in House 5 Laboratory

BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain a
Bachelor Engineering Degree

on

Laboratory of Reliability, Availability, and Management System
(RAMS)

Bachelor Program Department of Marine Engineering

Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

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SURABAYA

JULY 2017

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DEVELOPMENT OF A SIMULINK MODEL TO INVESTIGATE CONTROL STRUCTURE, SAFETY, AND STABILITY OF A WATER BRAKE SYSTEM AT MAIN ENGINE IN HOUSE 5 LABORATORY

BACHELOR THESIS

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JULY, 2017

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APPROVAL FORM

DEVELOPMENT OF A SIMULINK MODEL TO INVESTIGATE CONTROL STRUCTURE, SAFETY, AND STABILITY OF A WATER BRAKE SYSTEM AT MAIN ENGINE IN HOUSE 5 LABORATORY

BACHELOR THESIS

Submitted to Comply One of the Requirements to Obtain a Bachelor of
Engineering Degree

In

Double Degree Marine Engineering (DDME) Program
Department of Marine Engineering – Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember
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DECLARATION OF HONOR

I, who signed below hereby confirm that:

This final project report has written without any plagiarism act, and confirm consciously that all the data, concepts, design, references, and material in this report own by enginery and plant laboratory of the Faculty for maritime, Warnemünde, Rostock which are the product of research study and reserve the right to use for further research study and its development.

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If there is plagiarism act in the future, I will fully responsible and receive the penalty given by ITS and Hochschule Wismar according to the regulation applied.

Surabaya, July 2016

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Development of a Simulink Model to Investigate Control Structure, Safety, and Stability of a Water Brake System at Main Engine in House 5 Laboratory

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ABSTRACT

A water brake loads the diesel engine will set desired work points and work curves. So that can find a safe point and control safety. After this, the essential system component will be created the model in block diagram and the block diagram will be simulated with Simulink. This requires a model of combustion machine and its control as well as break system and its control. The valve angle also affects the amount of flow or discharge of water which resides in the brake system. The amount of water flow in the brake system affects the amount of load that will be accepted by the main engine.

The model is to be validated with measured data. To define load characteristics for a parallel operating visualization, these load characteristics are to be simulated. The results of the modeling were to know PI controller parameters to control the main engine.

In the investigation, then simplify the process of modeling results are displayed in the form of a curve. Where in the curve we can see the performance of the engine and brake system so that the operation of the main engine will get maximum condition within safe limits.

Keywords: Simulink, Matlab, Water Brake System, Control System, Fuel Consumption, Modelling, Diesel Engine, PI Controller

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Pengembangan Simulink Model untuk Investigasi Kontrol Struktur, Keselamatan, dan Stabilitas Sistem Pengereman Air Pada Mesin Induk di Laboratorium 5

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ABSTRAK

Pemuatan *water brake* pada mesin diesel akan mengatur titik kerja dan kurva kerja yang diinginkan. Sehingga bisa menemukan titik aman dan keamanan kontrol. Setelah itu, komponen sistem yang esensial akan dibuat model dalam diagram blok dan akan disimulasikan dengan *software* Simulink. Ini memerlukan model pada pembakaran *engine* dan kontrolnya, serta sistem pengereman dan kendalinya. Sudut katup juga mempengaruhi jumlah aliran atau pelepasan air yang berada pada sistem rem. Jumlah aliran air di sistem rem mempengaruhi jumlah beban yang akan diterima oleh mesin utama.

Modelnya harus divalidasi dengan data hasil pengukuran. Untuk menentukan karakteristik beban dan visualisasi operasi paralel, karakteristik beban ini harus disimulasikan. Hasil pemodelan adalah untuk mengetahui parameter pengendali PI untuk mengendalikan mesin utama.

Dalam penyelidikan, maka disederhanakan proses pemodelan hasilnya ditampilkan dalam bentuk kurva/grafik. Dimana pada grafik kita bisa melihat performa mesin dan sistem rem sehingga pengoperasian mesin utama akan mendapatkan kondisi maksimal dalam batas aman.

Kata Kunci: Simulink, Matlab, Sistem Pengereman Air, Sistem Kontrol, Konsumsi Bahan Bakar, Pemodelan, Mesin Diesel, Pengontrol PI

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PREFACE

All praise to Allah SWT who has provided His help, grace, and guidance so that I can finish my bachelor thesis.

This bachelor thesis submitted to fulfill the requirement to obtain Bachelor Engineering Degree in Department of Marine Engineering, Institut Teknologi Sepuluh Nopember and Hochschule Wismar.

Inside, presented about development of Simulink model to investigate control structure, safety, and stability of a water brake system at main engine in house 5 Laboratory in Hochschule Wismar. It is prepared based on relevance reference and supporting data. Some information and picture in this bachelor thesis referred to many sources. With that, author would like to appreciate through References section which listed all quoted source.

In preparing this bachelor thesis, I would like to thank those who have helped advise and clarify in accomplishing this bachelor thesis. I would like to thank you for:

1. My mother, my father, my sister, and my whole family have given support and encouragement to me.
2. Prof. Dr.-Ing Axel Rafter as my first supervisor in Bachelor Thesis.
3. Dr.-Ing Wolfgang Busse as my second supervisor in Bachelor Thesis.
4. Dipl. Ing. Harmut Schmidt as chairman of the house 5 Laboratory.
5. All technical engineer in house 5 Laboratory.
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8. All member of Double Degree (DD) Marine Engineering who support the construction of this bachelor thesis.
9. Vinca R.Y who is a special person and meritorious for me.
10. All parties which can't be mentioned one by one who helped the author until this report can be finished.

Finally, I realize that the writing of this Bachelor thesis is far from perfect. Therefore, I expect criticism and suggestions so that I can be better later. With all of the limitation, I hope this report could give advantages, especially for me while in studying process in Institut Teknologi Sepuluh Nopember Surabaya.

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LIST OF ABBREVIATIONS AND SYMBOLS

B_{mep}	brake mean effective pressure
$C_{(s)}$	output signal
C_v	calorific value of fuel
$f(x),g(x)$	functions defining working compartment surface
$G(s)$	first order approximate model of sigmoidal responses
I	integrator
J	momen inertia
K	response gain
K_i	gain of the integral term
K_P	proportional gain
K_L	characteristic of hydraulic power brake
LSE/PSU	power stage unit
\dot{m}	mass flow rate
N, n	rotational speed of engine (rpm)
P, P_{eng}, P_{load}	power ; engine power ; brake system
PRE/PCU	power control unit
PID	proportional, integral, derivative
$R_{(s)}$	input signal
SFOC	specific fuel consumption
t	time
T, T_{eng}, T_{load}	torque; engine; brake system
T_D	derivative time constant
T_I	integral time constant
TF	transfer function
η	efficiency fuel consumption
ρ	fluid density
ω	angular velocities

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CHAPTER I

INTRODUCTION

I.1. Background

For laboratory operation, the University of Applied Sciences Wismar in Warnemünde is using a main diesel engine. A water brake loads the diesel engine and sets desired work points and work curves. The water vortex brake is to be controlled by PLC. In order to find suitable controller parameters for the control and to define safety settings.

By modeling every essential system components, we can find a suitable controller parameter for the control and to define safety settings. The Model is to be validated with measured data. To define load characteristics for a parallel operating visualization, these load characteristics are to be simulated and tested based on the number formats used in the PLC. So that the entire system is to be modelled in a Simulink model/Mathlab.

Modelling is very important to be able to investigate the control structure, safety and stability of a water brake system at main engine fuel in laboratory operation, the University of Applied Sciences Wismar in Warnemünde.

I.2. Statement of Problems

The statement of problem in this study is how to find suitable controller parameters for the control and to define safety settings with regards of work points and work curves at water vortex brake.

I.3. Limitation of The Study

The limitation of the study from the statement of problems is needed to focus the topic in this thesis. The limitation of the study discussed is as follows:

- a. The object studied is water brake system at main engine in house 5 laboratory.
- b. The method using Simulink model.
- c. The study conducted is only based on the data obtained from in house 5 laboratory and the current measurement practicum.
- d. Cooling system ignored.

I.4. Objectives of The Study

The objectives of this thesis are:

1. To investigate the control structure, safety and stability of a water brake system at main engine fuel
2. To find suitable controller parameters for the control and to define safety settings with regards of work points and work curves at water vortex brake.

I.5. Benefit of The Study

From the study conducted is expected to provide benefits to various parties. The benefits include:

- a. As reference of monitoring the engine .
- b. As a reference of decision-making to investigate.

CHAPTER II

STUDY LITERATURE

In this chapter will be discussed about the brake system in general. The proper analysis is very important to be aware of the structure of an existing plant and the basis for understanding the function of the plant.

II.1 Mechanical Installation

II.1.1 Description of the Zöllner Hydraulic Power Brake

The Hydraulic Power Brake 9N38/12F also referred to as a water brake, is directly coupled to the MAN B&W 6L23/30A [1] main engine via a rigid shaft. It is used to deceleration of engine drive and designed for direct coupling to this engine [2]. The performance diagram shows the operating range of the brake at different speeds (figure 1 in attachment). With a certain revolution of the hydraulic power brakes, any work engine power can be recorded within the diagram.

The brake consists of rotating parts, oscillating, and standing parts. It is made up of a rotor composed of the clutch, shaft, and impeller, as well as the stator with the brake arm with the housing and the housing inserts, which are called pendulum bodies. The rotors and the brake has a pendulum body shaped half shell, water levels are regulated by electro-mechanical valve units (actuators and valve vane) controlled by the LSE. The standing parts are a base plate, bearing blocks as well as water supply and discharge pipes [2].

The hydraulic power brake is clockwise rotating, in accordance with the direction of rotation of the motor. The pendulum body oscillates in the fixed bearing blocks, transmits the force occurs in the housing to the weighing device via a brake arm. The weight force to be measured and resulting torque are determined by strain gauges in the weighing device, also referred to as a torque force receiving unit.

The brake has a water inlet connection and water outlet connection each with a nominal width of DN 80. These specifications correspond to a diameter of 88.9 mm outside and 80.8 mm inside diameter according to EN ISO 6708 [3]. A drainage line for emptying water in the brake housing and two cooling water lines [2] lead into the drainage tank placed below the brake (figure 2.1).



Figure 2.1: Hydraulic Power Brake

(source: Own photograph (enginery and plant laboratory of the Faculty for maritime, Warnemünde)).

The upper part of the tank is the foundation of the brakes and is directly connected with the foundation to avoid vibrations and to absorb the resulting reaction forces.

II.1.2 General Operation of Hydraulic Power Brake

The hydraulic power brake is a type of fluid coupling used to absorb mechanical energy and usually mounted in an enclosure filled with water. The hydraulic power brake concept is generally based on centrifugal pumping laws. A centrifugal pump works on the concept of displacing fluid radially from its inlet to its outlet, about the enclosure.

Hydraulic couplings consist of a drive side with a flow pump as the driving part, which is accelerated by the drive engine, and a turbine on the driven side (figure 2.2). The pump feeds the liquid medium which directly hits the turbine blades and accelerates them. This energy supply is supplied to the turbine by the conversion of the kinetic flow energy of the liquid into a pressure energy on the blade. The amount of torque produced by the engine is usually adjusted by either the use of a sluice gate between rotor and stator to reduce the area for fluid mass transfer or by reducing the mass of fluid in the working compartment. The output and input torque are the same. [4]

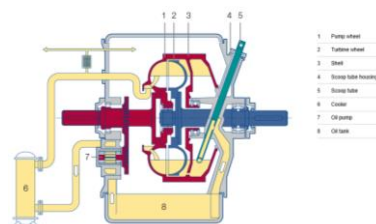


Figure 2.2: Diagram of Fluid Coupling

(source: <http://www.voith.com/en/products-services/power-transmission/variable-speed-drives/variable-speed-fluid-couplings-57899.html> (21.03.2017))[5]

II.1.3 Filling Controller

The Zöllner hydraulic power brake type 9N38/12F is a filling-controlled brake. It achieves its maximum capacity when the blades are completely loaded, that is the housing chambers are filled with operating water [2]. This makes it clear that one of to control the amount of load on the engine is controlled filling level. For the plant in the engine laboratory, only outlet valve can be controlled electromechanically by the PRE and LSE, the inlet valve is to be actuated manually and has no significance for the automatic control. The pressure and the amount of water flow adjusted by the opening of the electro-mechanical outlet valve. In the unloaded state, the outlet valve is set in the flow direction, which means it is fully open. The larger the load becomes, the further closes the outlet valve until its maximum twist angle of 45° relatives to the initial position at 100% power lever.

II.2 Electrical Installation

II.2.1. The Concept of Hydraulic Power Brake of Zöllner

The system concept of the company Zöllner for this hydraulic power brake is a modular system. The Program Control Unit (PRE/PCU) and the Power Stage Unit (LSE/PSU) take over the control function of the system. By setting the speed or the torque of the brake, the PRE generates a position signal for the valve, which leads to an adjustment of the valve unit by the control in the LSE. The load on the valve is adjusted by voltage regulation of a phase-angle control [2]. The plant was designed according to the scope and customer with respect to the range of function to the corresponding components. The existing system of engine laboratories Wismar University consists of the PRE 420 and the LSE 421 (figure 2.3).



Figure 2.3: PRE 420 and LSE 421

(source: Own photograph (enginery and plant laboratory of the Faculty for maritime, Warnemünde))

The control unit is installed in the engine laboratory, various sensors and an actuator which control the valve position are connected (figure 2.4).

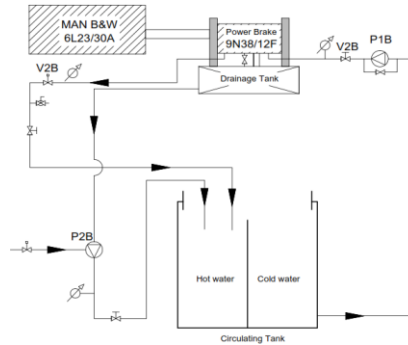


Figure 2.4: Schema of sensor and actuator of Hydraulic Power Brake

The sensors take the actual states of the brake, the LSE drives the actuator, sets the respective load step. The torque force receiving unit is designed as a Wheatstone bridge comprising a set of four strain gauges in a full bridge circuit. The change of the ohmic resistance by the physical force acting on the brake arm provides proportional to the applied torque value. Both actual value signal is routed and processed in the PRE 420. The information about the outlet valve position is detected by a potentiometer and transmitted to the LSE.

II.2.2. Structure Panel of The PRE 420

On the front panel of the PRE 420, all control and display element of the brake unit are merged (see figure 2 in attachment). The structure of the front panel consists of the following elements:

1. Digital display element for speed, torque, or power
2. Limit plates for the upper limit of the torque and speed
3. Reference potentiometer for manual setting of speed and torque
4. On/off switch for PRE and LSE
5. Lightening button to select the present characteristics (KL6-9).
6. Signal lamp for fault messages, limit violations, alarms and reset
7. Service-drawer as the extensible module for switching and changing the PI parameter of the PRE, the torque zero adjustment and test sockets for the various signal.

In running conditions, the engine speed and torque of brake can be adjusted manually with the lever by resetting the cab only and not on the potentiometer of the PRE. A control of the test stand on the basis of present braking curves, which are also selectable by the operator of the PRE 420 is not possible. This limitation of the function of the controller from the front panel has no direct effect on the operation of the engine. It just set the value of speed or torque of the brake. As for determining certain characteristics to be set by manually.

II.2.3. Brake Characteristics

The initial controlling the brake system involved the possibility with one that four preset braking characteristics could be selected by light button. The control by means of characteristics means that the torque is a function of the speed, are both sizes to each other, therefore, in a specific proportion. In the diagram, "torque versus speed" (see figure 3 in attachment) can be any point to reach the physical limits of the brake characteristic field:

KL6: Control with linear characteristic $T=B*(nL)$ (Fig.2.5):

This selection allows a linear characteristic of the brake in the diagram "torque versus speed", the slope of line (B) and the top speed (L) via the set point potentiometer can be adjusted.

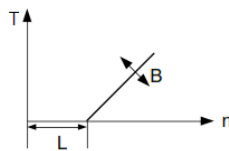


Figure 2.5: Graphic representation of KL 6

KL7: Control with parabolic characteristic $T=K+A*n^2$ (Fig.2.6):

Torque and speed are proportional to each other, the lowest torque (K) and the steepness of the curve (A) can be set via the two references potentiometer.

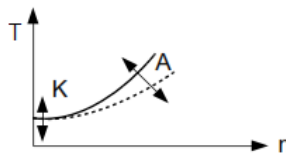


Figure 2.6: Graphic representation of KL 7

KL8: Variable speed curve $n=constant$ (Fig.2.7):

When operating with the characteristic KL8 a speed constancy is enforced. The setting of the speed set point is made with the reference potentiometer for speed.

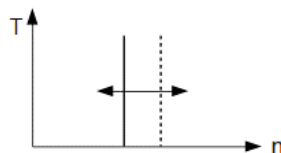


Figure 2.7: Graphic representation of KL8

KL9: Torque controlled characteristic $T=\text{constant}$ (Fig.2.8)

When operating with the characteristic KL9 a torque constant is enforced. Analogous to the characteristic KL8 setting the torque set point via the set point potentiometer of the torque is carried out.

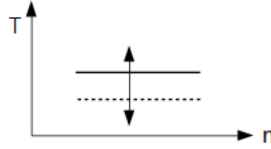


Figure 2.8: Graphic representation of KL9

For the characteristic KL6 and KL7, the equations for calculating the target values are stored in the control circuitry. The two references potentiometer the individual factors (K, A, B, L) are set as well as the speed or torque for the corresponding curve selection. The characteristics KL8 and KL9 a torque or speed constancy is enforced by the PID control amplifier.

II.3 Hydraulic Power Brake Model

These models estimate the hydrodynamic torque absorption T_{brake} of such a brake depending on the power of engine P and the engine speed / angular velocity, ω (figure 2.9).

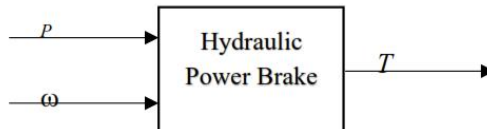


Figure 2.9. Hydraulic power brake model

The input on the model is the engine speed and torque reference. The main output is the actual power and torque on a dynamometer. In order to determine that value, then the value of the power obtained by the following equation,

$$P = \dot{m} \cdot C_v \cdot \eta \quad (1)$$

Where the value of flue rate, \dot{m} , derived from the value of PI controller are adjusted with the result of running engines. Calorific value, C_v , obtained from the project guide specifications of engine 6L23/30A and the efficiency engine, η , assumed 30%-40%.

To find out the actual torque values using the following equation,

$$T = \frac{P}{\omega} \quad (2)$$

To find out the angular velocity values, ω can use the following equation,

$$\alpha = \frac{T}{J} \quad (3)$$

$$\alpha = \frac{d\omega}{dt} \quad (4)$$

$$\omega = \int \alpha . dt \quad (5)$$

$$\omega = \int \frac{T}{J} \quad (6)$$

Where α are angular acceleration, rad/s^2 . The torque, T , is the torque reference value and moment of inertia, in Kgm^2 .

II.4 Simulink Model

Simulink is a graphical extension to MATLAB for modeling and simulation of systems [6]. The main advantages of Simulink are the ability to model a nonlinear system, which a transfer function is unable to do. Another advantage of Simulink is the ability to take on initial conditions. Simulink is integrated with MATLAB and data can be easily transferred between the programs. When a transfer function is built, the initial conditions are adjusted to the given reference value. Systems in Simulink are drawn on block diagrams. As well as virtual input and output devices such as function generators and oscilloscopes.

A dynamic Simulink model of the system was constructed to aid the development of a dynamometer controller. It is a tool to experiment with controllers more easily than with the actual hardware.

The system model can run separately from the engine model, which was created prior to the development of the dynamometer. It consists of a mathematical model of the physical system coupled to its controller. The following an overview of the dynamometer Simulink model.

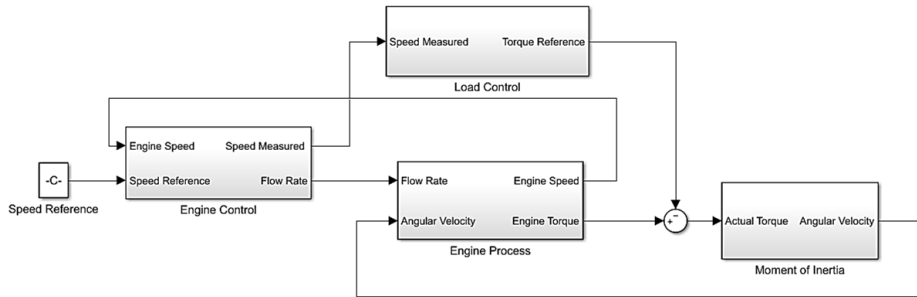


Figure 2.10. Overview of engine working system Simulink model

Inputs to the simulation are engine speed. The speed of engine will produce the flow rate of fuel by PI controller. The amount of flow rate of fuel will produce the power of the engine by multiplying the calorific value of engine and efficiency engine. The main output is actual torque at the engine.

II.4.1. PI Controller Model

A general block diagram of the engine working system and its controller appeared in figure 2.10. The block diagram of the controller in its current state appears in figure 2.11.

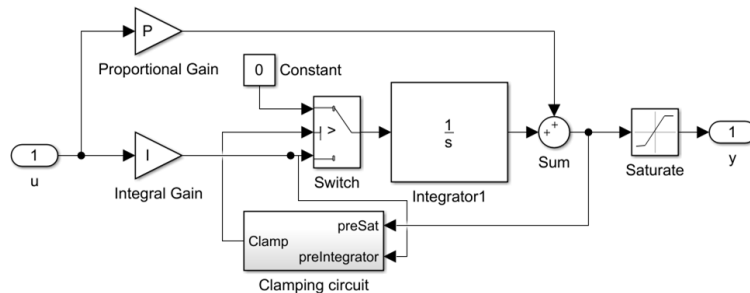


Figure 2.11. PI controller block diagram

The inputs (u) to the controller are the speed of the engine and input torque at the engine input shaft. Its outputs (y) are the amount of the flow rate of the fuel engine and proportional directional valve of dynamometer driving pump displacement commands. The clamping circuit is to stop integration when the sum of the block components exceeds the output limits and the integrator output and block input have the same sign. Resumes integration when the sum of the block components exceeds the output limits and the integrator output and block input have opposite sign [7]. The clamping circuit implements the logic necessary to determine whether integration continues. This controller varies the fuel injection pump to be transferred for the engine to control the power output.

CHAPTER III

METHODOLOGY

III.1. General

Methodology is a basic framework or groove to do something, in this case the thesis workmanship. The workmanship of this thesis takes several stages to describe the process that starts from the formulation of the problem that existed until the end result or goal workmanship thesis.

III.2. Methodology

All stages in the construction of this thesis / research methodology flow chart in figure 3.1. flowchart of methodology.

III.3. Statement of Problems

Statement of problem is an initial stage in the execution of the thesis. This stage is a very important stage, which at this stage is why there is a problem that must be solved so worthy to be used as ingredients in the thesis. Searches problems is done by looking for information about a problem that's happening now and the survey results directly to the field.

In this thesis, the problem is how to find suitable controller parameters for the control and to define safety settings with regards of work points and work curves at water vortex brake.

III.4 Study Literature

The problem is already known, the next step is the study of literature. At this stage, the search for and learn about the problems that exist, so it is clear what should be done in this paper so that these problems can be solved. The literature study can be done by means of direct surveys or reading the paper and journal related to the problems to be solved.

The study of literature in this thesis is done by collecting reference material to be studied as a supporting material which is very important for the preparation of this thesis. Activities include:

- The collection of data based on field survey on the condition of Main Fuel Engine.
- Searches several journals and papers relating to the Simulink Model.
- The general data as to work system of water vortex brake.

III.5. Data Collection

At this stage, the writer needs some supporting data for the preparation of the thesis, as for the data required for the preparation of this paper include:

- The kind of PLC used.
- The kind of Main Engine used and specification of the Main Engine.
- The kind of water brake used.
- Equation of water brake system.
- Simulink Model Method.

III.6. System Analysis

After the required data has been collected, the next step is to analyzing system used. At this stage it is certain that the system and components is a compatible or not. Because if the system and component not compatible, so the system must be repaired.

III.7. Model Development

Basically, a model has to be constrused from observed data. Modeling consists of two types of graphical models and mathematical models. Graphical models are made up from certain measurements. Mathematical models may be developed along two routes or combination of them. One route is to split up system into subsystems whose propoerties are well understood from previous experiences. These subsystems are then joined mathematically and a model of the whole system in obtained. This route is known as modeling and does not necessarily involve any experimentation on the actual systems. This techniques involve structuring of the process into block diagrams with blocks consisting of increasingly being done by computer, resulting in a software model rather than a mathematical model.

The other route to mathematical as well as graphical models is directly based on eperimentation. Input and output signals from the system are recorded and subjected to data analysis in orde to infer a model.

III.8. Model Valid

Three Basic Entities

The construction of a model from data involves three basic entities (Ljung, 1999):

1. The data.

The input-output data are sometimes recorded during a specifically designed identification experiment, where the user may determine input signals. In other cases, the user may not have the possibility to affect the experiment, but must use data from the normal operation of the system.

2. A set of candidate models.

A set of candidate models is obtained by specifying within which collection of models a suitable. This is no doubt the most important and at the same time the most difficult choice of the system identification procedure. It is here that a priori knowledge and engineering intuition and insight must be combined with formal properties of models. Sometimes the model set is obtained after careful modeling. Then a model with some unknown physical parameters is constructed from basic physical laws and other well-established relationships.

3. A rule by which candidate models can be assessed using the data.

Determine the "best" model in the set, guided by the data. This is the identification method. The assessment of model quality is typically based on how the models perform when the attempt to reproduce the measured data.

Model Validation

After we have known the basic entities, it then to test whether this model is "good enough" or "no" or that is whether it is valid for its purpose. The involving various procedures to assess how the model relates to observed data, to prior knowledge and to its intended use. Deficient model behavior in these respects make us reject the model, while good performance will develop a certain confidence in the model. A model can never be accepted as a final and true description of certain aspects that are of interest and the valid if the model to result from modeling value equal to the calculated value.

III.9. Model Based Analysis

Based on three basic entities, we can analyze models have been created. The factors that will be analyzed in this bachelor thesis as follows:

1. Control Structure.
2. Safety.
3. Stability.

All three items will be analyzed with graphs model produced and adapted to the rules used.

III.10. Conclusion and Recommendation

At this stage it will be drawing conclusions from the discussion in this thesis as well as the provision of advice to the company related to decision making.

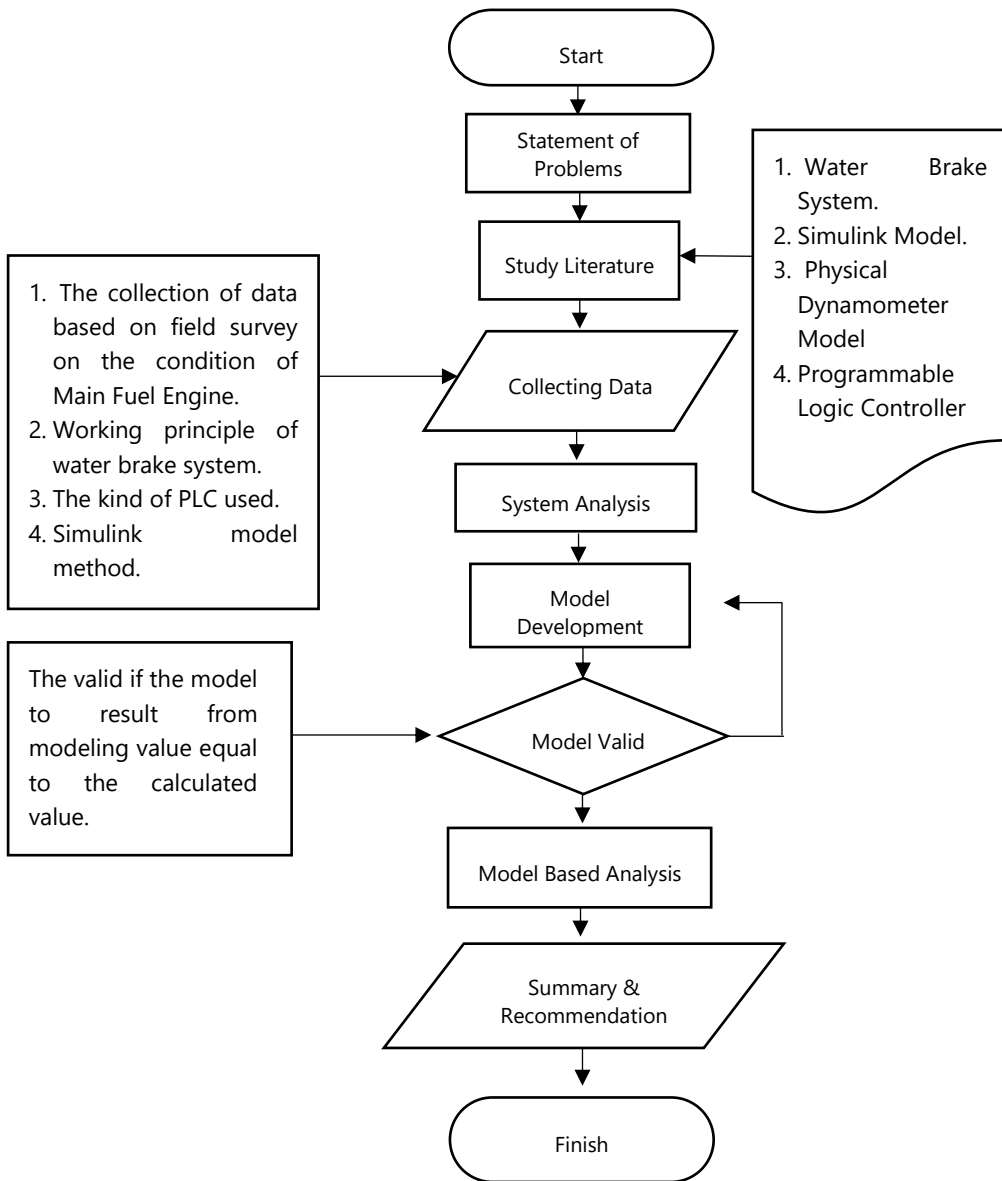


Figure 3.1. Flowchart of Methodology

CHAPTER IV

DISCUSSION AND ANALYSIS

4.1. General

In this chapter, there are several steps that need to be explained. The step that needs to be explained is about creating a model in Simulink. Then proceed with the validation process model that has been made and do some investigation on system by using the model.

4.2. Function Modules of The Control System

The modules which perform the necessary for controlling the brake functions are called function modules. The control system is to be replaced by a PLC based unit. The contents of the function modules with their respective tasks but not changed by this. That makes a representation necessary showing how the signals are with what content and what functions changed in the current function modules. From this, the signal processing for the PLC program must be derived.

4.2.1. The Control Response of The PI Controller

The PI Controller first compares the desired value (reference variable) with the detected value of the process. The comparison provides the control difference. The dynamic behavior of the PI controller continuously compensates for this difference, and supplies at the output a control variable, which always follows the setpoint. Thus, the adjustment range of the control variable is the same as the setting range of the setpoint. In this case, the system control range of the controlled variable and the setpoint 0V-10V, and thus the control difference is -10V to + 10V.

4.2.2. Engine Monitoring and Control System

The main engine monitoring and parts of the brake control system have been enhanced by the company ENITECH Energietechnik-Elektronik GmbH in 2012 and remodeled [9]. Consequently, eliminates the adjustment of speed and torque of the brake using the front panel of the PRE 420. The reference potentiometer of PRE is set and inoperative. There was the new adjustment of ENITECH installed.

The left control lever is used to control the speed of the motor, characterized the governor linkage and thus the filling of the prime mover is adjusted. The right lever is actuated, the actuator of the outlet valve of the brake this adjustment possibility regulates the power consumed by the brake motor torque. A variable speed setpoint is no longer possible.

The torque setpoint for the brake is transmitted to the PRE through the analog input for external control on the connector X5.1 [2] was from this point. Thus, only the source of the set point for the torque has been changed by the setting on the control lever. The connection of the terminals and the internal signal processing to the analog output of Saia PLC, against which the target value for the torque.



Figure 4.1. The setting lever of ENITECH

(source: Own photograph (enginery and plant laboratory of the Faculty for maritime, Warnemünde))

The engine monitoring and the process values of the brake as the drive lever position power and speed are in a built-in navigation station monitor in addition to the digital display elements of the PRE visualized (figure 4.2). The Saia PLC receives the information of the process variables (speed and torque) via connector X29 of PRE, the analog actual values for specific customer applications makes available [2].

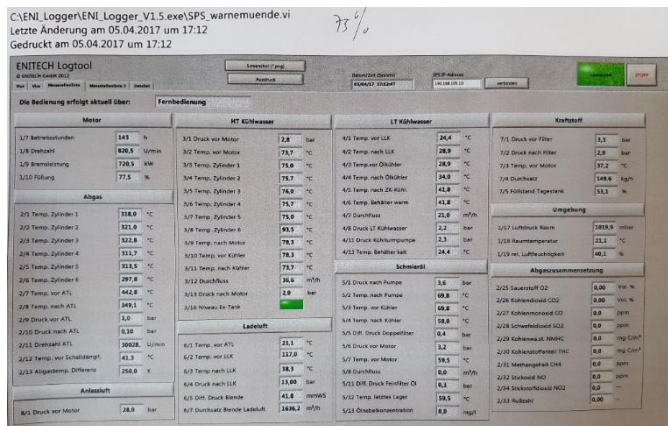


Figure 4.2. The result from the monitor of ENITECH

(source: Own photograph (enginery and plant laboratory of the Faculty for maritime, Warnemünde))

4.3. Engine Performance

Proceedings against the performance of engine involve several stages in generating power that is generated [10]. In figure 4.3 shows there are 3 stages in the generated power generating engine.

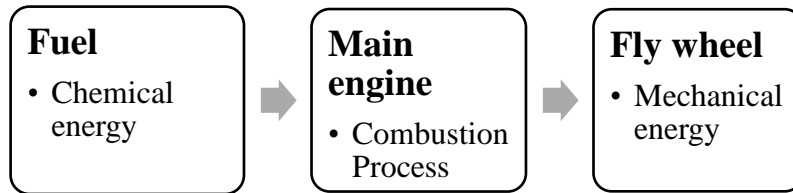


Figure 4.3. Stages of energy at main engine

The first stage is the energy derived from fuel, as shown in the equation 7 as follows;

$$P_{eng} = \dot{m} \cdot C_v \quad (7)$$

The energy produced is not fully used to generate power output, the energy losses caused by heat loss in cooling and exhaust, pumping loss and also friction on the component of engine. So that only about 30% - 40% of the energy used to produce the power output. So, the equation becomes same with equation 1;

$$P_{eng} = \dot{m} \cdot C_v \cdot \eta$$

Where P_{eng} is engine power, \dot{m} is mass fuel rate, C_v is calorific of fuel and η is the efficiency of the engine. Equation 7 represents that the magnitude of the engine power is proportional to the amount of fuel supplied to the engine. Meanwhile, the amount of fuel supplied is dependent on the setting of the speed and power settings in the control room.

In the second stage is the combustion process, engine power can be expressed as follows,

$$P_{eng} = bmep \cdot L \cdot A \cdot n \quad (8)$$

From equation 8 shows that the magnitude of engine power depends on the amount of brake mean effective pressure (bmep) occurring in the engine, due to the Length of stroke (L), Area of piston-bore (A), and Rate of power strokes (n) on an engine is fixed. So, in other words, the amount of engine power is proportional to the value of bmep that occurs.

The third stage is the power engine measured by the braking method in the engine test bed, which is the power output of the engine as shown in the equation 9 as follows;

$$P_{eng} = T \cdot \omega \quad (9)$$

$$\omega = \frac{N}{(60 \cdot 2 \cdot \pi)} \quad (10)$$

Where T is the torque (Nm), ω is the angular velocity (rad / s) and N is the engine speed (rpm). Based on the equation 9 it appears that a significant change in engine power can only be done by changing the value of the torque engine. Each potential variable in the equation 1, equation 8, and the equation 9 has an attachment and influence proportionately, so that the condition may be simplified as follows;

$$\dot{m} \propto b_{mep} \propto T$$

Table 4.1. Data from test running engine

Speed (rpm)	Torque (Nm)	Power (kW)	Fuel rate (Kg/h)
568	4000	237.93	54.8
713	6430	480.11	104.7
818	8400	719.57	150
900	10230	964.18	203

It means "engine torque (T) value will be significantly changed if in combustion process inside cylinder there is a change of brake mean effective pressure (bmep) value. And the bmep value change depends on the amount of mass fuel rate (\dot{m}) supplied to the engine".

In figure 4.4, we can see the relationship of torque set point and engine speed set point on the load variation.

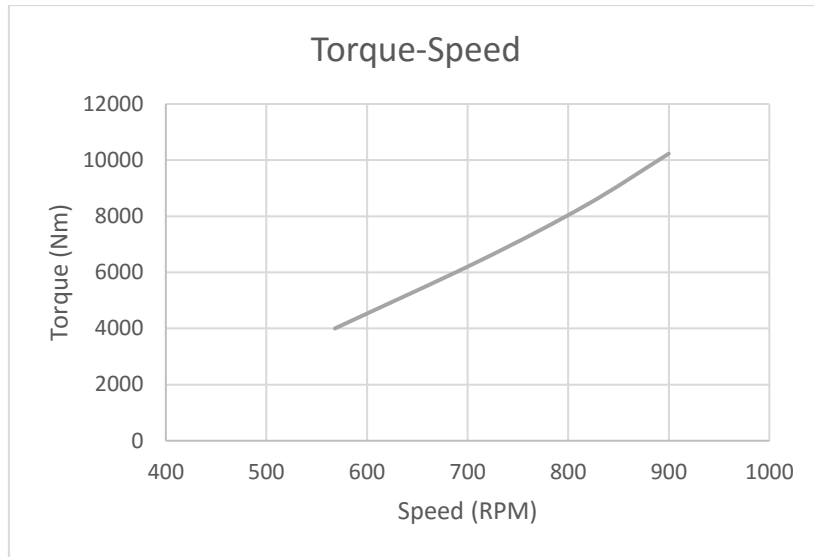


Figure 4.4. The relationship graph of torque and engine speed

In figure 4.4, shows that the value of engine torque also affects the value of speed, which when the torque gets higher, then the speed engine is also getting higher.



Figure 4.5. The relationship graph of power and engine speed

In figure 4.5, it represents the relationship between engine power and engine speed. Where the change in engine power depends on the fraction engine torque or bme_p so that when there is a setpoint change on the torque engine, then the engine power will also change along with the engine torque changes.

4.4. Simulink Model of The System

In this chapter discusses the Simulink model used in the system. For modeling in Simulink, we must know how the system works in the machine described in section 4.3. In figure 4.6, shown the simple model of engine working system.

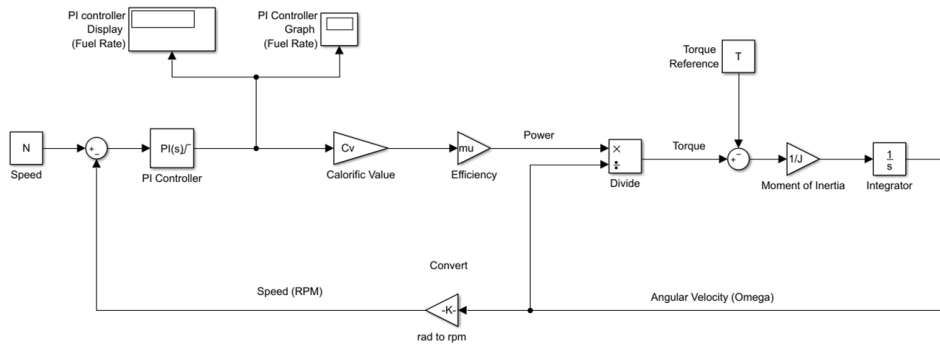


Figure 4.6. Simple model of engine working system

The inputs to the simulation are an engine speed. The speed of engine will produce the flow rate of fuel by PI controller (engine control block). The amount of flow rate of fuel will produce the power of the engine by multiplying the calorific value of engine and efficiency engine (engine process block). The main output is actual torque at the engine.

Base on figure 4.6, the simple diagram developed to be the complex block diagram with be equipped by the time delay in every given input data. So, the transfer block can be grouped into several subsystems. (figure 4.7)

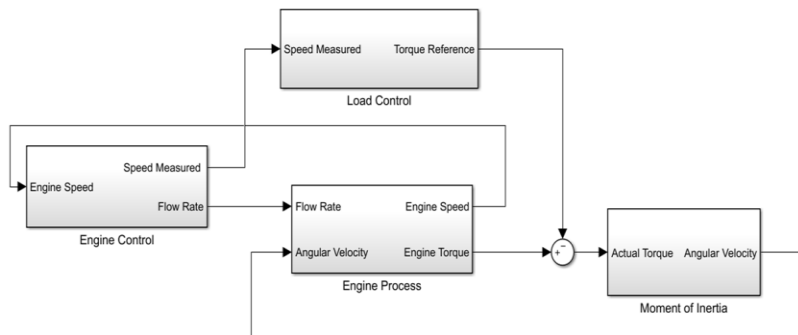


Figure 4.7. Overview of the engine working system Simulink model

Model Simulink of engine working system consists of four subsystems. Each subsystem has different transfer block. Each block subsystem will be explained on the following sub – sub chapters.

4.4.1. Engine Control Block

Engine control block serves to control the amount of fuel flow to be transferred to the engine. The input to this subsystem is the speed reference and speed generated by engine or engine speed. Speed reference is the initial speed value assigned to the engine.

Setting the initial speed of the engine can use two ways, that is constant value parameter or step value parameter which can be moved using a manual switch. Constant value parameter is the granting of engine speed for constants conditions. Step value parameter is the granting of engine speed for speed conditions inconstant, that means we can change the speed any given time. The step value setting in this model is divided into 2 block parameters that is step parameter and pulse generator parameter. In step parameter, we can only do one time change of speed in one run, while block parameter of pulse generator we can make a change of speed up and down repeatedly in one running.

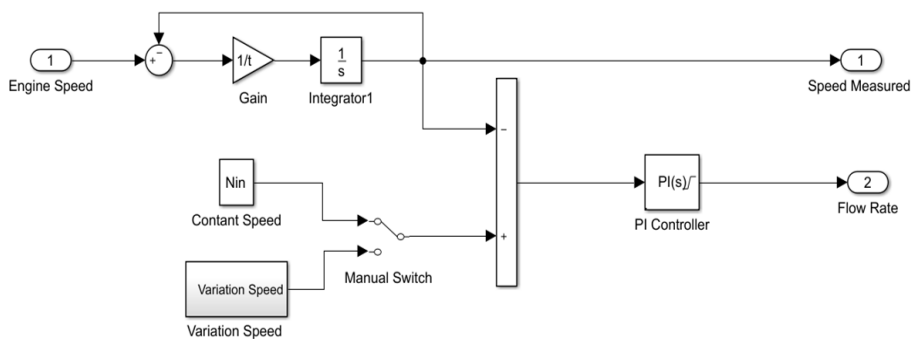


Figure 4.8. Transfer block on the engine control block

Then the second input is engine speed. Value at engine speed is obtained from engine process block. Where the value at engine speed will be filtered to the value of oscillation produced engine speed. So, the engine speed will produce speed measured. Then the speed reference will be in subtract with speed measured value to minimize the error value.

The subtract will go to the PI controller block to set the amount of fuel rate to be transferred to the engine process block. The PI controller working system is describe in section 2.4.2. The PI controller block is equipped with a saturation function that acts as the injection working limit of the fuel pump. Where the fuel injection limit is obtained from equation 1 using maximum power.

So, the output of engine control bock is speed measured and the flow rate of fuel.

4.4.2. Static Process Analysis

The static process characteristic is a curve that gives the steady state relation between input signal "u" and output signal "y". The curve has a physical interpretation only for a stable process. All process investigation should start by a determination of the static process model. It can be used to determine the range of control signal required to change the process output over the desired range, to size actuators, and to select sensor resolution. It can also be used to assess whether static gain variations are so large that they have to be accounted for in the control design.

The static model can be obtained by an open-loop experiment where the input signal is set to a constant value and the process output is measured when it has reached steady state. This gives one point on the process characteristics. The experiment is then repeated to cover the full range of inputs.

The data to setpoint obtained from software "Intouch". When creating the visualization due to the clarity of the user interface, ensure those process parameters are appropriate and necessary in relation to the practical laboratory units and the trials of the main engine test. The previous control system displays the recorded actual process values in a digital display on the front panel of the PRE 420. The "Torque" has three display modes. The display can be switched between the torque based on the theoretical lever arm, the torque, and the power. The digital display "speed" has only one mode and displays the applied speed of the brake.

The values of the speed, torque, and power are required basic components and for the manual start of an operating point of the prime mover. All other displays are optional for direct operation. The lever position is shown on the monitor of the motor control. The data obtained from "Enitech Logtool" monitor display while running engine.

To set the parameters of the corresponding PI controller on the engine. Making this model will be tailored to the results of the test engine running. In the original design of the system, the torque or speed through two reference potentiometers are set. In the deviation of the specified value of the applied speed or torque value, this means adjusting the combustion and power rate to achieve the required process parameters (figure 4.9).

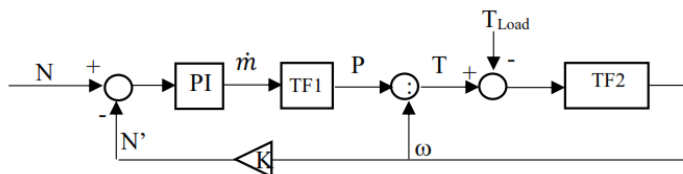


Figure 4.9. Schematic diagram of the system

By setting a torque and a speed reference potentiometer generates the corresponding set point for speed (N) and torque (T_{load}). From calculation on the system, the controller receives information about the size of the currently applied actual value from speed (N') and torque (T). Actual value (N') and setpoint (N) of speed are compared in an operational amplifier which is configured as a subtractor with each other. The result of this comparison is the difference between the potentiometer set at the desired value for the rotational speed (N) with the measured actual value for at the brake speed (N'). This value is corrected in PI control1er and then the desired value for the fuel rate (\dot{m}).

The target value fuel rate (\dot{m}) of the PI controller is validated by the measured data on the "Enitech Logtool" monitor display while running engine. The value of the fuel rate (\dot{m}) generated by the PI controller is multiplied by the transfer function (TF1) to obtained the power value (P) of the engine (equation 1).

Calorific value (C_v) obtained from project guide specification engine 6L23/30A and efficiency of the engine (η) assumed 30%-40%. The power value (P) divided with the angular velocity (ω) to get the actual torque value (T) (equation 2).

Actual value (T) and setpoint (T_{load}) of torque are compared in an operational amplifier which is configured as a subtractor with each other. The result of this comparison is the difference between the potentiometer set at the desired value for the actual torque (T) with the value for the torque of load (T_{load}). This value will use to get the angular velocity (ω) (equation 6).

Where α is the angular velocity in rad/s^2 . The torque (T) used are the torque reference and the moment of inertia (J) Kgm^2 .

One we know the engine working system described in chapter 5 and using the simple model in chapter 6 of figure 6.1, we get the following simulation results.

Table 4.2. Table of measured data and static model result

No.	Speed (rpm)	Fuel rate (Kg/h)	
		Measured Data	Static Model
1	568	54.8	54.93
2	713	104.7	104.8
3	818	150	151.6
4	900	203	203.1

For the Simulink model of static model is in the attachment.

4.4.2.1. Analysis of Factor Losses

In this section discusses the extension of Simulink model to find factor losses. The losses factor is the loss of power in the engine. As for some factors that affects the factor losses are as follows:

- Heat escaping from the cylinders and the engine.
- Friction between moving parts converts some of the energy to heat which is dissipated to the environment.
- Pumping fuel to the engine.
- Incomplete combustion.
- Braking.

In figure 4.10, shown the model with factor losses of engine working system.

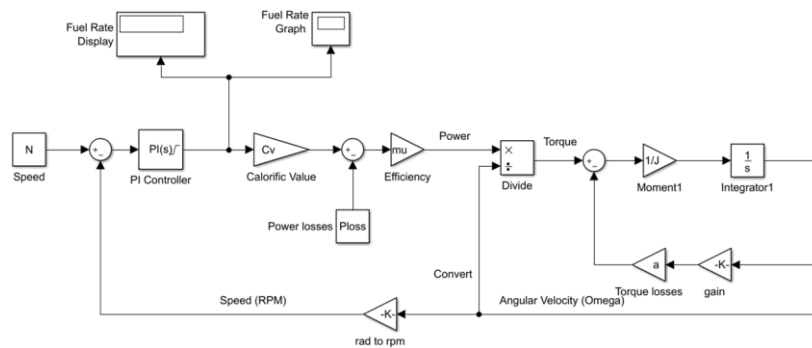


Figure 4.10. Extension of Simulink model to find factor losses

The model aims to find out how much value losses that occur in power and torque engine. Where power losses engine varied. Furthermore, the power of chemical process in subtract with power losses then multiplied by efficiency engine to produce mechanical power in engine. To calculate the losses in torque, angular velocity factor obtained by using the equation.

$$Factor \ \omega = \left(\frac{\omega}{\omega_{rated}} \right)^4 \quad (11)$$

Then, the torque losses multiply the factor of angular velocity.

By simulating the model, so we can know the amount of fuel rate generated from PI controller then validated with measured data.

By varying the losses factor in the model to produce the same fuel rate value with the measured data.

Table 4.3, shows the results of the model test and measured data.

Table 4.3. Table of measured data and model with factor losses

No.	Speed (rpm)	Fuel rate (Kg/h)		Power Losses (%)	Torque Losses (%)
		Measured Data	Model		
1	568	54.8	54.81	5.5	4
2	713	104.7	104.9	2	2.1
3	818	150	149.7	5	3
4	900	203	202.8	5	1

In the table 4.3, at each speed have different losses. The things that affect the losses are already discussed at the beginning of this chapter. Average the power losses of 4.375% and the torque losses of 2.525%.

4.4.3. Engine Process Block

Engine process block describes the engine working system in generating engine torque. The block transfer in this block describes the process of generating mechanical energy in the engine through a chemical energy process.

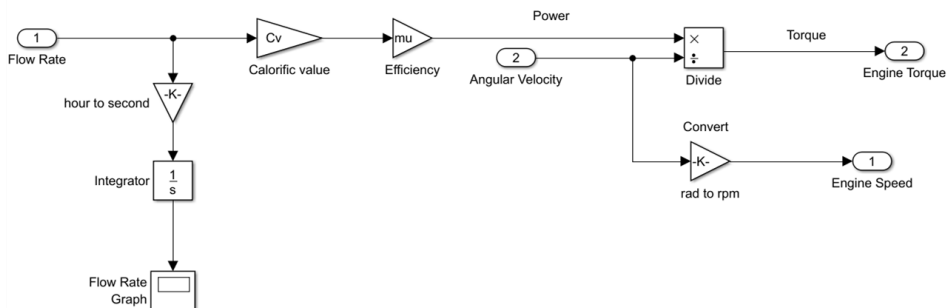


Figure 4.11. Transfer block on the engine process block

Fuel rate generated from PI controller multiplied by calorific value and efficiency engine will generate power engine. Then the power engine divided by angular velocity will produce engine torque. The value of angular velocity comes from the moment of inertia.

So, the output of engine process block is the engine torque and engine speed.

4.4.4. Load Control Block

Load control block serves to control the torque reference to the engine. The input to this subsystem is the speed measured and step of input torque parameter (figure 4.12). From this speed measured value will be seen correlation relationship or influence the value of speed to the resulting torque or known as regression.

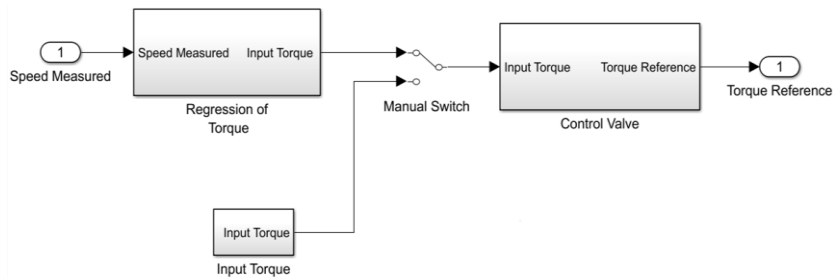


Figure 4.12. Transfer block on the load control block

Setting the reference torque of the engine can use two ways, that from regression torque block or step value parameter which can be moved using a manual switch. To find the regression value of torque, we use slope system. Slope is a measure of the slope of a line. Where the slope value shows how much contribution is given to produce torque value. The slope value is obtained using the following equation,

$$\text{Slope} = \frac{\text{Torque maximum}}{(\text{speed maximum} - \text{speed minimum})} \quad (12)$$

So, obtained the value of input torque derived from engine speed (figure 4.13).

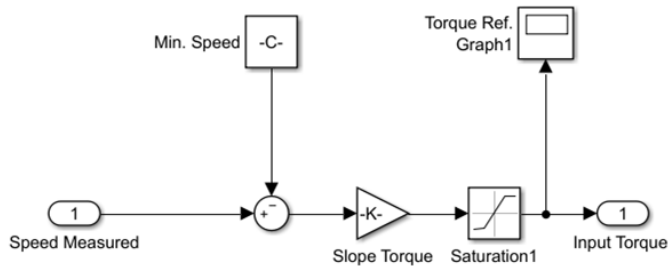


Figure 4.13. Transfer block on the regression torque block

Step value parameter is the granting of torque reference for torque conditions inconstant, that means we can change the torque any given time. The step value setting in this model is divided into 2 block parameters that is "step parameter" and "pulse generator" parameter. In step parameter, we can only do one time change of torque in one run, while block parameter of pulse generator we can make a change of torque up and down repeatedly in one running. For constant torque condition, we just change step parameter with "constant parameter".

The value of the regression block or step parameter will be the torque input which will then become input on the control valve block. Control valve block is also called hydraulic power brake. Where we set open the valve cap to produce the desired torque. So, the output of this block there is a torque reference.

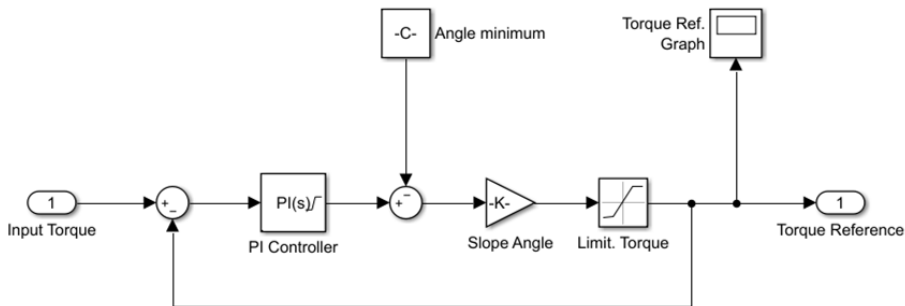


Figure 4.14. Transfer block on the control valve block

The PI controller working system is describe in section 2.4.2. The PI controller block is equipped with a saturation function that acts as the maximum and minimum open the angel valve. Where the maximum open angle is 90° and minimum angel 0° . The slope value is obtained using the following equation,

$$Slope = \frac{Torque\ maximum}{(input\ angle\ maximum - input\ angel\ minimum)} \quad (13)$$

Where the maximum input angle of 30° and the minimum input of 20° . So, the output of load control bock is torque reference.

4.4.5. Moment of Inertia Block

Then the engine torque will be in subtract with torque reference value to minimize the error value and get the actual torque. Actual torque is what will be the input on the moment of inertia block. Where the output on this block is the speed of engine speed. Where to find angular velocity, we can use equation 6 and for the block transfer can be seen in figure 4.15.

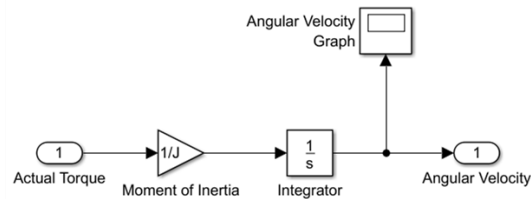


Figure 4.15. Transfer block on the moment of inertia block

4.5. Model Validation

Model validation is performed to ensure that the model in Simulink is working correctly or not. So, the model in Simulink will display the same result or close to measured data.

4.5.1. Convert Data Proccess

In this chapter, explained that the data has been obtained should be converted before being processed. The data obtained from the calculation result when a test is running engine (table 4.4). In table 4.4, we have had 4 cases of experimental data on the respective speed and torque. Where we have data speed setpoint in rpm, the torque set point in Nm, power in kW, the potentiometer value that consists of a "reference value" and "measurement value" in voltage and fuel rate in Kg/h.

Table 4.4. Data from measurement

No.	Speed (RPM)	Torque (Nm)	Power (kW)	Potentiometer Value (V)		Fuel rate (Kg/h)
				Reference	Measure.	
1	568	4000	237.9	0.51	1.6	54.8
2	713	6430	480.1	1.58	2.03	104.7
3	818	8400	719.6	2.34	2.33	150
4	900	10230	964.2	2.92	2.57	203

Once the data is obtained, then we look for factor speed. Factor speed will be used to determine the actual speed value on further experiments of unknown setpoint speed value (rpm). In calculating factor of speed, "speed reference factor" with "speed measurement factor" differs from each other. Calculate our "speed reference factor" using a linear equation, $y = ax + b$. Where "y" is the rated speed obtained and "x" is the known potentiometer value. The values "a" and "b" are the factors sought. To validate the values of "a" and "b" then the result of "y" must equal to or close to the speed from measured data. While to calculate the "speed measurement factor" is to divide the value of known speed with potentiometer value and then averaged by the number of experiments. So, get the value factor speed in table 4.5.

Table 4.5. Data speed with factor speed

No.	Speed (RPM)	Potentiometer Value (V)		Factor Speed		
		Ref.	Meas.	Measurement		Reference
				(RPM/V)	(RPM)	(RPM)
1	568	0.51	1.6	355	563	567.1
2	713	1.58	2.03	351.2	714.3	714.3
3	818	2.34	2.33	351.1	819.9	818.9
4	900	2.92	2.57	350.2	904.3	898.7
Average (Factor speed measurement)				351.87		

In Table 4.5, where the factor speed value in "measurement" is 351.87 and for the speed factor of the reference based on the equation $y = ax + b$, for "a" is 137.63 and "b" is 496.86. Can be seen in the column "factor speed reference" value close to the value of the speed at setpoint during the test engine running.

Speed factor value will be used to calculate the next experiment which is in condition of variation of speed and load variation. In figure 4.16, it shows the value of speed in units of voltage (V) per unit of millisecond (ms). The value is obtained from intouch software on trial speed variations. In this case, we do not know how much speed of the engine in rpm.

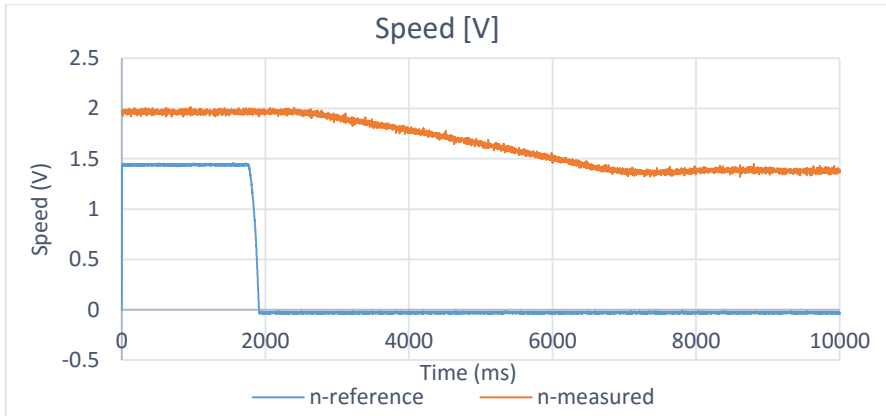


Figure 4.16. Graphic of variation speed (V)

From figure 4.16, we can calculate the speed value in rpm by using the previous calculation method, so we can get the speed in rpm per time to work in millisecond (ms) (figure 4.17).

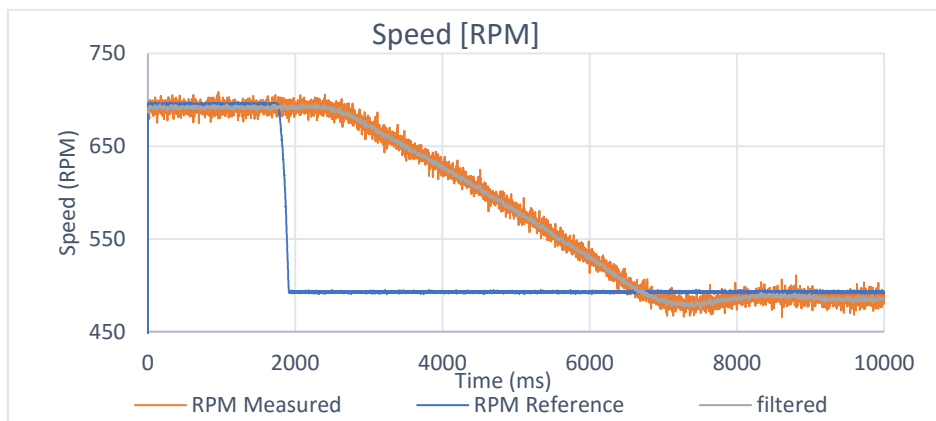


Figure 4.17. Graphic of variation speed (rpm)

In figure 4.17, we perform a speed variation with fixed load at 2000 Nm. So, it can be seen the value of the initial speed of the engine 692 rpm then at 2.3 seconds, the speed is reduced to 485 rpm (RPM reference). At the time of the decrease, there is a time required to reach the value 485 rpm, it can be seen in the picture "RPM Measured".

Filtered is a value of speed derived from measured filtered speed to reduce oscillation at speed. The filter is done per 10 milliseconds.

The process in the previous discussion is done on another experiment, so we can know the value of engine speed in units of rpm.

4.5.2. Static Process

The result of Static process in section 4.4.2 will be validated with the measurement data when running engine. So, we get the comparison of measured data with model results.

Table 4.6. Fuel rate comparison data

No.	Speed (rpm)	Fuel rate (Kg/h)		
		Measured Data	Model without factor losses	Model with factor losses
1	568	54.8	54.93	54.81
2	713	104.7	104.8	104.9
3	818	150	151.6	149.7
4	900	203	203.1	202.8

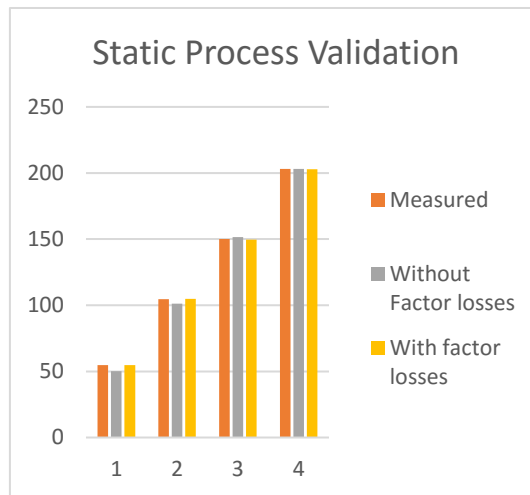


Figure 4.18. Graphics of the fuel rate comparison data

Can be seen from table 6 and in figure 4.18, that the model created in Simulink in accordance with the existing system. Where the results in the Simulink model have the same value and close to the value of the measured data.

4.5.3. Dynamic Process

A static process model like the one discussed in the previous chapter tells the steady state relation between the input and the output signal. A dynamic model should give the relation between the input and the output signal during transients. This applies to linear time invariant systems. Such model can often be used to describe the behavior of control systems when there are small deviations from an equilibrium. The fact that a system is linear implies that the superposition principle holds. This means that if the input "u₁" gives the output "y₁" and the

input “ u_2 ” gives the output “ y_2 ” it then follows that the input $au_1 + bu_2$ gives the output $ay_1 + by_2$. A system is a time invariant if its behavior does not change with time.

A dynamic Simulink model of the dynamometer was constructed to aid development controller. It is a tool to experiment with controllers more easily than with the actual hardware.

On a dynamic model in which the values of rpm and torque reference to determine the parameters vary PI controller that corresponds to the system. The parameter is used to reduce the time delay on the engine. Time delay in this dynamic model because of the time that is used during the change of torque or speed. Models made in Simulink will be in validation with data obtained when test running engine.

A simple PI controller was used to control the flow rate of fuel. The amount of fuel flow into the engine will affect the stability of the engine speed. Changes to the torque engine are then used to determine the engine rotation by adjusting the engine throttles position (fuel stroke position). Where in the time of unloading the speed of engine remains in the desired condition. The dynamometer tracked a sinusoidal signal with increasing frequency (chirp).

In this dynamic model has 4 cases of different data input. The first two cases by varying the speed and the other two variations varying the load.

4.5.3.1. Variation Speed

In the first case by varying the speed of the engine and so get a graph of the system as in figure 4.19.

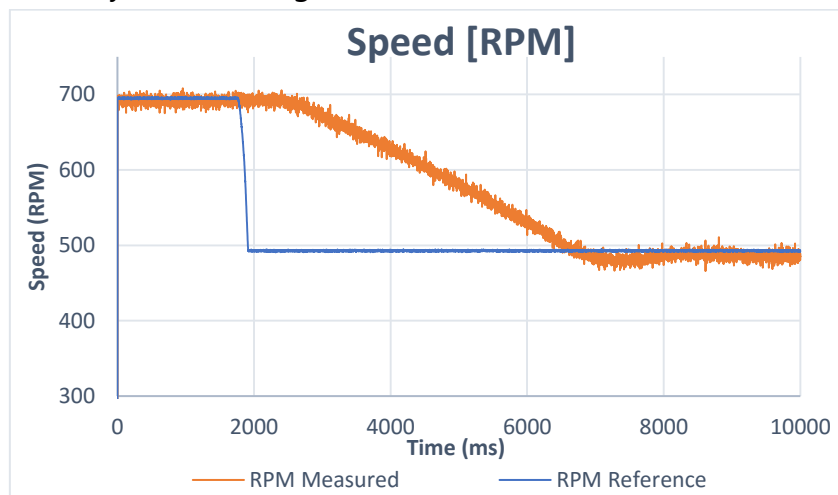


Figure 4.19. Graph of the system with variation speed at case 1

In the first case, where perform a speed variation with fixed load at 2000 Nm. So, it can be seen the value of the initial speed of the engine 692 rpm then at 2.3 seconds, the speed is reduced to 485 rpm. At the time of the decrease, there is a time required to reach the value 485 rpm, it can be seen in the picture "RPM Measured".

Furthermore, making a model on Simulink as section 4.4. By entering the value of each block function and resulting in a graph in figure 4.20.

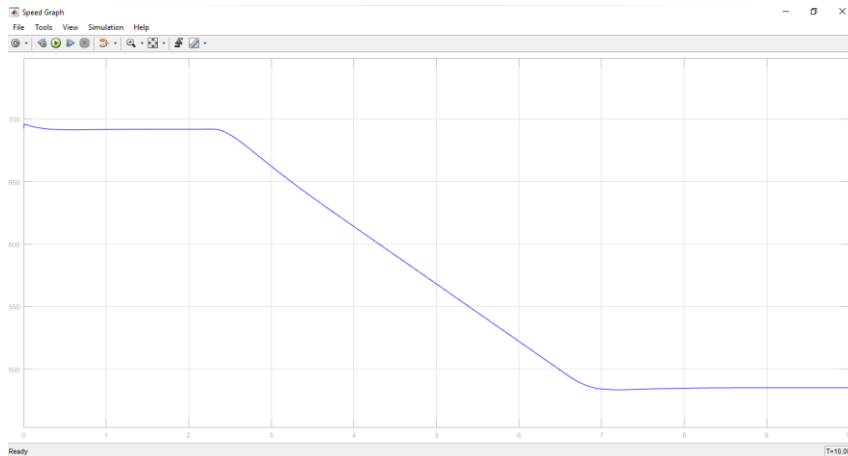


Figure 4.20. Graph of the system with variation speed at Simulink model

In figure 4.20, the graph shows the speed of the model same with the speed graph of the measurement in the laboratory. Where the initial speed 692 rpm then at 2.3 seconds to down with delay time for 5 seconds and back to stable in the 9th seconds with a speed of 485 rpm.

For the other cases is in the attachment.

4.5.3.2. Variation of Load

In the third case by varying the load of the engine and so get a graph of the system as in figure 4.21. Base on dynamic model with variation load and data from excel. The minimum torque of the chirp signal was 1071.43 Nm and the maximum was 5000 Nm. The speed of the engine remains on the specified 852 rpm conditions. At the time of the decrease in the load, there is a significant speed surges (image graphics system). Here the function PI controller is needed to restore the speed surges back to the initial speed condition by adjusting the amount of fuel that goes into the engine.

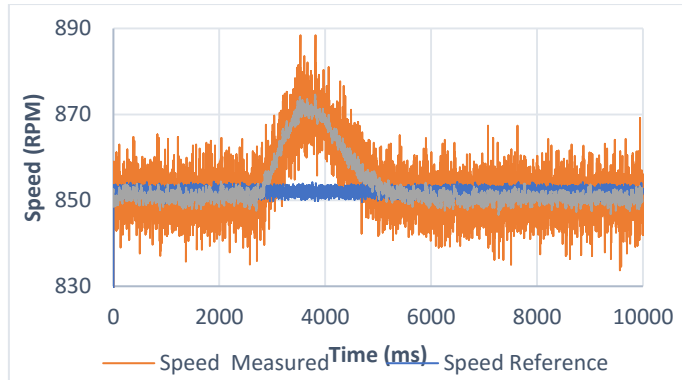


Figure 4.21. Graph of the system with variation load at case 3

So, it can be seen the value of the initial load of the engine 5000 Nm then at 2.4 seconds, the load is reduced to 1071.43 Nm. At the time of the decrease in the load, there is a significant speed surges (image graphics system). Here the function PI controller is needed to restore the speed surges back to the initial speed condition by adjusting the amount of fuel that goes into the engine.

Using the physical equation from section 2.3, a controller was developed for the engine. For this experiment, the operator entered the desired torque manually use lever control of ENITECH. The speed controller operated by the Simulink program, so that the actual and desired speed match.

Furthermore, making a model on Simulink as section 4.4. By entering the value of each block function and resulting in a graph in figure 4.22.

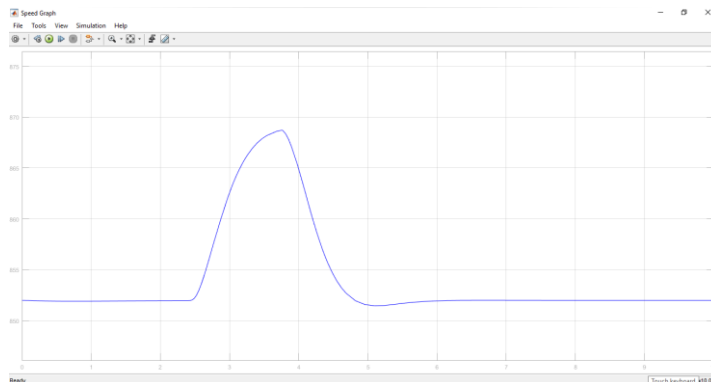


Figure 4.22. Graph of speed with variation load at Simulink model

In figure 4.22, the graph shows the speed of the model same with the speed graph of the measurement in the laboratory. Where the speed

constant in 852 rpm and increase at 2.4 seconds to down with delay time for 2.5 seconds and back to stable with a speed of 852 rpm.

For the script data of the model Simulink and the other cases is in the attachment.

4.6. Investigations of Simulation

The input data for the Simulink model engine is the desired value for viewing the performance of the engine. In this bachelor thesis the input data used is to see the performance of the engine at 100% power and 100% speed and in the condition of variation speed and load.

By using the block diagram that has been described in chapter 6, so we just enter the desired input value. For parameters, the PI controller has the same value of the dynamic model and static model. In this chapter, limitation of the fuel transfer is also varied in order to obtain the appropriate engine stability and to changes the parameters of controller to look condition of respons performance engine.

The maximum permissible filling of diesel engines must be limited to prevent excessive soot due to incomplete combustion and thermal overstress. Since limiting the filling affects the output from the diesel engine torque directly, the fuel limitation must be replicated in the simulation models. As can be judged based on simulation calculations of how much power the diesel engine can emit at different operating conditions.

The approved by the fuel limitation filling feet is the maximum of the power and 110% power. Limitation on the fuel rate is calculated using equation 1.

4.6.1. Investigation Model with Variation Load

In this chapter discusses the Simulink model used in the system with variation load. Where loads will be varied under one step load and more step load (unstable condition) to compare engine fuel consumption used and compare different fuel consumption limits.

4.6.1.1. One Step Load

1. Limit Fuel at 100% Power

In this condition, the PI controller's fuel consumption limitation, located on the engine control block is set to 100% power. So, the maximum fuel consumption based on the equation 1 obtained value of 210.8 Kg / h. In the load control block, the torque input is moved to the step parameter position (figure 4.23).

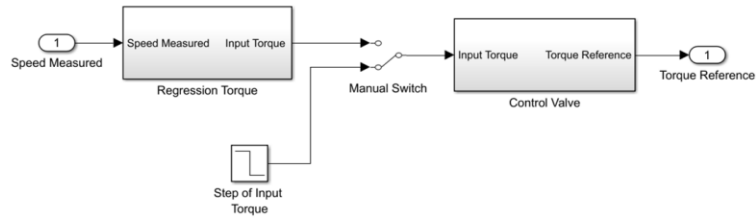


Figure 4.23. Condition manual switch at step load parameter

So, the model can visualize the conditions in which the engine accepts load changes at a time. Simulink modeling uses 10000 Nm load for 50 seconds and then converted to 8000 Nm at 50 to 100 seconds. Resulting in graph in figure 4.24.



Figure 4.24. Graph of the load at one step condition (100% Power)

In figure 4.24, where at the beginning there is a torque spike and the decline then returns constantly at 10 seconds with a load of 10000 Nm and then at the turn of the torque, the graph decreases to 8000 Nm and steadily returns to 8000 Nm in the last 50 seconds. Both are caused by adjustment of PI controller on each received torque. So, the total fuel consumption is 4.96 per unit.

2. Limit Fuel at 110% Power

In this condition, the PI controller's fuel consumption restriction located on the engine control block is set at 110% power. So, the maximum fuel consumption based on the equation 1 obtained value of 231.85 Kg / h. For the load control, same with the first part of section 4.6.1.1.

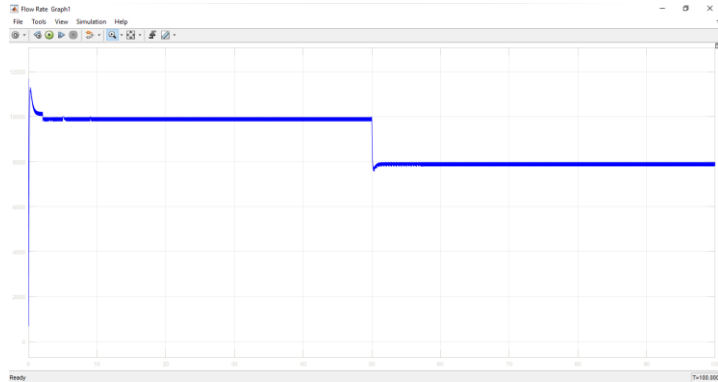


Figure 4.25. Graph of the load at unstable condition (110% power)

In figure 4.25, where at the beginning there is a torque spike and then returns constant at 10000 Nm load for the first 50 seconds then at the turn of the torque, the graph decreases to 7600 Nm and steadily returns at 8000 Nm in the last 50 seconds. Both of these are caused by adjustment of PI controller on each received torque. So, the total fuel consumption is 4.96 per unit.

4.6.1.2. Unstable Load

1. Limit Fuel at 100% Power

In this condition, the PI controller's fuel consumption limitation, located on the engine control block is set to 100% power. So, the maximum fuel consumption based on the equation 1 obtained value of 210.8 Kg/h. In the load control block, the torque input is moved to the step parameter position (figure 4.26).

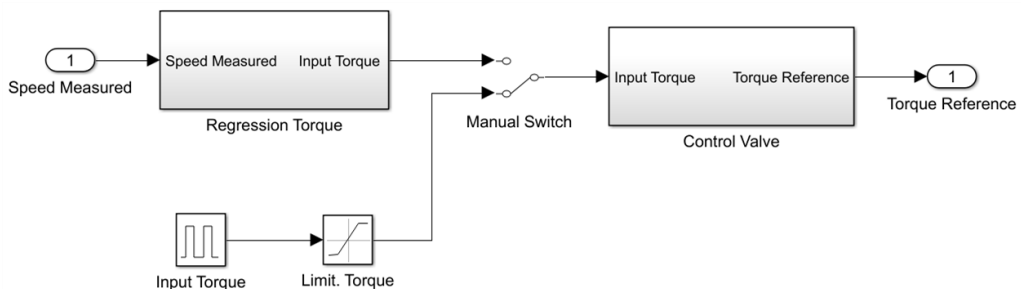


Figure 4.26. Condition manual switch at unstable load parameter

So, the model can visualize the conditions in which the engine accepts load changes every 5 seconds. Simulink modeling uses 10000 Nm and 8000 Nm up and down repeatedly during the process. Resulting in graph in figure 4.27.

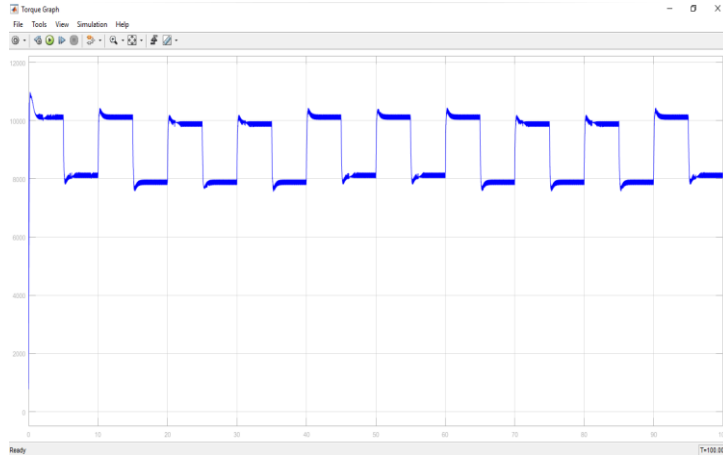


Figure 4.27. Graph of the load at unstable load condition (100% Power)

In figure 4.27, where at the beginning there is a torque spike, and then returns constantly at 10000 Nm load until 5 seconds then at the turn of the torque, the graph decreases to 7600 Nm and steadily returns at 8000 Nm until 5 seconds and going up again up to 10000 Nm the down to 8000 Nm and so on during the process. So, the total fuel consumption is 4.96 per unit.

2. Limit Fuel at 110% Power

In this condition, the PI controller's fuel consumption restriction located on the engine control block is set at 110% power. So, the maximum fuel consumption based on the equation 1 obtained value of 231.8 Kg / h. For the load control, same with the first part of section 4.6.1.2.

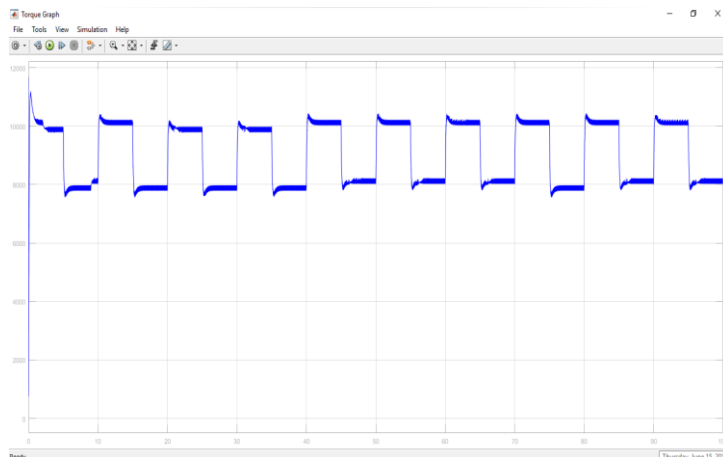


Figure 4.28. Graph of the load at one step condition (110% Power)

In figure 4.28, where at the beginning there is a torque spike, and then returns constantly at 10000 Nm load until 5 seconds then at the turn of the torque, the graph decreases to 7600 Nm and steadily returns at 8000 Nm until 5 seconds and going up again up to 10000 Nm the down to 8000 Nm and so on during the process. So, the total fuel consumption is 4.96 per unit.

4.6.2. Investigation Model with Variation Speed

In this subchapter discusses the Simulink model used in the system with variation speed. Where the speeds will be varied under one step load and more step load to compare engine fuel consumption used and compare different fuel consumption limits.

4.6.2.1. One Step Speed

1. Limit Fuel at 100% Power

In this condition, the PI controller's fuel consumption limitation, located on the engine control block is set to 100% power. So, the maximum fuel consumption based on the equation 1 obtained value of 210.8 Kg / h. In the engine control block, the torque input is moved to the step parameter position (figure 4.29).

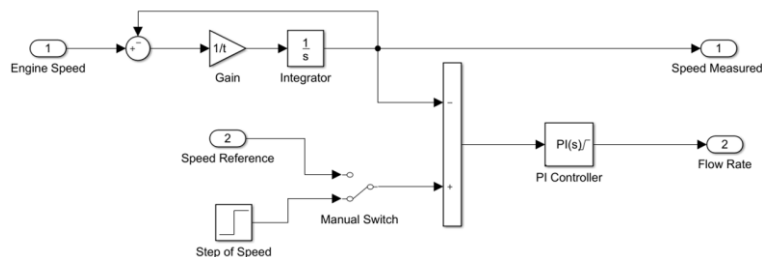


Figure 4.29. Condition manual switch at step speed parameter

So, the model can visualize the conditions in which the engine accepts speed changes at a time. Simulink modeling uses 800 rpm load for 50 seconds and then converted to 900 rpm at 50 to 100 seconds. Resulting in graph speed in figure 4.30.

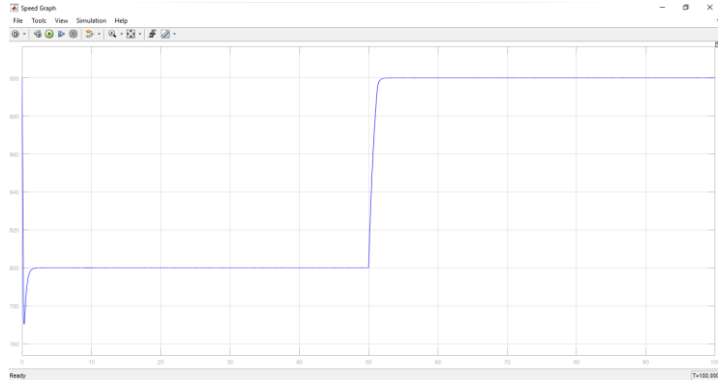


Figure 4.30. Graph of the speed at one step speed condition (100% Power)

Changes in engine speed will affect engine torque. So that torque will also increase at the time of change of speed. However, by setting the torque at a constant state, so the function of the controller will work. The controller will adjust the amount of fuel transferred to the engine to maintain the torque under constant conditions (figure 4.31).

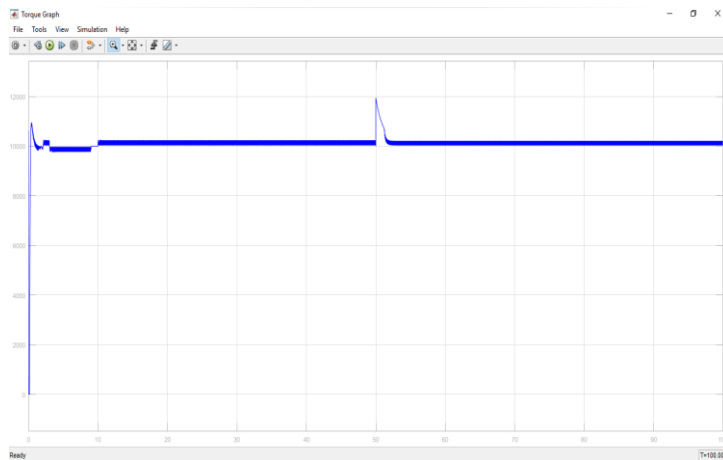


Figure 4.31. Graph of the load at one step speed condition (100% Power)

In figure 4.31, where at the beginning there is a torque spike and the decline then returns constantly at 1.5 seconds with a load of 10000 Nm. During the first ten second, the PI controller seek to stabilize the resulting fuel rate. At the turn of the speed, the graph increases up to 11942 Nm and steadily returns to 10000 Nm at 52 seconds until 100 seconds. Both of these are caused by adjustment of PI controller on each received torque. At the time, changes the speed, the controller trying to maintain the amount of fuel rate generated. So, the total fuel consumption is 5.2 per unit.

2. Limit Fuel at 110% Power

In this condition, the PI controller's fuel consumption restriction located on the engine control block is set at 110% power. So, the maximum fuel consumption based on the equation 1 obtained value of 231.85 Kg/h. For the engine control, the speed same with the first part of section 4.6.2.1.

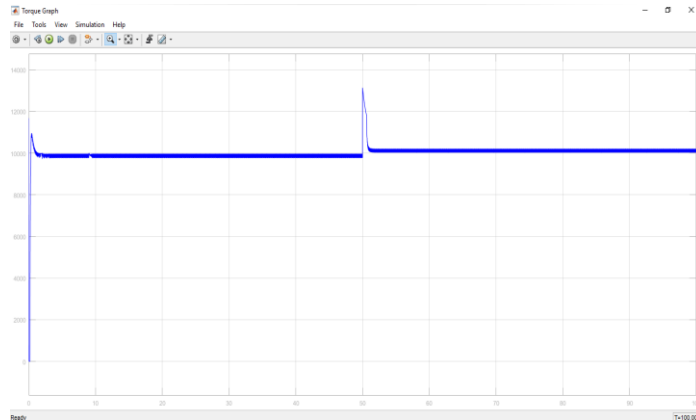


Figure 4.32. Graph of the load at unstable speed condition (110% power)

In figure 4.32, where at the beginning there is a torque spike and the decline then returns constantly at 1.5 seconds with a load of 10000 Nm and then at the turn of the speed, the graph increases up to 13137 Nm and steadily returns to 10000 Nm at 51.2 seconds until 100 seconds. Both are caused by adjustment of PI controller on each received torque. At the time, changes the speed, the controller trying to maintain the amount of fuel rate generated. So, the total fuel consumption is 5.21 per unit.

4.6.2.2. Unstable Speed

1. Limit Fuel at 100% Power

In this condition, the PI controller's fuel consumption limitation, located on the engine control block is set to 100% power. So, the maximum fuel consumption based on the equation 1 obtained value of 210.8 Kg/h. In the engine control block, the speed input is moved to the step parameter position (pulse of speed Reference) (figure 4.33).

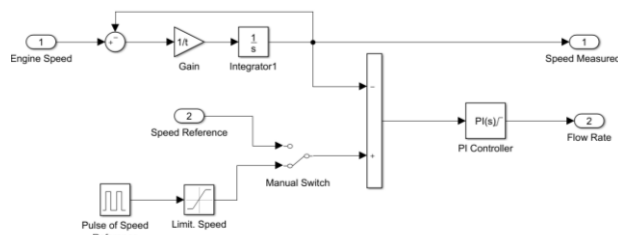


Figure 4.33. Condition manual switch at unstable speed parameter

So, the model can visualize the conditions in which the engine accepts speed changes every 5 seconds. Simulink modeling uses 900 rpm and 800 rpm up and down repeatedly during the process. Resulting in graph speed in figure 4.34.

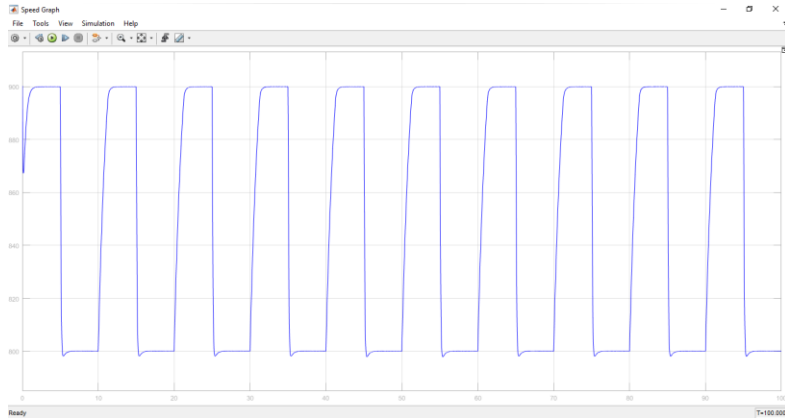


Figure 4.34. Graph of the rpm at unstable condition (100% Power)

Changes in engine speed will affect engine torque. So that torque will also change at the time of change of speed. However, by setting the torque at a constant state, so the function of the controller will work. The controller will adjust the amount of fuel transferred to the engine to maintain the torque under constant conditions (figure 4.35).

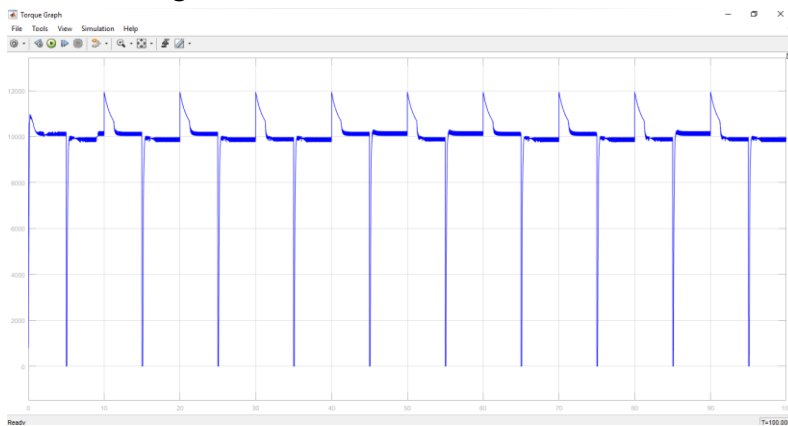


Figure 4.35. Graph of the load at unstable speed condition (100% Power)

In figure 4.35, where at the beginning there is a torque spike, and then returns constantly at 10000 Nm load until 5 seconds then at the turn of the speed, the graph decreases until 0 Nm during 0.09 seconds and steadily returns at 10000 Nm until 5 seconds. At the time, the speed becomes to higher, the torque going up until 11942 Nm and returns constantly at the 1.1 second and so on during the process. So, the total fuel consumption is 5.17 per unit.

2. Limit Fuel at 110% Power

In this condition, the PI controller's fuel consumption restriction located on the engine control block is set at 110% power. So, the maximum fuel consumption based on the equation 1 obtained value of 231.85 Kg/h. For the speed control same with the first part of section 4.6.2.2.

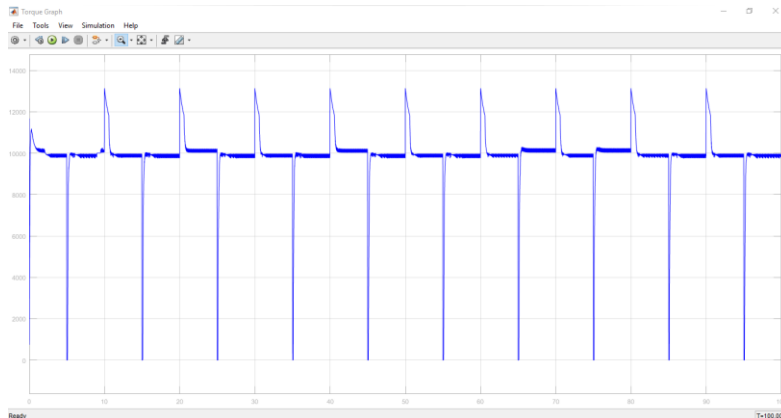


Figure 4.36. Graph of the load at unstable speed condition (110% Power)

In figure 4.36, where at the beginning there is a torque spike, and then returns constantly at 10000 Nm load until 5 seconds then at the turn of the speed, the graph decreases until 0 Nm during 0.09 seconds and steadily returns at 10000 Nm until 5 seconds. At the time, the speed becomes to higher, the torque going up until 13137 Nm and returns constantly at the 0.9 second and so on during the process. So, the total fuel consumption is 5.19 per unit.

Based on the two variations in section 4.6, where the fuel consumption value at one step change is higher than the unstable condition. This is because when the one step change condition only has one time delay during torque and speed changes. Time delay is the effect on the length of time the engine operates at the desired conditions Thus, the total effective time of the engine operation is the time the engine operates is subtract by the total delay time at the time of change of torque or speed. So, at one step change conditions have a longer time compared to unstable conditions.

Variation limit of fuel affects engine stability. Can be seen in figure this chapter that the graph on the 100% power fuel limitation has a higher oscillation compared to the 110% power limitation. It represents the stability of the engine at a limit of 110% power better than at 100% power.

4.6.3. Investigation for The Condition Engine

4.6.3.1. Slow Conditions

In this condition, the PI controller parameter is set to give a slow response. This condition allows to be applied to the engine but this condition does not provide effective working engine. In this condition, the value of P and I parameters on PI controller of load and PI controller of the engine is set respectively 1.

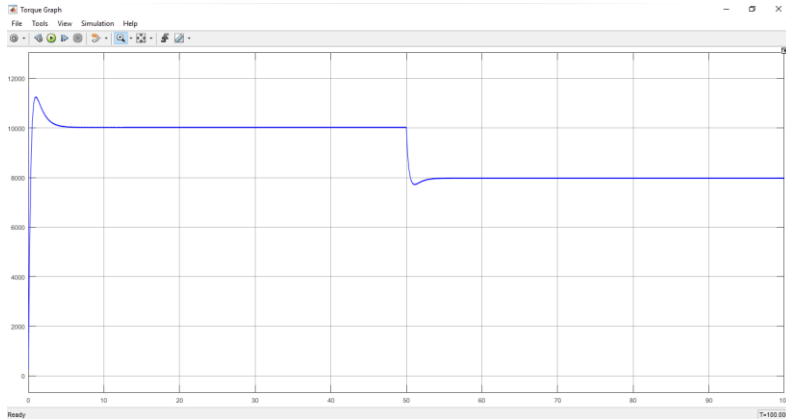


figure 4.37. Graph of the slow conditions

In figure 4.37, there is a fairly slow response time when a given torque change occurs. In this condition has a magnitude value on oscillation of 45 Nm where the condition is quite stable. But it has a long time response. In the first time response for 5 seconds to get to stable condition and at time of change of torque have response time 3.5 seconds to stable condition.

4.6.3.2. Stable conditions

The stable condition is a good enough condition for engine performance. In this condition, the PI controller parameter is set to provide a quick response by providing stable conditions. In this condition, the engine works effectively. In this condition, the P and I parameter values on the PI controller of load are 1 and 100. The P and I parameters in the PI controller of engine are set to 4.5 and 13.

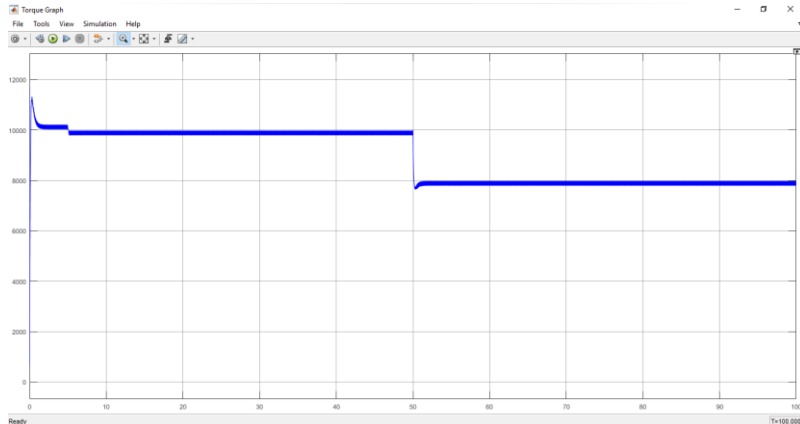


Figure 4.38. Graph of the stable conditions

In figure 4.38, the response time is quite fast when a given torque changes. In this condition has a magnitude value on oscillation greater than the slow condition. The magnitude is 172 Nm where the condition is quite stable. In the first time response for 1.2 seconds to get to stable condition and at the time of change of torque have a response time of 1 second to stable condition.

4.6.3.3. Dangerous condition

This condition is very dangerous when applied to the engine. In this condition, the PI controller parameter is set to provide a very fast response but gives a considerable oscillation value. So, it is dangerous for the engine condition. The limit of the given oscillation value is 10% of the given load value. In this condition, the engine works by being forced to get a very fast response time. In this condition, the P and I parameter values on the PI controller of load are 1 and 100. The P and I parameters in the PI controller of engine are set at 30 and 10.

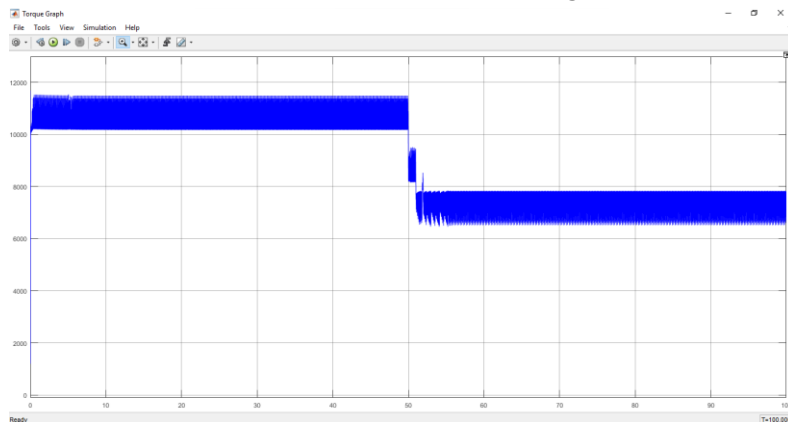


Figure 4.39. Graph of the dangerous conditions

In figure 4.39, there is a very quick response time when a given torque change occurs. In this condition has magnitude value on oscillation greater than in condition slowly and stable condition. Its magnitude value is 1400 Nm where conditions are sufficiently feasible for engine performance. In the first response time for 0.05 seconds to get to a stable condition and when the torque changes have a response time of 0.02 seconds to a stable condition.

CHAPTER V

CONCLUSIONS AND RECOMENDATION

Conclusion

1. Control System

The lever for the performance of ENITECH offers the possibility to intervene in the process and to control the torque absorbed by the brake. A potentiometer generated proportional to the position of the lever from 0% to 100%, an output signal with the bandwidth between 0V to 10V.

2. Engine Performance

Engine stability can be seen from the power generated engine. Where the power engine depends on the amount of fuel that goes into the engine. If the fuel transferred into the engine does not match the engine's need to generate the desired power, the performance engine will decrease. But if the amount of fuel transferred too much can cause damage to what the engine is. So here the PI controller is very important to regulate how much fuel required by the engine to produce the desired power.

3. Simulink Model Simulation

By using Proportional parameter value of 4.5 and Integral of 13 on PI controller, to get a more stable system so that used limitation of fuel rate is 231.85 Kg/h or 110% power engine.

4. Static Process

The static model serves to provide the relationship curve of the steady state model between input and output signals. The relationship curve can be used to determine the range of control signals required to change the output of the process to the desired range.

In this process is also used to determine the variation of static gain on the model which is the value of engine efficiency and moment of inertia. So, obtained for the value of engine efficiency at 568 rpm speed 36.5%, speed 713 rpm 38.6% and at speed 818 rpm and 900 rpm has the same efficiency of 40%. For the moment of inertia (J) value of 150 Kgm².

5. Factor Losses Analysis

Factor losses influence generating power output on the engine. The greater the losses in power losses the more the amount of material needed to produce the same power. Losses factor at the load is relatively lower than the

losses factor in power. So that in test Simulink model got average power losses at engine is 4,375% and torque losses 2,525%.

6. The Process of Convert the Data

This process is to find the value of speed factor used to find the value of speed in cases where we do not know the value of engine speed in rpm. Speed obtained from Intouch analog signals software with voltage units. By using the formula $y = ax + b$, so we get a factor value of 137.63 and 496.86 b with an average error of 0.005125.

7. Dynamic Process

Simulink dynamic process are built to assist in controlling the system control, so we are free to experiment to determine the appropriate control system for the system.

In the Simulink model there are two PI controller functions. In the block engine control, PI controller serves to adjust the amount of fuel that is transferred to the engine. In block Load control, PI controller function to set valve on hydraulic power brake.

The proportional (P) parameter of the PI controller serves to provide the control and stability response. The greater the value of P, the faster response time. But it will cause steady state errors are getting bigger too. The integral (I) parameter serves to reduce steady state state errors but provides a slower response response and can cause instability.

The output of this dynamic model is to determine the value of proportional and integral parameters in the controller. In the PI Controller which regulates the amount of fuel flow into the engine has the value of proportional parameters (P) is 4.5 and the integral parameter (I) is 13.

PI controller here serves to maintain engine stability at the time of the load changes received by the engine. So, the engine rotation remains stable despite changes in the load.

Recommendation

Based on the model validation results on the static model and dynamic model and on the investigation with other cases, so that the corresponding PI controller parameter values obtained on the engine control are for proportional (P) 4.5 and for Integral (I) 13. With the limit fuel of 231.85 Kg / h. The PI controller parameters on the load control are for proportional (P) 1 and for Integral (I) 100 values.

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REFERENCES

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- [2] Zöllner GmbH: Betriebsanleitung der Zöllner Hydraulik-Leistungsbremse Typ 9N38/12F, Fabrikatsnummer 3986, Arbeitsnummer 30 0783, 1989
- [3] Standard DIN EN ISO 6708:1995 09 . Pipeline parts - Definition and Selection of DN (nominal diameter)
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APPENDIX 1
TECHNICAL DATA

A1: Technical Data

1. Technical data of Hydraulic Power Brake System [2]

Manufacturer	Zöllner
Type	9N38/12F
Maximum Power (P_{\max})	1200 kW
Maximum Speed (n_{\max})	3500 r/min
Maximum Scale Display (F_{\max})	7500 N
Measuring range of the speed displa (n)	0-3500 r/min
Water throughput at P_{\max} (at $\Delta t = 40^{\circ}\text{C}$)(Q)	25.2 m ³ /h
Brake regulation	Electromechanical
Number of impellers	1
Blanding type	Inclined blade
Rotational direction of the brake	One, clockwise
Type of shaft seal	Gap seal
Type of running lubrication	Grease lubrication
Electrical connection	U=220V; f=50 Hz

2. Technical data of Main Engine [1]

Manufacturer	MAN B&W 6L23/30A		
Type	Supercharged	4-stroke	diesel
	engine		
Cylinder bore	225 mm		
Stroke	300 mm		
Stroke per bore	1.33 ratio		
Power per cylinder	160 kW		
Nominal power	960 kW		
Nominal speed	900 r/min		
Compression	12.5 ratio		
Effective pressure	1.79 MPa		

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APPENDIX 2
ADDITIONAL FIGURES

A2. Figure

Figure 1. Diesel MAN B&W 6L23/30A

(source: Own photograph (enginyery and plant laboratory of the Faculty for maritime, Warnemünde))

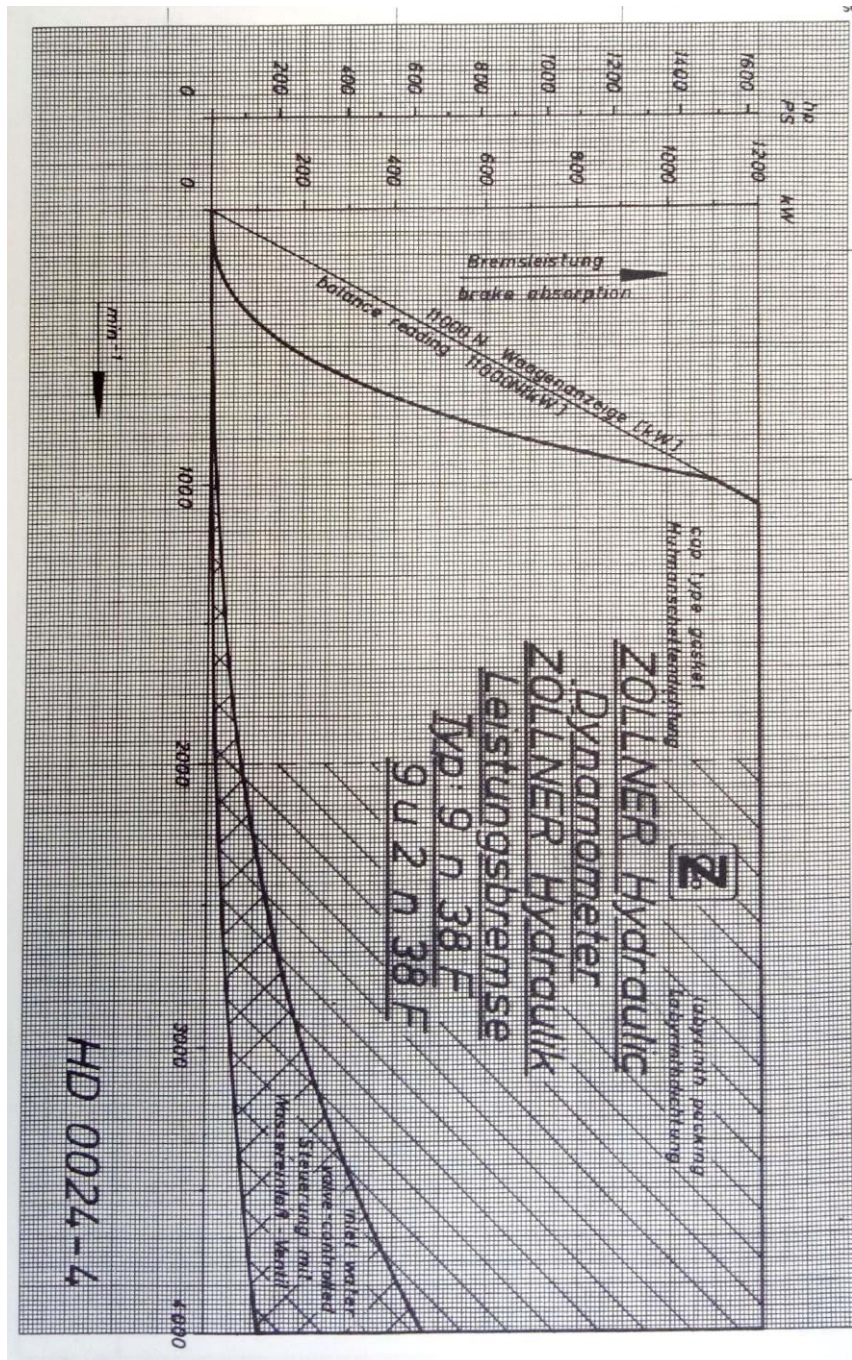


Figure 2. Operating range of the brake at different speeds
 (source: Zöllner GmbH: Betriebsanleitung der Zöllner Hydraulik-Leistungsbremse Typ 9N38/12F [2])

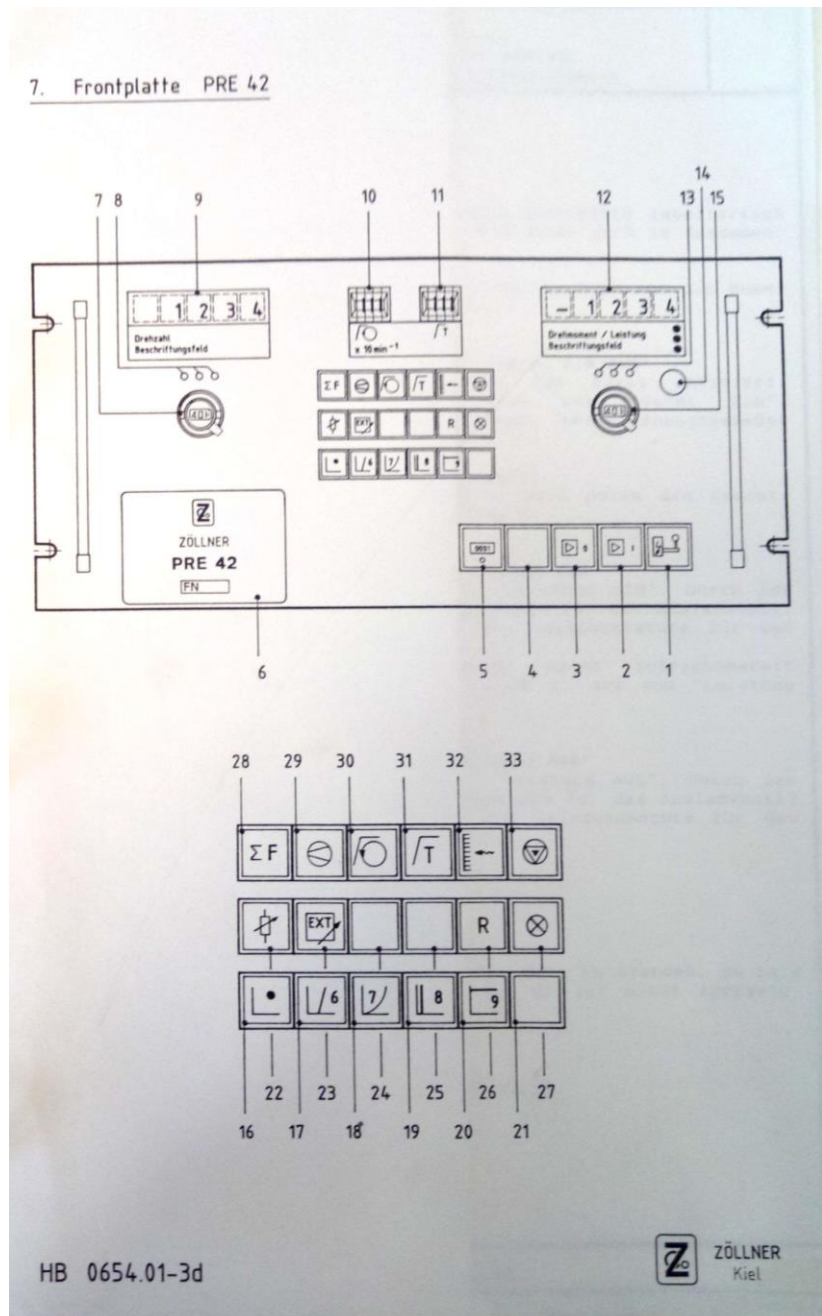


Figure 3. Construction of the front plate of the PRE 42
(source: Zöllner GmbH: Betriebsanleitung der Zöllner Hydraulik-Leistungsbremse Typ 9N38/12F [2])

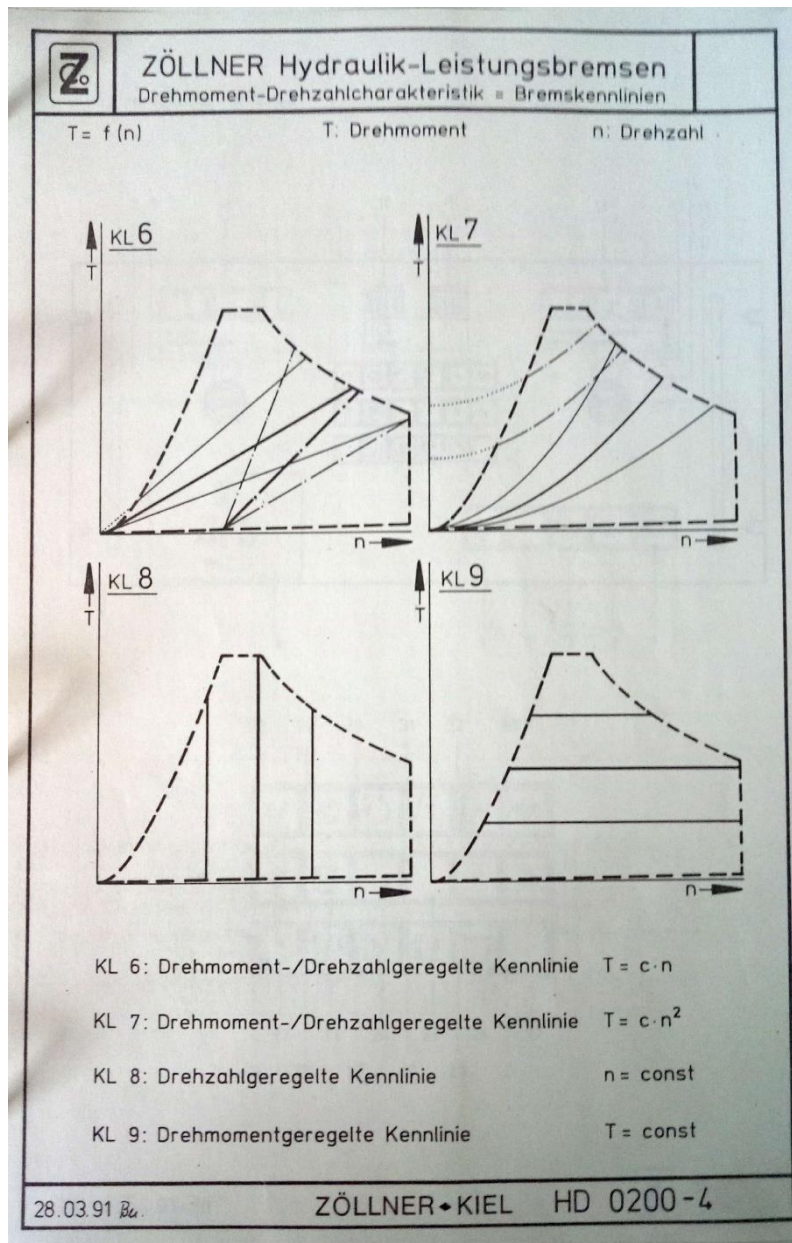
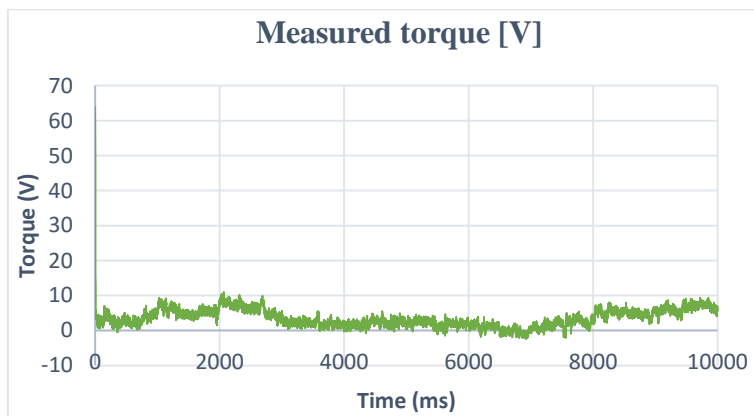
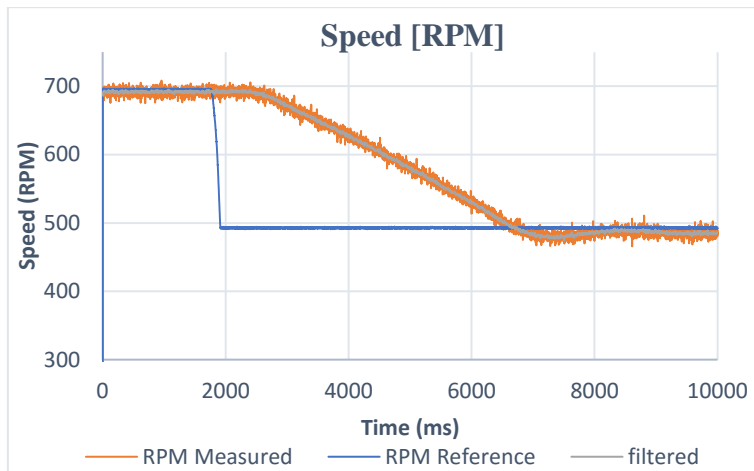
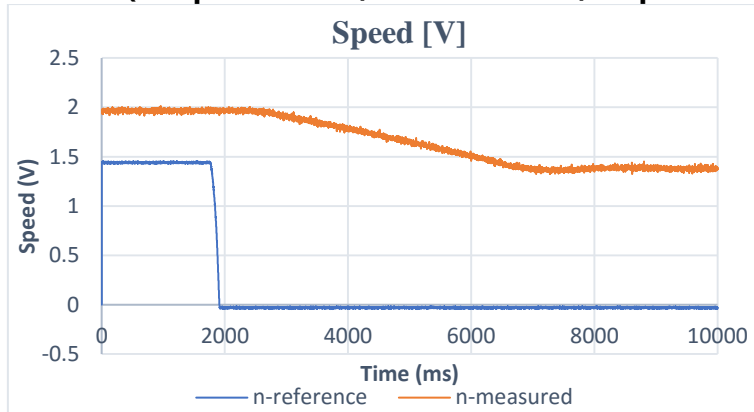


Figure 4. Drawing of customs officers' brake characteristics

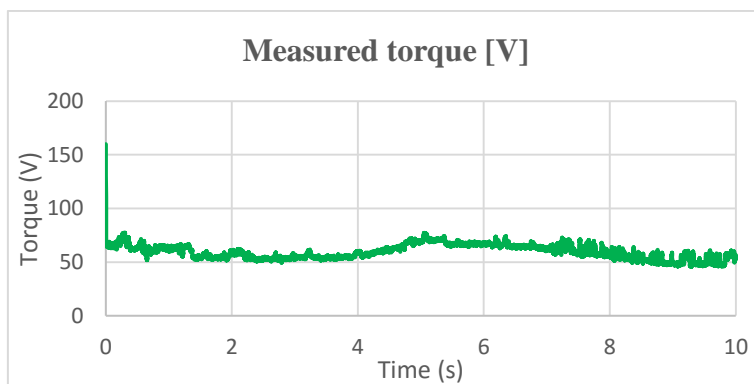
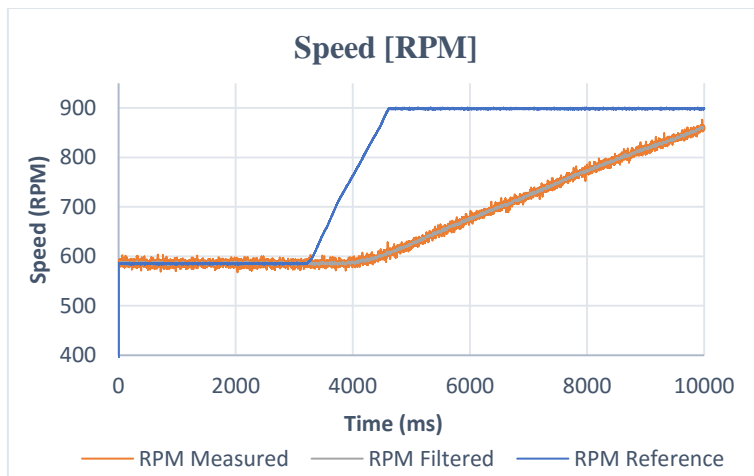
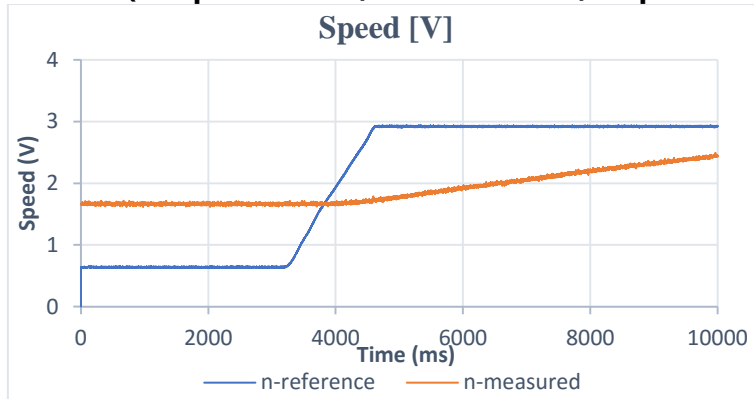
(source: Zöllner GmbH: Betriebsanleitung der Zöllner Hydraulik-Leistungsbremse Typ 9N38/12F [2])

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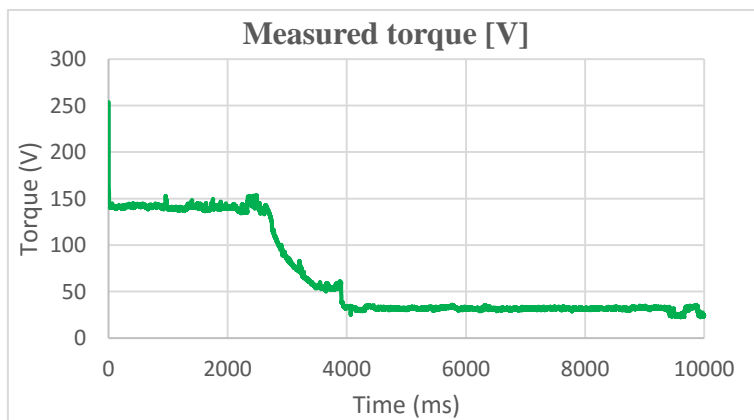
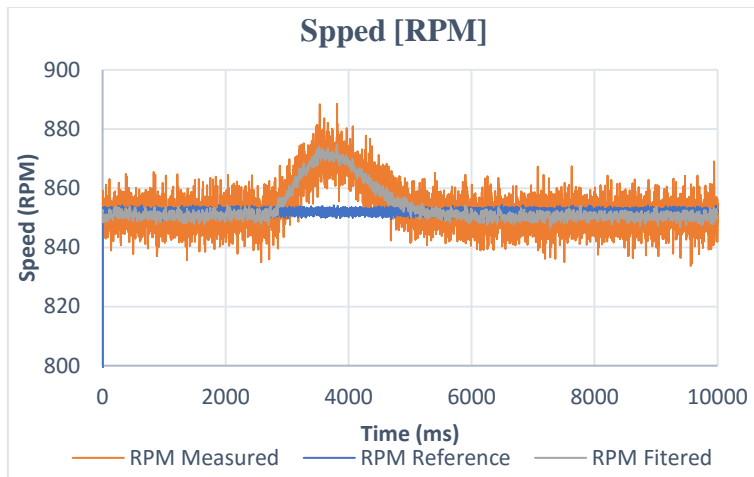
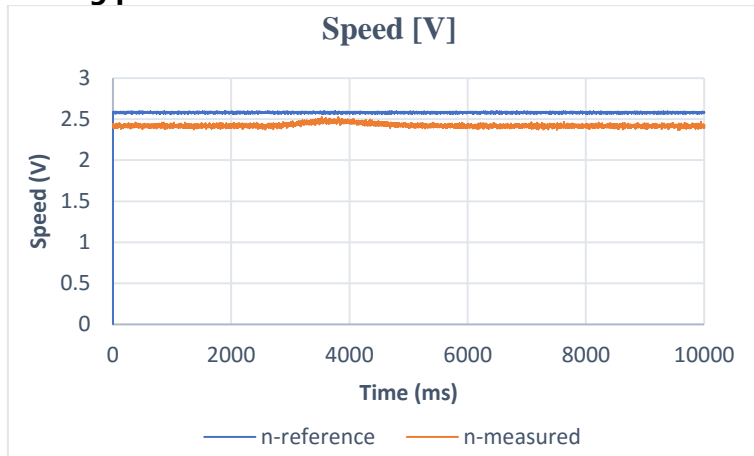
APPENDIX 3
DATA SHEET

1. Case 1 (Torque 2000Nm; RPM 692 - 485, Step time 2.3 sec)

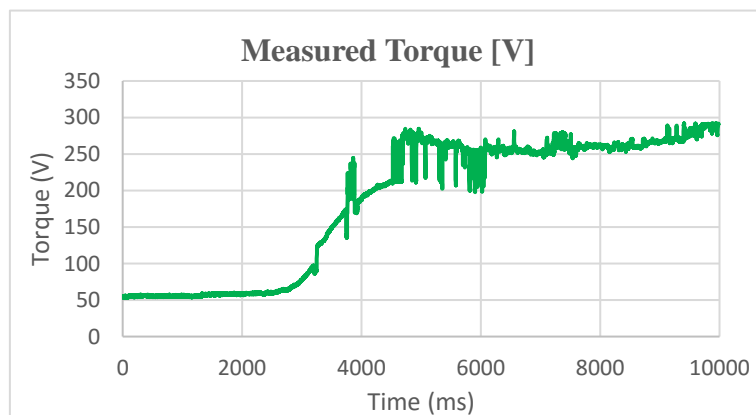
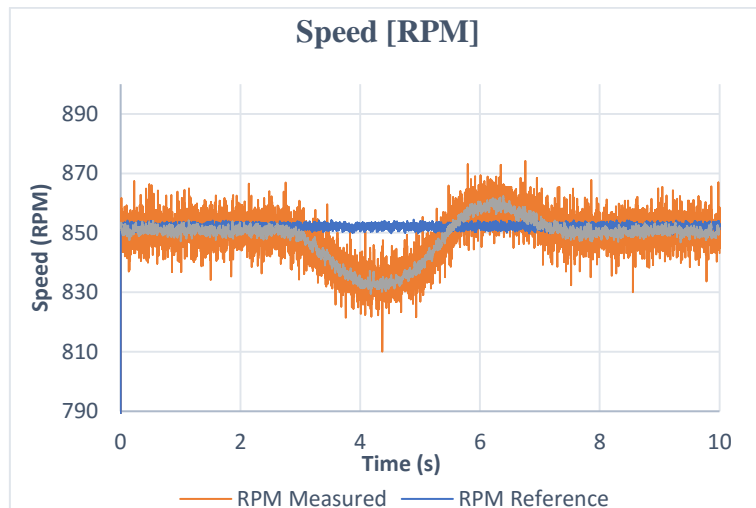
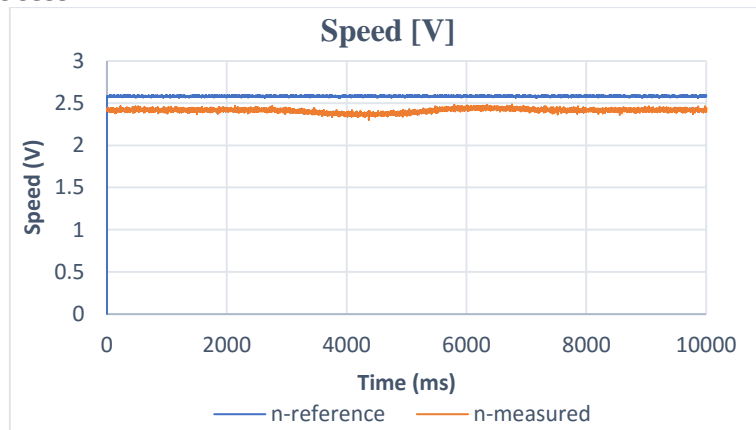
2. Case 2 (Torque 2000Nm; RPM 590 - 860, Step time 4.1 sec)



3. Case 3 (Torque 5000Nm-1071.43Nm, Step time 2.4 sec; RPM 852) Unloading process



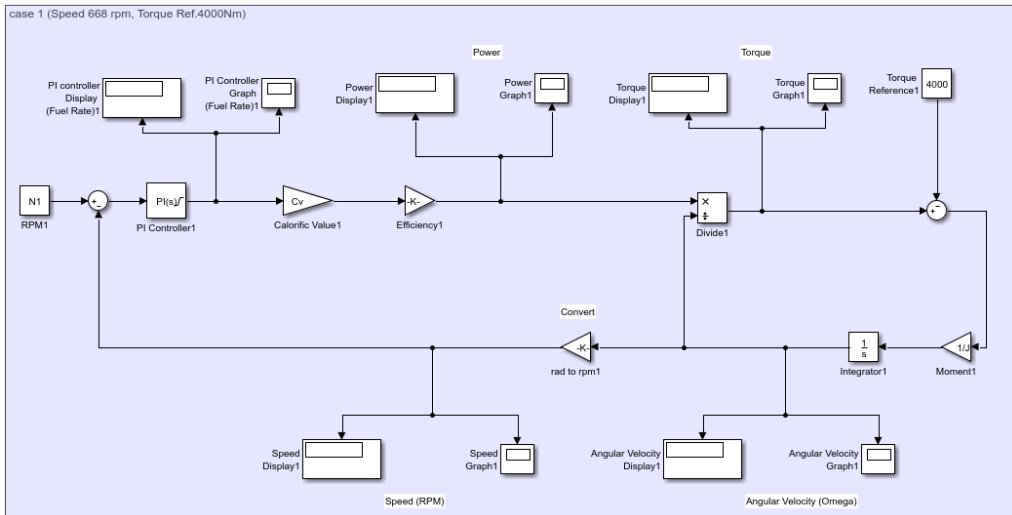
4. Case 4 (Torque 1100Nm-5000Nm, Step time 3 sec; RPM 850) Loading process



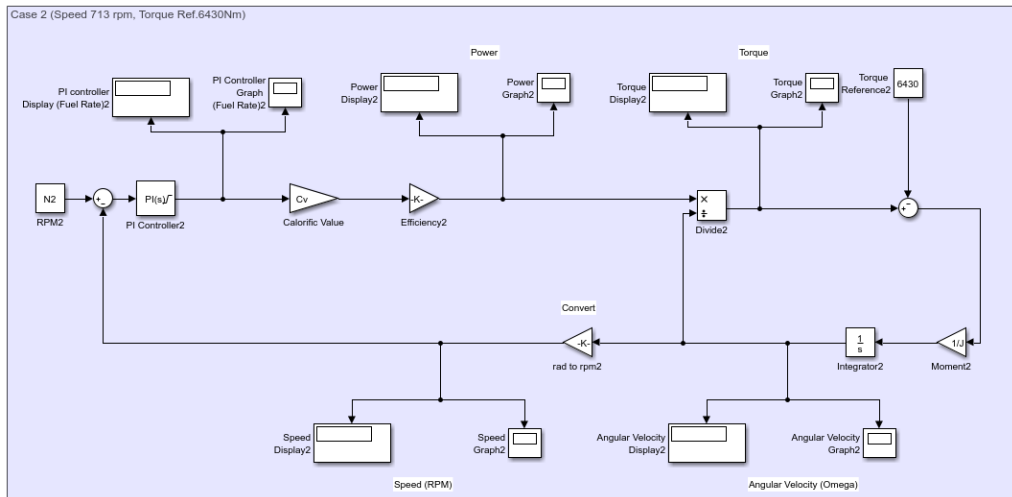
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APPENDIX 4
SIMULINK MODEL

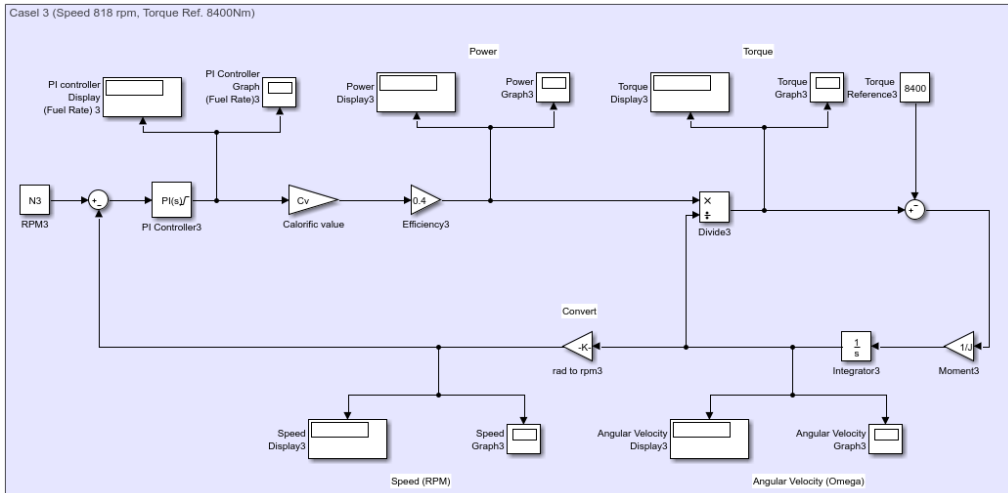
1. Static Simulink Model



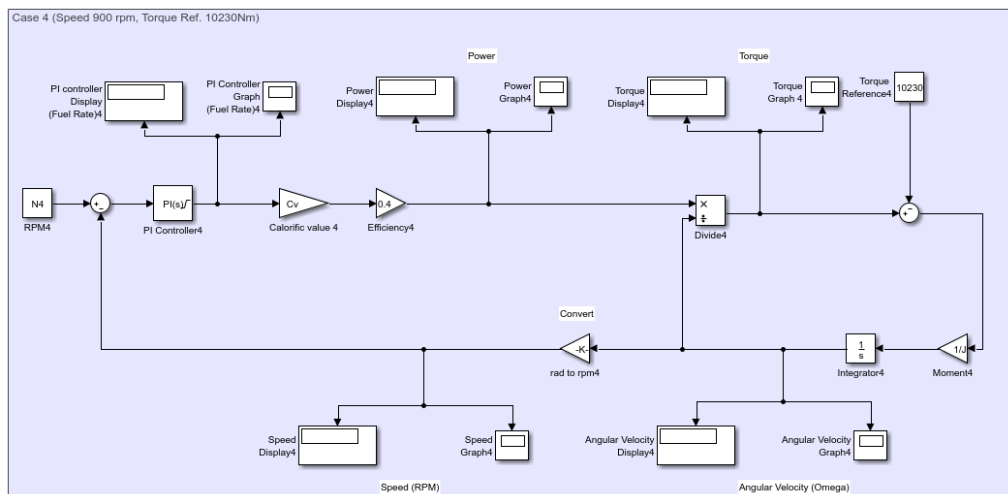
Static Simulink model case 1



Static Simulink model case 2



Static Simulink model case 3



Static Simulink model case 4

2. Static Data Script

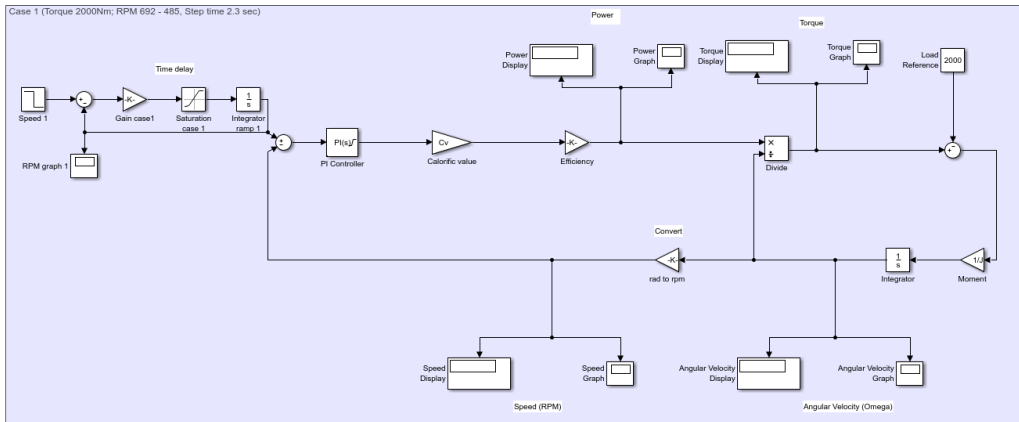
```

% "Bachelor Thesis Model_Static Model_Script"
% Creator          = Muhammad Tri Kurniawan
% Date            = 28.03.2017
% Place           = room 10.15, Haus 4, Friedrich-Barnewitz-
Str 12,
%                 Rostock, German
%-----
%-----
%-----
%-----
% for the speed and torque reference data from the excel file
name "Static and Dynamic Data Process"
% Known
% Controller
P      = 4.5;
I      = 13;
Lim    = 210.7730;    % limit of fuel rate

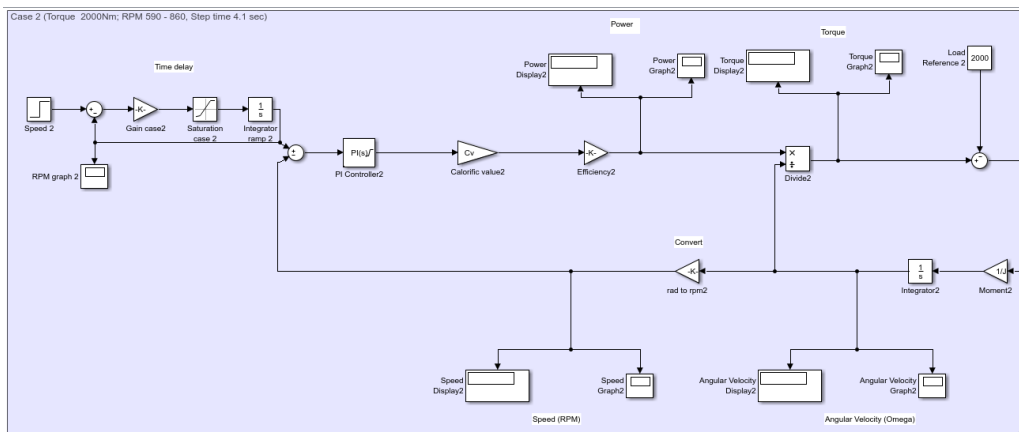
% Engine Process
Cv     = 11861.1;    % Calorific value (Wh/kg)
J      = 430;       % Moment of inertia (kgm^2)
pi     = 3.14;
N1     = 568;       % Speed case 1 (rpm)
N2     = 713;       % Speed case 2 (rpm)
N3     = 818;       % Speed case 3 (rpm)
N4     = 900;       % Speed case 4 (rpm)
T1     = 4001.165;  % Torque case 1 (MNm)
T2     = 6428.499;  % Torque case 2 (MNm)
T3     = 8404.988;  % Torque case 3 (MNm)
T4     = 10217.43;  % Torque case 4 (MNm)
FOC1   = 54.8;      % Fuel consumption Case 1 at measured data
(Kg/h)
FOC2   = 104.7;     % Fuel consumption Case 2 at measured data
(Kg/h)
FOC3   = 150;       % Fuel consumption Case 3 at measured data
(Kg/h)
FOC4   = 203;       % Fuel consumption Case 4 at measured data
(Kg/h)

```

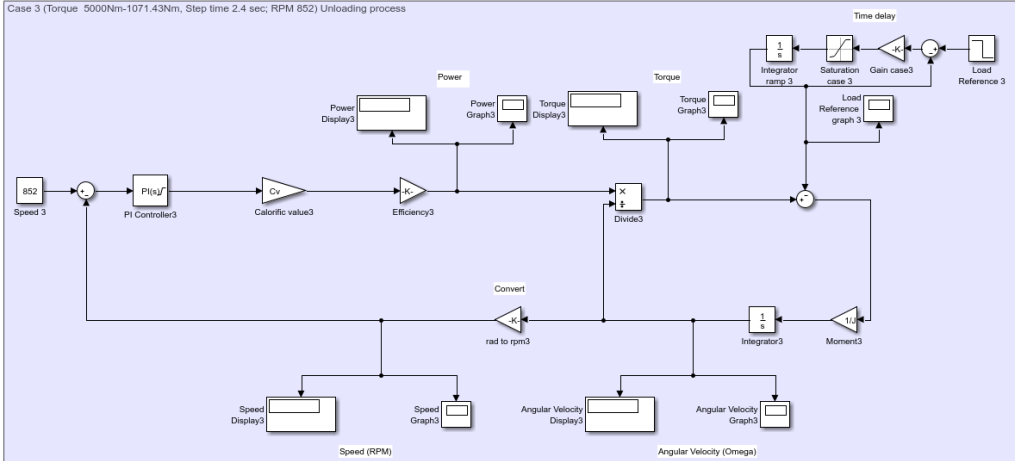
3. Dynamic Simulink Model



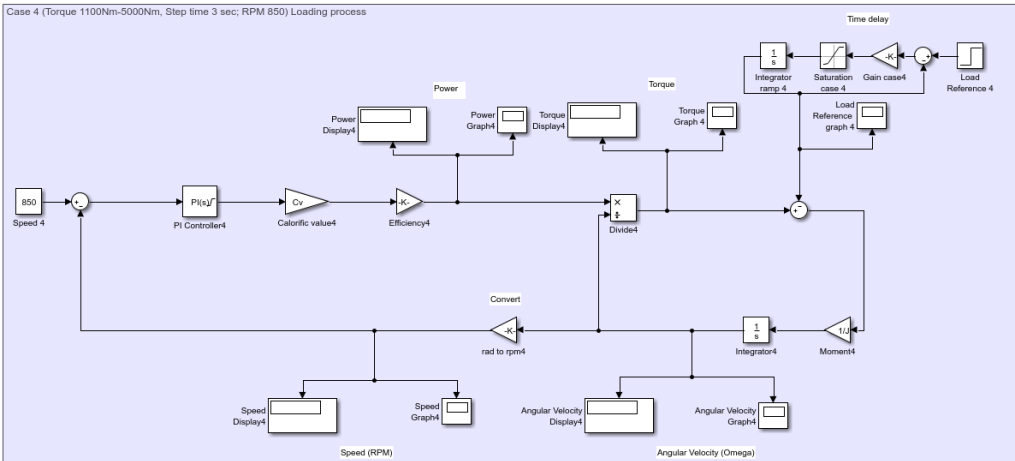
Dynamic Simulink model case 1



Dynamic Simulink model case 2



Dynamic Simulink model case 3



Dynamic Simulink model case 4

4. Dynamic Data Script

```

% "Bachelor Thesis Model_Dynamic Model_Script"
% Creator          = Muhammad Tri Kurniawan
% Date            = 19.04.2017
% Place          = room 10.15, Haus 4, Friedrich-Barnewitz-
Str 12,
%                  Rostock, German
%-----
%-----
%-----
%-----
% for the speed and torque reference data from the excel file
name "Static and Dynamic Data Process"
% Known
% General
% Engine Process Block
pi          = 3.14;
mu          = 0.4;          % Efficiency of Engine
Cv          = 11861.1;      % Calorific value (Wh/kg)
% Inertia Block
J           = 150;          % Moment inertia (kgm^2)
% Engine Control Block
Pengine    = 1.5;          % Proportional gain of PI
controller to engine
Iengine    = 3.5;          % Integral of PI controller to
engine
Nin        = 900 ;         % Constant speed reference (RPM)
Pmax       = 1000000;      % power maximum (W)
x          = 100/100;      % Percentage of Power
Lim        = (Pmax*x)/(mu*Cv); % Flow maximum
t          = 0.002;        % First order (indicate the time
it takes the system to reach a value 63.2% of the steady state)
% Load Control Block
Pload      = 1;           %Proportional gain of PI controller
to load
Iload      = 1;           % Integral of PI controller to load
Anglemin   = 20;          % Input valve angle minimum
(Degree)
Anglemax   = 30;          % Input valve angle maximum
(Degree)
Maxangle    = 90;          % Maximum angle of valve (Degree)
Minangle    = 0;           % Minimum angle of valve (Degree)
Tmax       = 11671.4;     % Torque maximum (110%) (Nm)
Tmin       = 1000;        % Torque minimum (Nm)
Tin        = 2000;        % Constant Torque input
Nmax       = 900;          % Maximum speed of engine (RPM)
Nmin       = 400;          % Minimum Speed of engine (RPM)

```

```

Nrated          = 900;          % Speed rated of engine (RPM)
SlopeAngle     = Tmax/(Anglemax-Anglemin);
Slopetorque    = Tmax/(Nmax-Nmin);

% Each case has different input data for several block input,
such as:
% For case 1 and case 2 has input torque 2000 Nm and has
different input at
% the engine control block
% case 1
Ninitial1      = 692;          % Initial value of step function
for speed case 1
Nfinal1        = 485;          % Final value of step function for
speed case 1
StN1           = 2.3;          % Time at change speed for case 1
% case 2
Ninitial2      = 590;          % Initial value of step function
for speed case 2
Nfinal2        = 860;          % Final value of step function for
speed case 2
StN2           = 4.1;          % Time at change speed for case 2

% For case 3 and case 4 has different input data for speed
constant at
% speed reference block and different input torque for load
control block
% at step load block
% case 3
Nin3           = 852;          % Constant speed reference (RPM) for
case 3
Tinitial3      = 5000;         % Initial value of step function for
load case 3
Tfinal3        = 1071.43;      % Final value of step function for
load case 3
StT3           = 2.4;          % Time at change torque for case 3
% case 4
Nin4           = 850;          % Constant speed reference (RPM) for
case 4
Tinitial4      = 1100;         % Initial value of step function for
load case 4
Tfinal4        = 5000;         % Final value of step function for
load case 4
StT4           = 3;           % Time at change torque for case 4

```


AUTHOR BIOGRAPHY



Muhammad Tri Kurniawan was born on 20 August 1995 in Medan. The author is the third child of four children from Jon Harry Fauzi and Lilik Harliani. The author accomplished his formal education in SDS Dharma Wanita Medan, SMPN 1 Medan, and SMAS Dharma Pancasila Medan. After study in SMAS Dharma Pancasila Medan, the author proceeds to bachelor degree program in Double Degree Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember (ITS) Surabaya with Hochschule Wismar Germany. The author has done his On The Job Training (OJT) in PT Yasa Wahana Tirta Samudera (YWTS) Semarang and PT Maritim Sumber Energi (MSE) Bengkulu. The author has joined the NASDEC surveyor team in 2016 on the feasibility study project of fishing vessel Mina Jaya Niaga at PT Industri Kapal Indonesia (PT IKI) Makassar. In addition to academic activities, the author also actively organizes in the Student Activity Unit (UKM) Maritime Challenge. In his final year, the author placed in laboratory operation University of applied sciences Wismar in Warnemünde, Rostock, Germany to undertake the bachelor thesis project and discussion.