PERFORMANCE COMPARISON OF THE AFC-CRUDE APPROXIMATION AND AFC-FUZZY LOGIC CONTROLLERS IN REDUCING THE VIBRATION OF THE SUSPENDED HANDLE

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DECLARATION

I hereby declare that the project is based on my original work except for quotation and citations which have been duly acknowledged. I authorized Universiti Sains Malaysia to lend this thesis to other institutions or individuals for purpose of scholarly research.

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HAZIQ BIN JAMALUDIN
JUNE 2017

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LIST OF SYMBOLS

Symbols	**Descriptions**	**Unit**
A	acceleration	m/s^2
c	Dynamic damping of the handle	kg/s
k	Dynamic stiffness of the handle	N/m
K_d	Derivative gain	-
K_I	Integral gain	-
K_p	Proportional gain	-
m	Dynamic mass of the handle	kg
s	Displacement	m
v	Velocity	m/s
t	Time	s
q	Actuator stiffness gain	N/m

LIST OF ABBREVIATIONS

Symbols	**Descriptions**
AFC	Active Force Control
AVC	Active vibration control
CA	Crude-Approximation
CTS	Carpal Tunnel Syndrome
DOF	Degree-Of-Freedom
EAV	Exposure Action Value
ELV	Exposure Limit Value
EM	Estimated Mass
FL	Fuzzy Logic
GA	Generic Algorithm
HAV	Hand-arm vibration
ILM	Interative Learning Method
MD	Mass Displacement
MF	Membership Function
PID	Proportional-integral-derivative
VWF	Vibration White Finger

ABSTRAK

Kajian ini bertujuan untuk menyekat getaran yang dihasilkan oleh mana-mana alat kuasa kepada alat pemegang model digantung menggunakan kaedah kawalan daya aktif (AFC) dengan dibantu dengan kaedah pintar yang lain. Penggunaan alat kuasa dengan tahap getaran yang tinggi secara berpanjangan boleh membawa kepada sindrom getaran hand-arm (HAVs). Oleh yang demikian, analisis dinamik bagi model pemegang digantung adalah perlu untuk mengurangkan getaran sistem tersebut. Pemegang digantung dimodelkan sebagai satu darjah kebebasan sistem (SDOF) dan gelombang gangguan sinus diaplikasikan kepada sistem. Selain itu, beberapa pekali seperti jisima, spring dan nilai peredam dan parameter kawalan diperolehi daripada kajian sebelumnya. Dalam kajian simulasi ini, empat sistem dikaji dan dibandingkan iaitu sistem pasif, AVC dengan berkadar integrasi derivatif (PID), AVC dengan PID-AFC-mentah Penghampiran (CA) dan AVC dengan PID-AFC-Fuzzy Logic (FL) pengawal. Daripada kajian yang lepas, skim AFC telah terbukti sebagai pengawal yang teguh pada pemegang digantung. Berdasarkan ini, kajian ini diperluaskan dengan menggunakan kaedah yang pintar (FL) untuk menentukan pengawal parameter AFC yang merupakan jisim anggaran (EM). Dari kajian itu, EM yang optimum diperolehi dari kaedah CA adalah 0.04 kg manakala bagi kaedah FL adalah 0.04223 kg. Nilai ini dihasilkan oleh fungsi keahlian yang berbentuk segi tiga di dalam alat kawalan FL. Di samping itu, persembahan keseluruhan juga dibandingkan dengan menukar nilai input sasaran kepada sifar dan AFCFL masih boleh menghasilkan hasil keputusan yang terbaik kepada sistem.

ABSTRACT

This study aims to suppress the vibration produced by any power tools to the suspended handle model using Active Force Control (AFC) method with embedded of an intelligent method. Prolonged use of the power tool with the high level of vibration can lead to the hand-arm vibration syndrome (HAVs). Due to this, a dynamic analysis of the suspended handle model is necessary in order to reduce the vibration of the system. The suspended handle is modelled as a single-degree-of-freedom (SDOF) system and a sine wave disturbance is applied to the system. Apart from that, some coefficients such as mass, spring and damper values and the control parameters are obtained from the previous study. In this simulation study, four systems are investigated and compared which are passive system, AVC with proportional-integration-derivative (PID), AVC with PID-AFC-Crude Approximation (CA) and AVC with PID-AFC-Fuzzy Logic (FL) controllers. From the previous study, the AFC scheme has been proven as a robust controller to the suspended handle. Based on this, the study is extended using the intelligent method (FL) to determine the AFC controller parameter which is an estimated mass (EM). From the study, the optimum EM obtained from CA method is 0.04 kg while for the FL method is 0.04223 kg. This value produced by the triangular-shaped membership function in the FL controller. In addition, overall performances are also compared by changing the target input value to zero and the AFCFL can still produce the best result to the system.

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter presents the research background, problem statement, objectives, scope of research, and the thesis outline.

1.2 Research background

The exposure to the high level of vibration from the power tools can lead to the serious health issues. Typically, handheld power tools produce a low operating frequency with high level of vibration (below 500 Hz) and this is the source of movement that propagate to the whole hand–arm system, including the shoulder.

A continuous exposure to the vibration can resulting the hand–arm system under stress and consequently which may cause of muscular and skeletal pathologies. Usually, pains and muscle weakness are common consequences [1]. Moreover, the long exposure to the vibration will cause of Hand-Arm Vibration syndrome (HAVs) which includes Carpal Tunnel Syndrome (CTS) and Vibration White Finger (VWF). Some of the effect can be appear right after using the power tools and disappear after a short time. However, in some cases when the vibration rate is high and the exposure time is long, it could affect their nerve system and hand permanently.

According to the Control of Vibration at Work Regulation 2005, every employers should know the risk of the vibration and how to control them, so that the health problems that related to vibration effect can be avoided [2]. There are some recommendations that being suggested such as to wear an anti-vibration gloves as shown in Figure 1.1.The anti-vibration glove can isolate the operator hand from the effect of vibration.

Another solution, the workers should have an interval break during the working period and many more [1]. These two solutions are the method of passive vibration control. There is also another alternative solution using active vibration control (AVC) method such as Active Force Control (AFC) and Fuzzy Logic (FL) control methods. Both are the intelligent method in controlling the vibration. In this research, the performance of AFC is compare between AFC- crude approximation (CA) and AFC- fuzzy logic (FL) in reducing the vibration of the power tools using an active suspended handle.

Figure 1.1 : Anti vibration gloves [3]

1.3 Problem Statement

Power tool is a machine that can assist human in their daily work such as the use of sander. Nowadays, many industries used the power tool due to its mobility factors. In previous study, the PID-AFC controller has been developed to reduce the vibration of the power tools using an active suspended handle [4]. From the study, 91% of vibration reduction has been achieved using the PID-AFC controller. This vibration reduction can be improved by using the intelligent methods for the tuning of PID-AFC controller such as FL. In this research, the performance of the AFC intelligent method such as AFC-CA and AFC-FL in reducing the vibration of the suspended handle is investigated and compared.

1.4 Objectives

In this research, two main objectives are set to be achieved:

- To develop an active suspended handle model using AFCCA and AFCFL controllers.
- To compare the performance of AFCCA and AFCFL in reducing the vibration of the suspended handle.

1.5 Scope of research

In this research, the simulation of an active suspended handle model is carried out using the MATLAB and Simulink software. The vibration of the suspended handle model will be reduced to the desirable value using an intelligent AFC tuning methods such as AFC-CA and AFC-FL. Then, the performance of both controllers are compared and analyzed. The parameter of the model has been generated from the previous study [4].

1.6 Thesis outline

This thesis is divided into five chapters which includes:

- Chapter 1 (Introduction) presents the overview, research background, problem statement, objectives, scope and thesis outline.
- Chapter 2 (Literature review) presents the literatures on the high vibration of power tools, HAVs, model of AVC system and controller studies such as PID, AFCCA and AFCFL.
- Chapter 3 (Methodology) presents the overview of the methodology, modelling of SDOFs suspended handle model, disturbances model, passive and active system with PID, AFCCA and AFCFL controllers.
- Chapter 4 (Results and discussion) presents the simulation results of the suspended handle for passive and active system and the tuning of the PID, AFCCA and AFCFL of the AVC system.
- Chapter 5 (Conclusion) presents the outcome of the research work and the recommendation of the possible future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, there are five main parts which includes the high vibration of power tools, HAVs, model of AVC system and controller studies such as AFC and FL controllers.

2.2 High vibration of power tools

Prolonged exposure to the high level of vibration can cause the Hand-Arm Vibration syndrome (HAVs). The HAVs can be affected in the high-risk work situations such as drilling of wall and grinding operation in road construction and many more [5]. In the previous study, researchers have evaluated the vibration level (frequency-weighted acceleration) of several power tools such as orbital sander, rock drill, pneumatic hammer and grass trimmer. The result shows that all the tools produced high level of vibration as shown in Table 2.1.

Table 2.1: High vibration level of power tools [6]

Power Tools	Weighted acceleration (a_{hv})
Orbital sander	3.9 – 7.3 m/s^2
Rock drill	24 – 25 m/s^2
Pneumatic hammer	30 m/s^2
Grass trimmer	4.5 – 11.3 m/s^2

The Exposure Action Value (EAV) is designated as the daily amount of vibration exposure which employers are required to take action to control. The higher the exposure level means that, the greater the risk, thus necessitating more action by an employer to reduce the risk. The Exposure Limit Value (ELV) is designated as the maximum amount of vibration exposure that employee may be exposed in a single day. It represents a very high risk that employees should not be exposed [7].

For hand-transmitted vibration, the directive specifies the EAV and ELV vibration magnitudes in terms of an 8 hours equivalent frequency weighted RMS (EAV=2.5 m/s^2 A (8), ELV=5 m/s^2 A (8)). The ELV is the maximum allowable exposure for an employee in a working day. This directive has been paralleled in the US with ANSI S.2.70 (2006) which uses identical criteria for risk evaluation [8].

2.3 HAVs

HAVs is a neurodegenerative and vasospastic disease observed from workers who is regularly use handheld percussive or impact power tools [9]. HAVs consists of neurovascular symptoms including paresthesia, pain, vasospastic episodes, decreased strength, and decreased dexterity in the hand. In the United States, 1.5 million workers are exposed to hand-transmitted vibration [10]. HAVs usually causes by pneumatic tool such as grinders, drill, jackhammer and chainsaw. Figure 2.1 shows the health problem that cause by HAVs which is VWF syndrome. This injuries basically being triggered by high exposure of vibration level which effect the blood vessel and nerve. The worker will feel the pain, numb and lost ability in grab action.

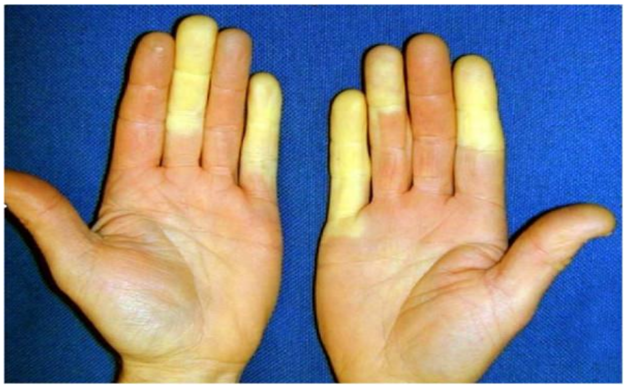


Figure 2.1: White finger syndrome (VWF) [11]

2.4 Model of AVC system

AVC is a system that have an active power sources such as actuator to control and attenuate the vibration of the system [12]. In addition, AVC is an active application of counter vibrtion in an equal and opposite fashion to the vibration imposed by external sources [13]. Moreover, there are two types of control in AVC system which are open loop and closed loop. Basically, open loop is where the system has a switch (on and off) and closed loop needs a specific controller to the system which it will process the feedback the signals to solve it [14]. Figure 2.2 shows that a basic control system that have a closed loop method to control the vibration. The sensor used as a feedback mechanism to analysis the actual value and the desired value for the counter signal. Lastly, the actuator will supplied the counter signal from the controller to reduce the vibration of the system.

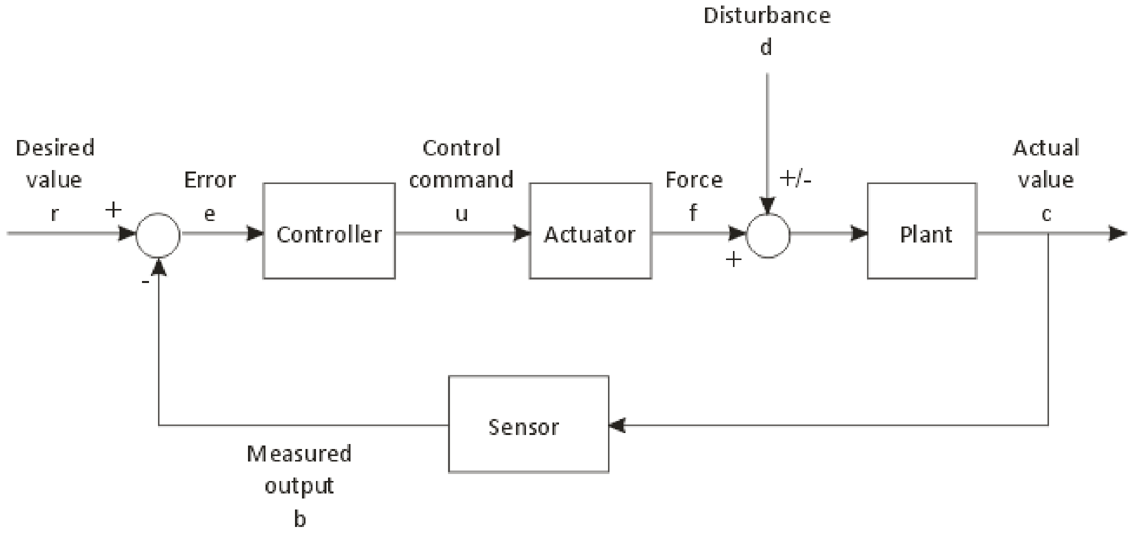


Figure 2.2: Basic Control System [15]

One approach of developing the suspended handle was done by Oddo et al;.2004. In the study, the pneumatic jackleg drills which used in the mining industry is taken as a vibration source. The passive SDOF suspended handle was designed to provide the vibration attenuation between 35 Hz and 45 Hz. The study also shown the effect of combining the suspended handle and the hand-arm system of four-degree-of-freedom lumped parameter system. The hand-arm model was found to have a significant influence on the vibration transmissibility responses by suspended handle model [16].

2.5 Controller studies

There are many type of controller that can be used in order to get the accurate and suitable solution for the vibration related problems. Commonly, PID is one of the controller that usually been used but the solution was limited. Nowadays, there are some controllers using an intelligent method such as AFCCA and AFCFL.

2.5.1 AFC controller

Basically, there are two techniques to control the vibration of the system which is passive and AVC [17]. AFC is one of the AVC method that has been introduced and applied by Hewit in the late 70s for controlling a dynamic system. A number of experimental studies have verified that this controller can give a good stability, robustness and effectiveness to the system even in the presence of unknown disturbances, uncertainties and varies operating condition. Basically, AFC operates by computing the estimated disturbance force, F^* via measurement of the mass acceleration, a and actuator force Fa with an appropriate tuning of the estimated mass, M^* as given by following equation:

$$F^* = Fa - M^* a \tag{2.1}$$

The basic schematic of the AFC scheme applied to a dynamic system is illustrated in Figure 2.3.

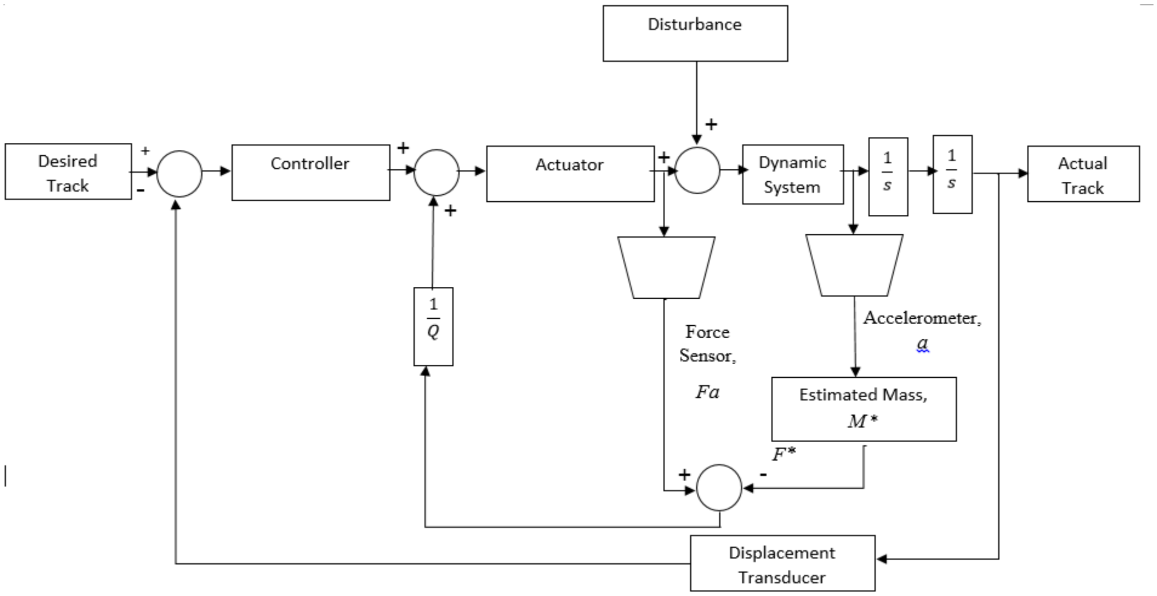
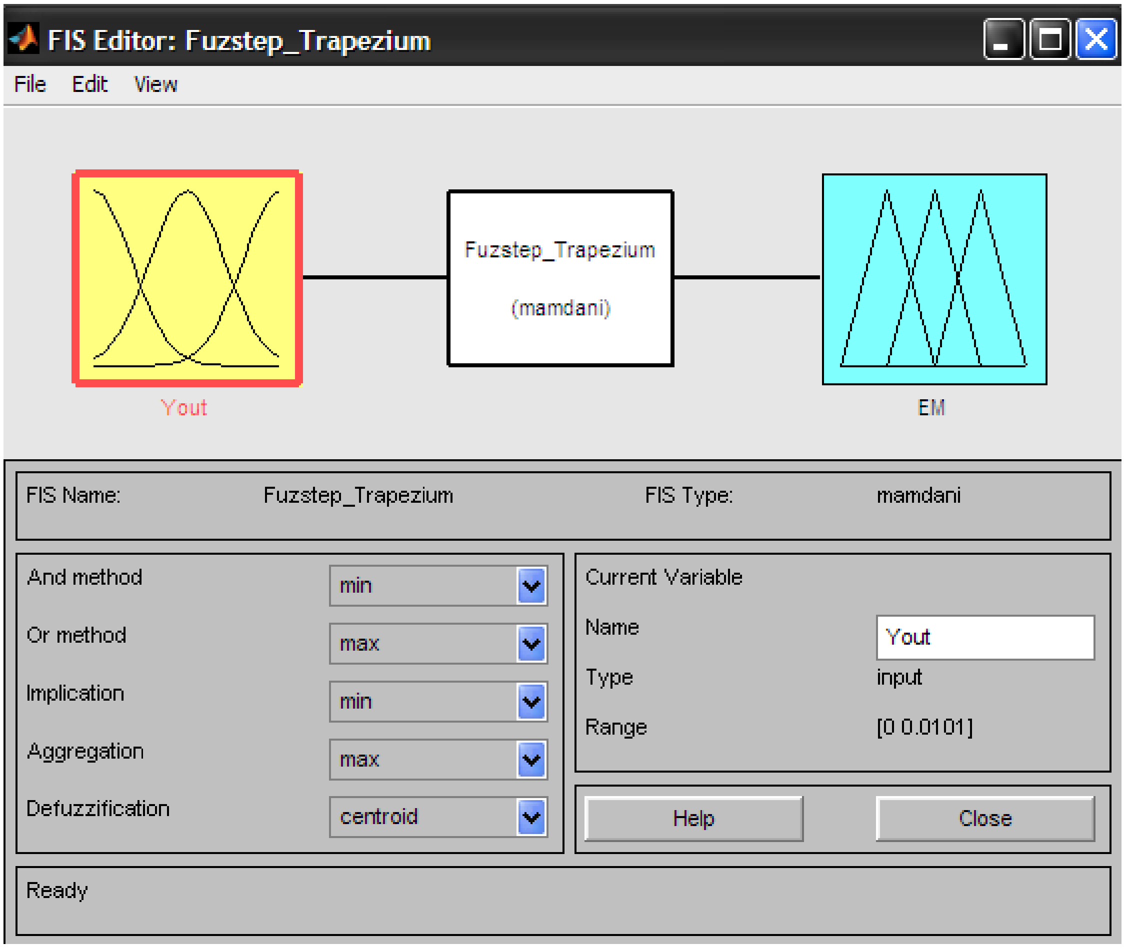


Figure 2.3: Block diagram of AFC scheme [18]

2.5.2 FL controller

There is an intelligent methods to generate the parameter for the AFC controller such as using the Fuzzy Logic (FL) controller. FL was first introduced by Professor Lotfi Zadeh from University of California in 1965. FL works by executing rules that correlate the controller inputs and the desired output. A system which makes use of FL and the corresponding mathematical frame work is called a fuzzy system. Three basic steps involved in fuzzy logic controller; the fuzzification of the controller inputs, the execution of the rules of the controller and the defuzzification of the output to a scrip value that been implemented by the controller. Figure 2.4 shows one of the example of FL tuning diagram using trapezium tuning method [18].



FIS Name: Fuzstep_Trapezium
FIS Type: mamdani

And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid

Current Variable
Name: Yout
Type: input
Range: [0 0.0101]

Ready

Figure 2.4: Example of FL diagram [18]

2.6 Summary

From the literature, it can be summarized that:

- Section 2.2 (high vibration of power tool) summarized that the vibration that exceed the values of EAV and ELV can caused a serious health problems.
- Section 2.3 (HAVs) summarized that this is one of the health problems that commonly occur if the worker is exposure to the high vibration.
- Section 2.4 (model of AVC system) summarized that the usage of actuator can be implemented in AVC system to reduce the vibration in the system.
- Section 2.5 (controller studies) summarized that in this research, there are two controller that been discussed and analyzed such as AFCCA and AFCFL to reduce the vibration in the system.

CHAPTER 3

METHODOLOGY

3.1 Overview

The objective of the chapter is to give an information about the research methodology and procedures. This chapter aim on explanation of how the model of the system was done and the development of AVC model using PID, AFFCA and FL toolbox in MATLAB and Simulink software. In addition, each of analysis preparation is also been described.

In vibration field, a basic procedure to study the characteristic of the structure is called modal analysis. In the process of making the system model by simulation, several processes have been carried out during the research as shown in Figure 3.1. Figure 3.1 shows the overall flow chart of the methodology from the beginning until the end of the study.

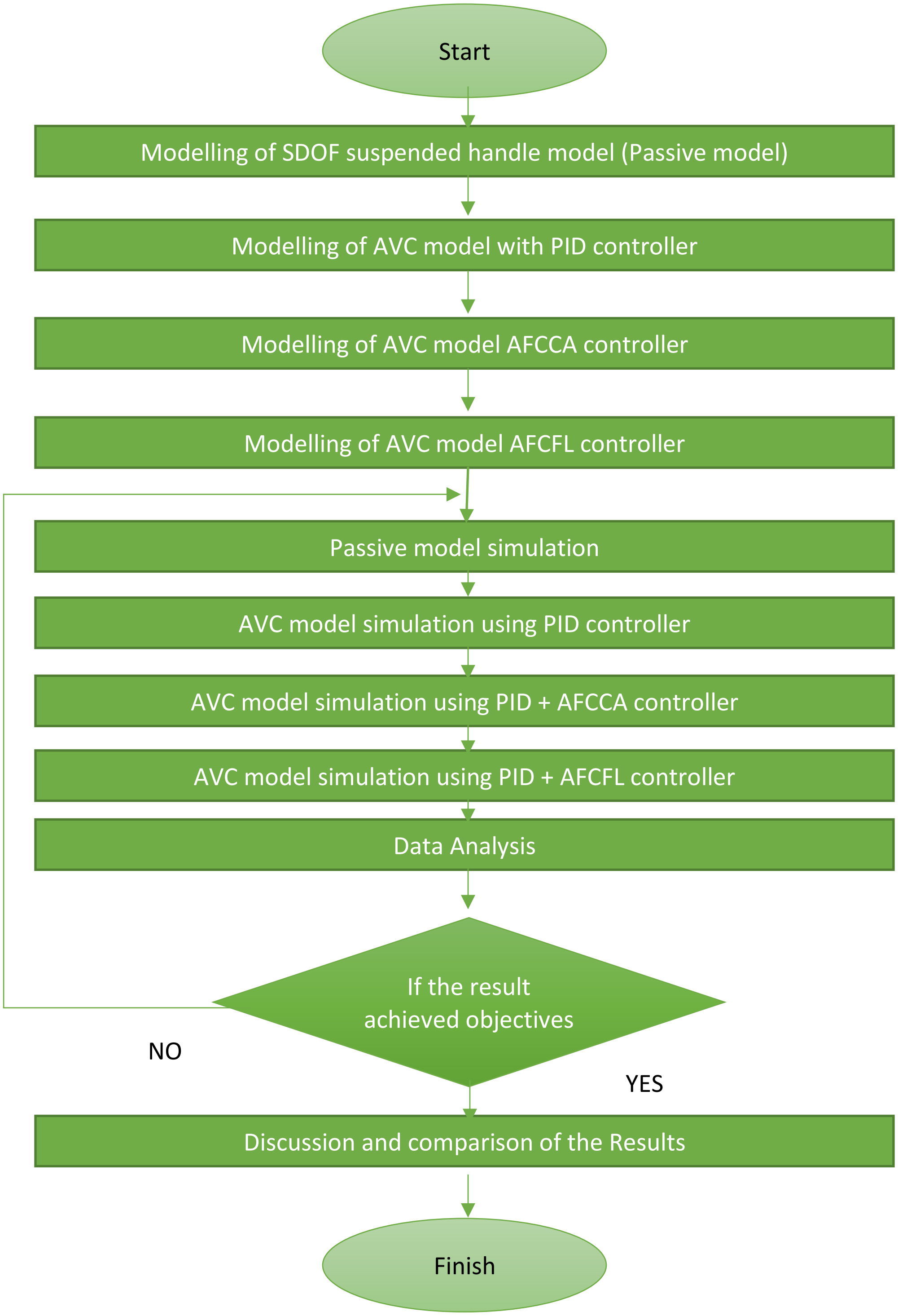


Figure 3.1: Flow chart of the methodology

3.2 SDOF suspended handle model

In this study, the suspended handle has been modelled as a mass-spring-damper system (*m*, *k*, *c*) with a single degree of freedom (SDOF) system. This model correlated with the previous study done by Mazlan and Ripin (2015).

The model consists of many important components which can be represented by the block diagrams in Simulink software. The block diagrams used are mainly to reduce vibration of the suspended handle. For the active system, the mathematical model is modelled by adding an actuator to the passive system which can provide an equivalent counter force, F_a to the disturbances, F by exciting the body based on the body response measured by sensor as shown in Figure 3.2 The actuator force is directly proportional to the signal given by the controller.

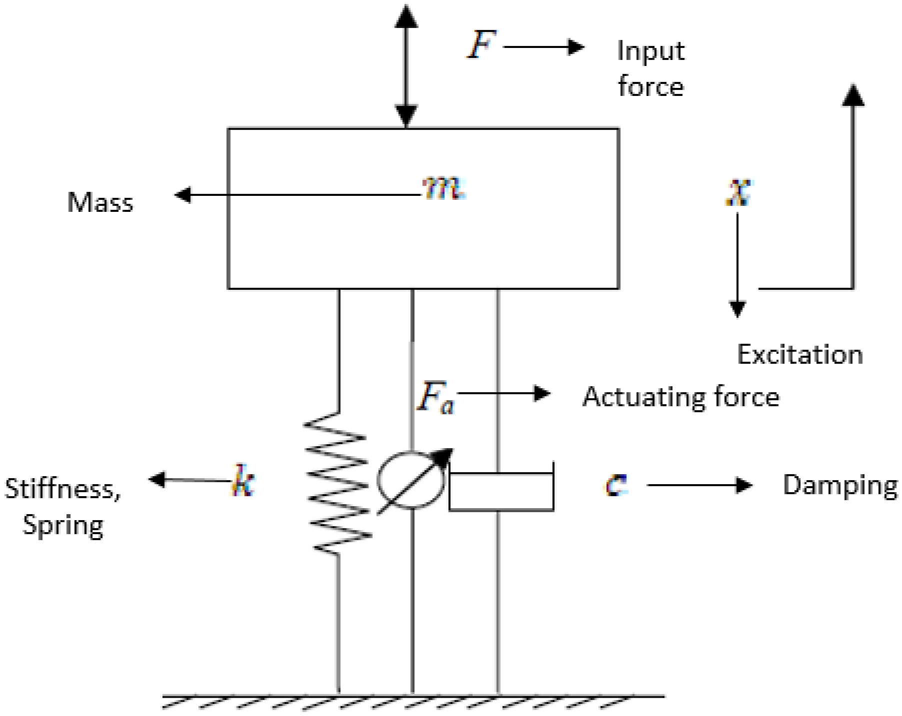


Figure 3.2: AVC model for the suspended handle

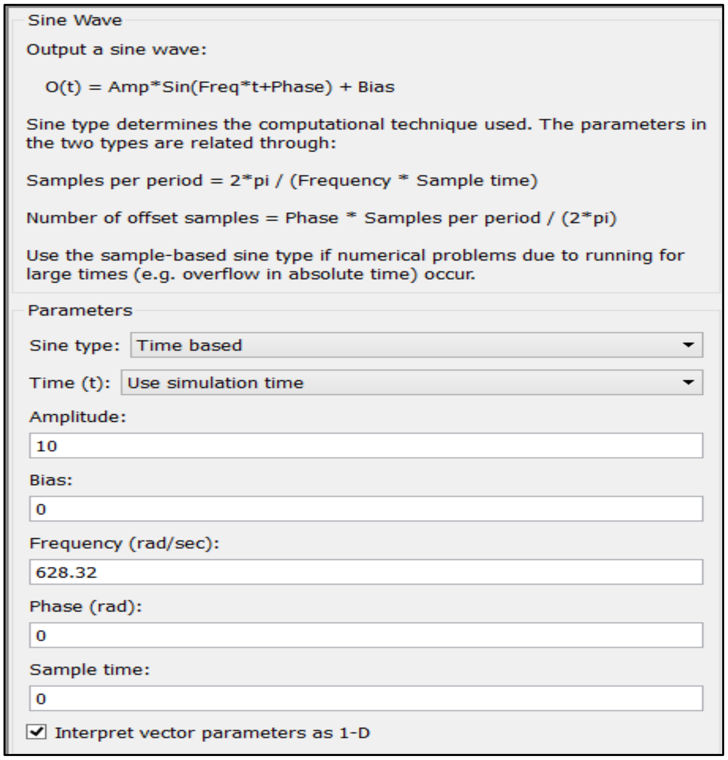
The equation of motion of the active suspended handle can be presented as follows:

$$m\ddot{x} + c\dot{x} + kx - Fa = F \qquad (3.1)$$

From equation (3.1), the actuator that been choose must be suitable for the AVC system. Usually, a piezo actuator can be used as an actuator due to its reliable and easy to handle but a little bit more sensitive. In this study, the actuator is assumed to be linear with a constant gain.

3.3 Disturbances model

In this study, only one type of vibration disturbance is introduced to the system. This disturbance is introduced to the system during the tuning process according to the control scheme parameter. In the process of modelling the suspended handle in Simulink software, sine wave is used as a disturbances to the system. The amplitude and frequency are set to be 10N and 628.32 rad/sec, 100 HZ respectively.



Sine Wave

Output a sine wave:

O(t) = Amp*Sin(Freq*t+Phase) + Bias

Sine type determines the computational technique used. The parameters in the two types are related through:

Samples per period = 2*pi / (Frequency * Sample time)

Number of offset samples = Phase * Samples per period / (2*pi)

Use the sample-based sine type if numerical problems due to running for large times (e.g. overflow in absolute time) occur.

Parameters

Sine type: Time based

Time (t): Use simulation time

Amplitude: 10

Bias: 0

Frequency (rad/sec): 628.32

Phase (rad): 0

Sample time: 0

☑ Interpret vector parameters as 1-D

Figure 3.3: Disturbance model (sine wave block parameter)

3.4 Passive system

In this study, the passive system has been modelled without any feedback mechanism that could provide the correction element. The system would experience a bad response and did not followed the reference input signal that being given to the system. Figure 3.4 shows the Simulink model of passive system. This Simulink diagram was constructed based on the equation of motion in Equation (3.1) without the presence of actuator.

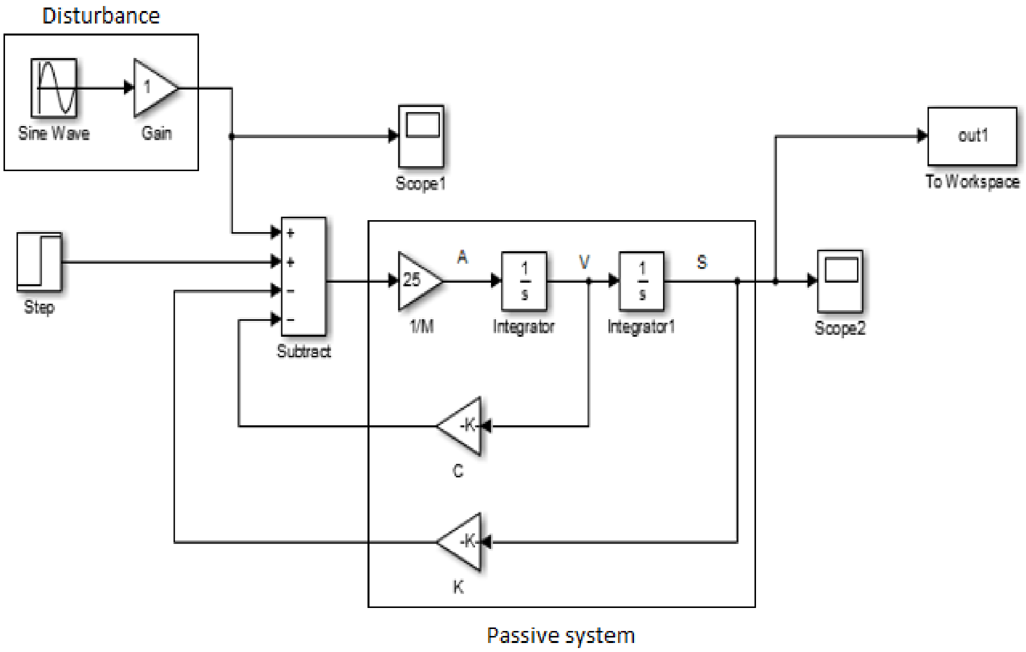


Figure 3.4: Simulink diagram of the passive system

3.5 Active system with PID controller

The disturbance that has been modelled before is included to the system with the presence of actuator to control the AVC system. There are a number of control schemes that can be used to attenuate the disturbances of the system to the desired value. For example, PID controller, AFC with Crude Approximation (AFFCA) and AFC with Fuzzy Logic (AFCFL). For the AVC system, a PID controller can be used as a basic control element to the system.

The equation for the PID controller can be presented as follows:

$$S_a = K_p e(t) + K_I \int e(t)dt + K_D de(t)/dt \tag{3.2}$$

Where:

K_p= Proportional gain

K_I= Integral gain

K_D= Derivative gain

Figure 3.5 shows the Simulink diagram for active system using a PID control scheme. This system is modelled based on equation (3.1) with the presence of actuator and PID controller. The difference between output displacement and desired output is called an error signal which can be tuned using the PID controller and will be amplified by the actuator gain to the system. In this case, the actuator gain is set as 1. The method that can be used for the PID parameters tuning is by manual tuning or using an auto tuning method tuned that been provided in the simulation software.

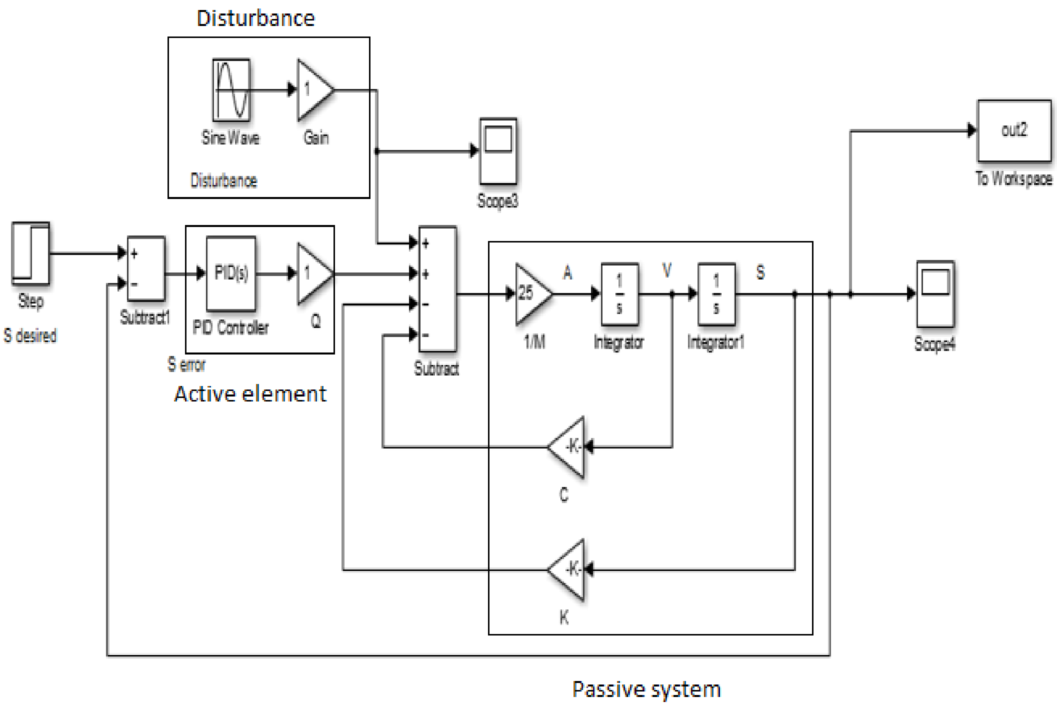


Figure 3.5: Simulink diagram for AVC system with PID controller

3.6 Active system with AFCCA controller

For the AVC system with AFC controller, the estimated disturbance force, F* is generated from the measurement of the actuator, Fa, mass acceleration, a and appropriate estimation of estimated mass, M* in equation (2.1) before.

In AFC system, the presence of PID controller is an advantage to the AVC system since there will be a two-ways counter signals for the system. Figure 3.6 shows the schematic diagram for the AVC system with AFCCA type of controller. In AFCCA system, the estimated mass (EM) is being tuned by manual tuning until the desired output is obtained.

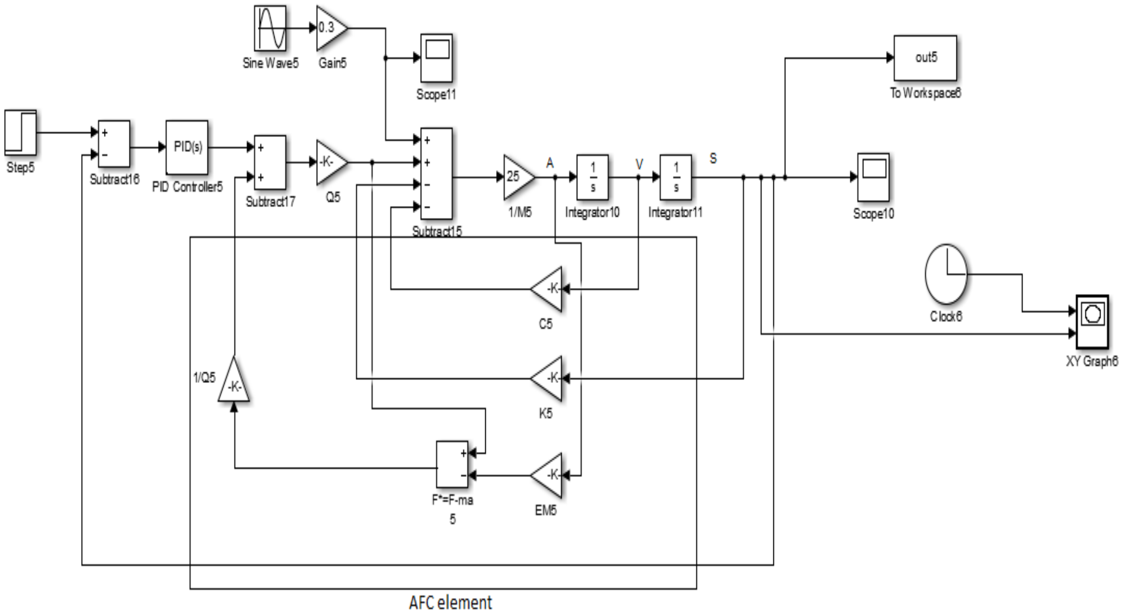


Figure 3.6: Schematic diagram for AVC system with AFCCA controller

3.7 Active system with AFCFL controller

In this section, the PID controller has been set as previous PID controller setup which tuned using an auto-tuning method to make sure that the tuning processes will be accurate with desired condition parameters. Next in order to make the system become AFCFL, the FL block has been added before the EM block. The FL can tune the EM parameter intelligently, so that the accurate value of estimated mass (EM) can be determine. Figure 3.7 shown the Simulink diagram for AVC system with AFCFL controller.

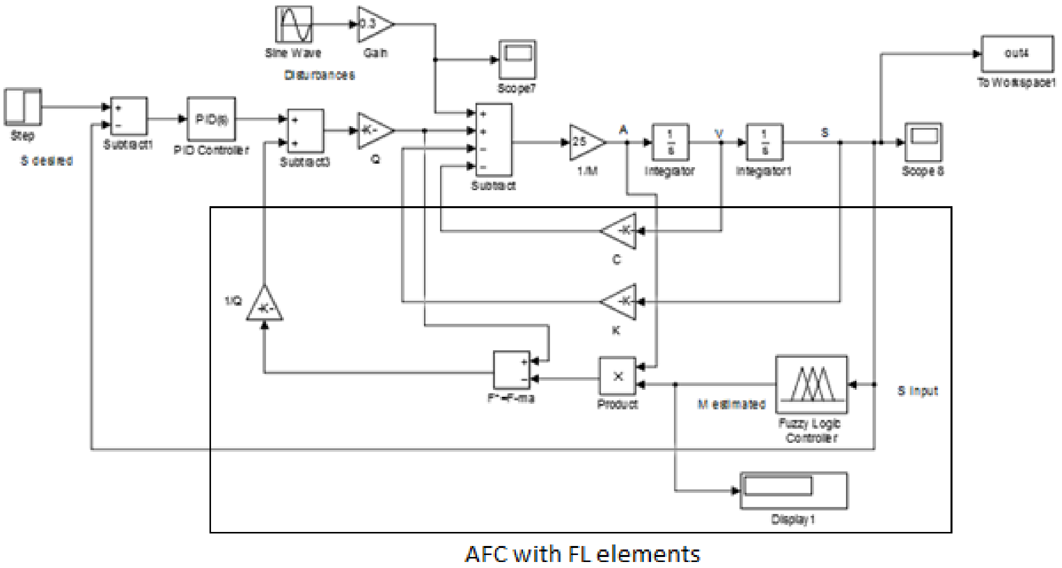
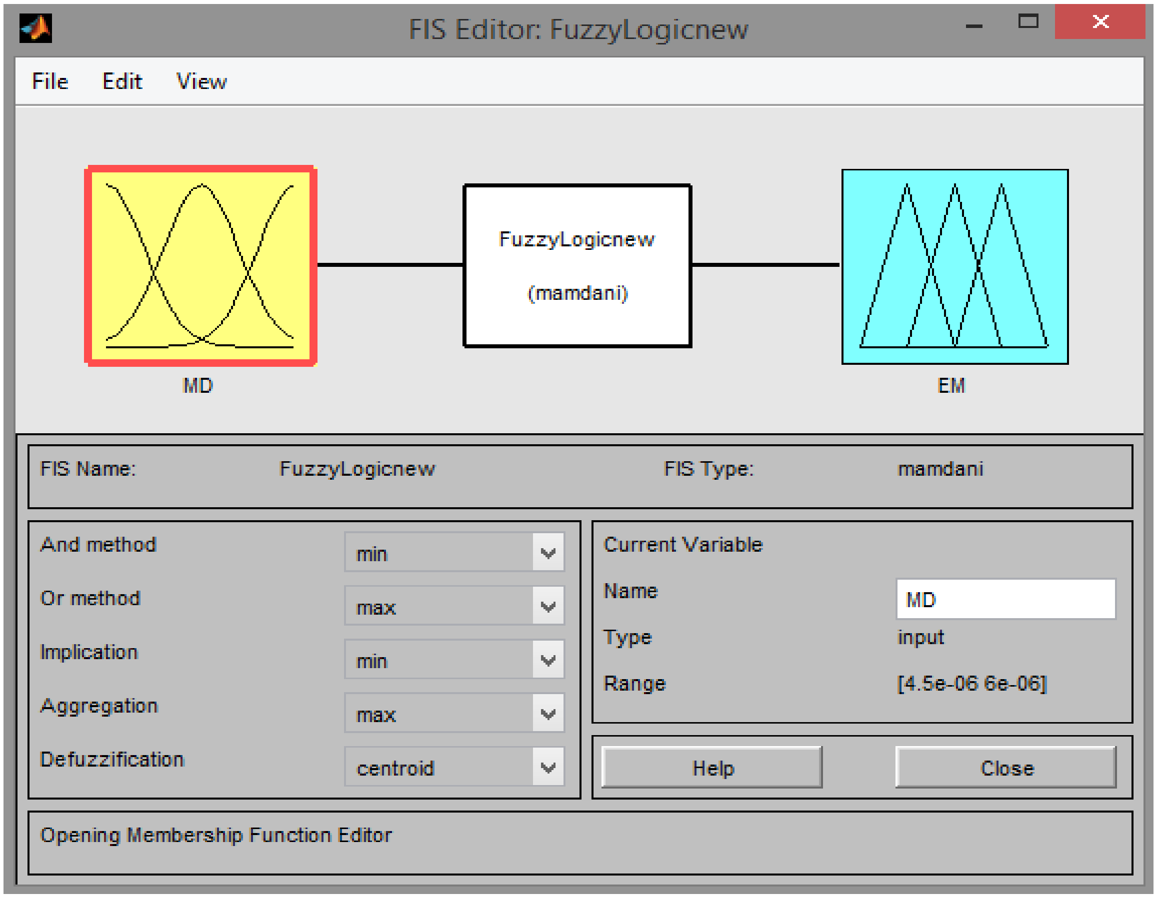


Figure 3.7: Simulink diagram for AVC system with AFCFL controller

3.7.1 Parameters setting of AFCFL controller

In order to start creating the FL controller, the FL toolbox is needed to be called out at the Simulink command window. The FL toolbox has one input in the system which is a mass displacement (MD) and also has one output which represented EM. Next, the method to be used in FL toolbox has to be determine such as mamdani method. There are three main steps that been used in FL such as fuzzification of system, execute the rules to the system and defuzzification of the system. Defuzzification that will be used for this study is at the centroid. In FL, there are many membership function that can be used. In this study, three of membership functions are used such as triangular shaped, trapezoidal shaped and generalized bell-shaped.

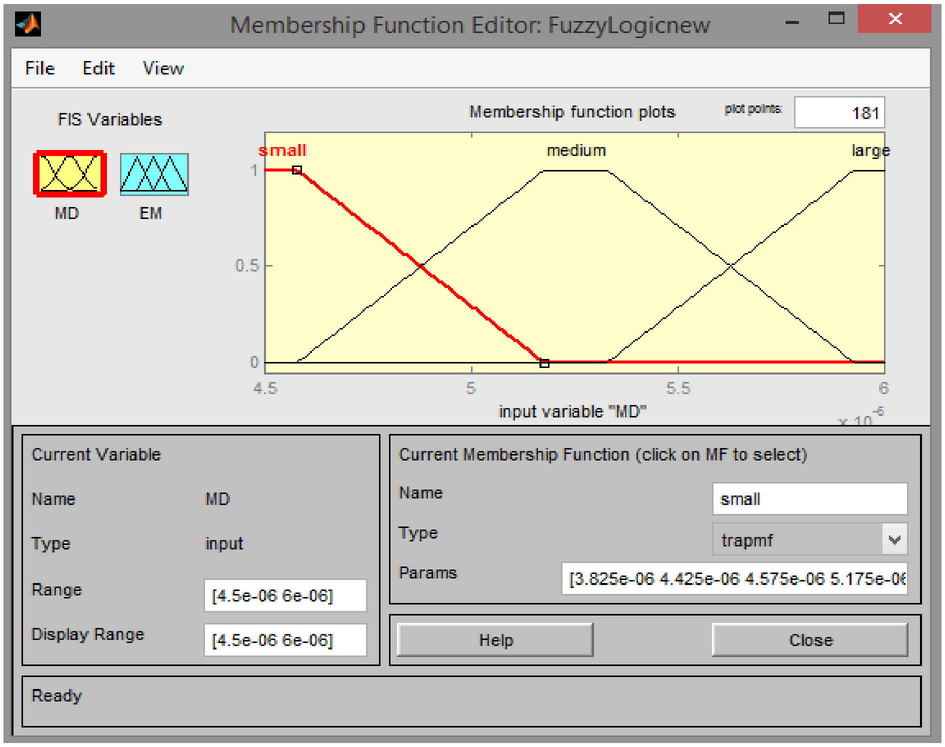


FIS Name: FuzzyLogicnew
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: MD
Type: input
Range: [4.5e-06 6e-06]
Opening Membership Function Editor

Figure 3.8: Fuzzy Logic Toolbox Command Window with one input and output

Figure 3.8 shows the fuzzy logic command window with one input and output. From Figure 3.8, the "And method" was set at min, "Or method" was set at max, "Implication" was set to min, "Aggregation" was set at max and "defuzzification" was set to be centroid as mention earlier. All of these parameters were set based on default setting.

One input has been implemented in the FL toolbox which has three membership functions with linguistic variable names such as small, medium and large. In addition, the output also has the same membership functions as the FL input. Figure 3.9 and 3.10 shows the input and output toolbox for the trapezoidal shaped respectively. The range for the input has been set between 4.5×10^{-6} to 6×10^{-6} m based on the result of mass displacement from the AFCCA controller. Meanwhile, the range for the output has been set between 0 to 0.08 kg. This value are based on the EM determine from the AFCCA controller.



plot points 181

Name MD

Type input

Range [4.5e-06 6e-06]

Display Range [4.5e-06 6e-06]

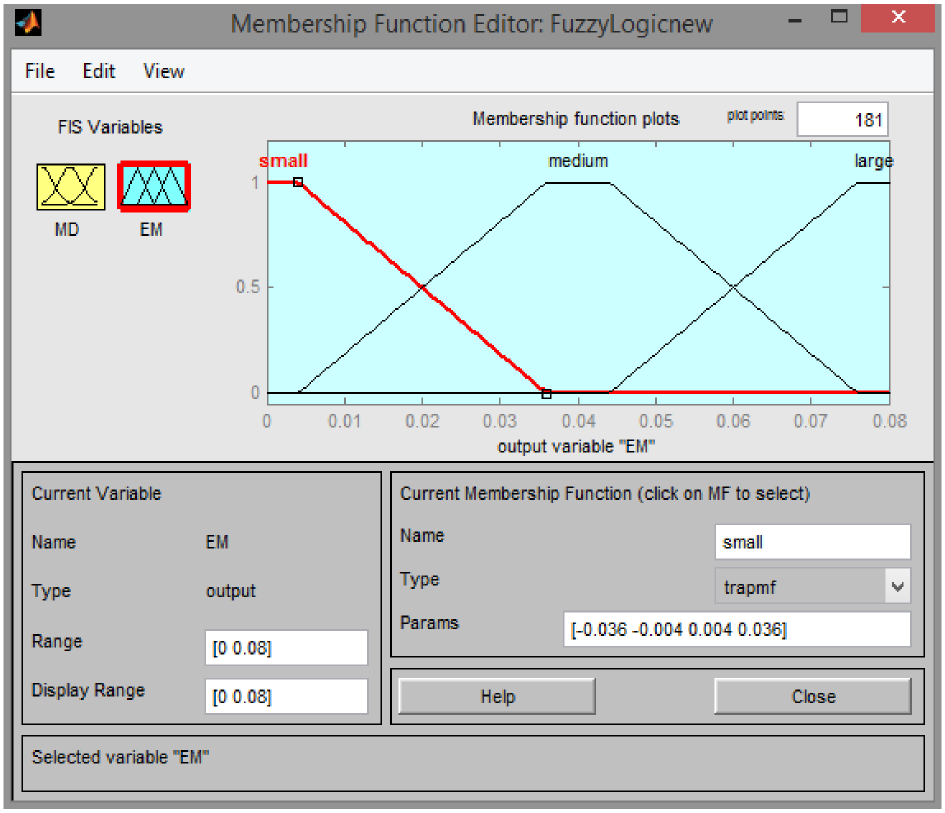
Name small

Type trapmf

Params [3.825e-06 4.425e-06 4.575e-06 5.175e-06

Ready

Figure 3.9: Fuzzy Logic Toolbox Command Window of input in trapezoidal shaped



plot points 181

Name EM

Type output

Range [0 0.08]

Display Range [0 0.08]

Name small

Type trapmf

Params [-0.036 -0.004 0.004 0.036]

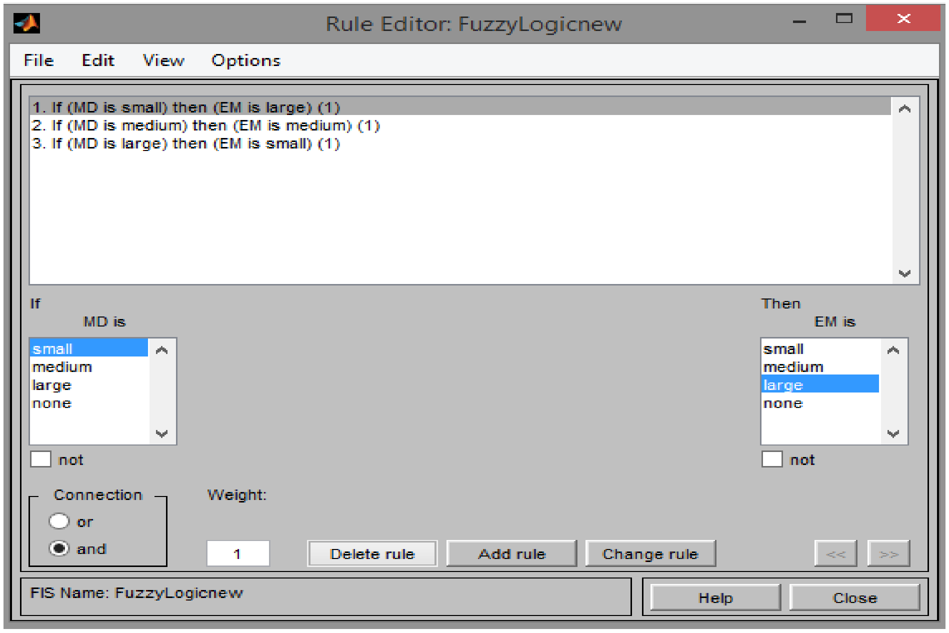
Selected variable "EM"

Figure 3.10: Fuzzy Logic Toolbox Command Window of output in trapezoidal shaped

In order to determine the optimize result for the system, three possible rules for the AVC system are summarized as in Figure 3.11 and it can be plotted through the surface viewer as in Figure 3.12[18].

Below are the rules that have been set for the AFCFL controller:

1) If MD is small then EM is large
2) If MD is medium then EM is medium
3) If MD is large then EM is small

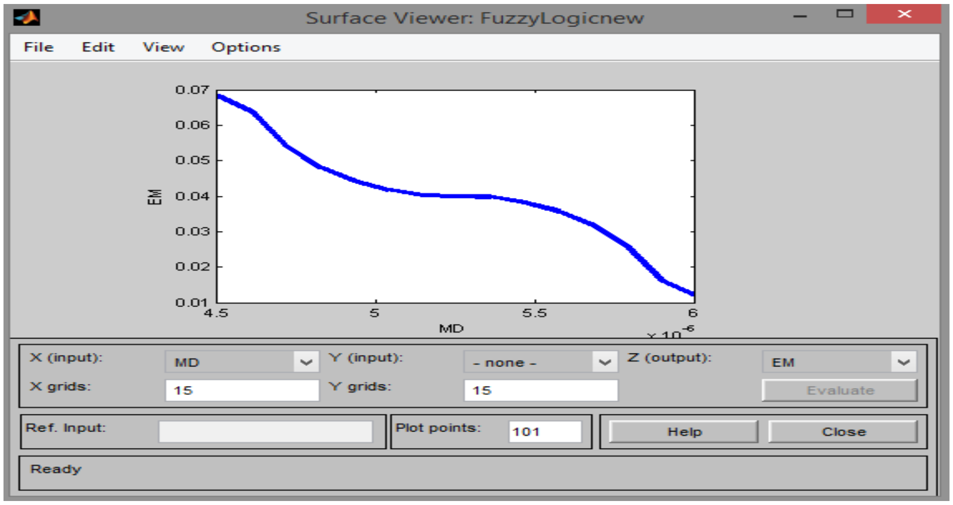


1. If (MD is small) then (EM is large) (1)
2. If (MD is medium) then (EM is medium) (1)
3. If (MD is large) then (EM is small) (1)

MD is: small
☐ not
EM is: large
☐ not
Connection: ○ or ● and
Weight: 1

FIS Name: FuzzyLogicnew

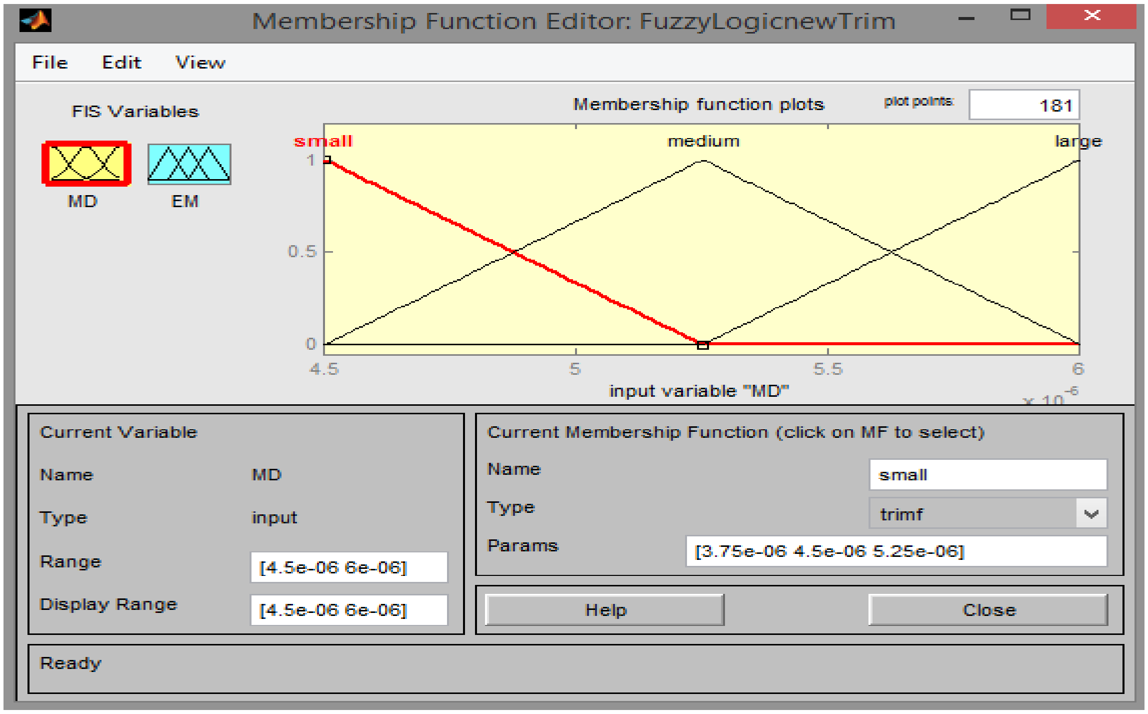
Figure 3.11: Execution of rules in FL rules toolbox



X (input): MD
Y (input): - none -
Z (output): EM
X grids: 15
Y grids: 15
Ref. Input:
Plot points: 101
Ready

Figure 3.12: Surface viewer in FL toolbox

Figures 3.13 to 3.16 show the membership functions of triangular-shaped and generalized bell-shaped, respectively.



Current Variable

Name MD

Type input

Range [4.5e-06 6e-06]

Display Range [4.5e-06 6e-06]

Current Membership Function (click on MF to select)

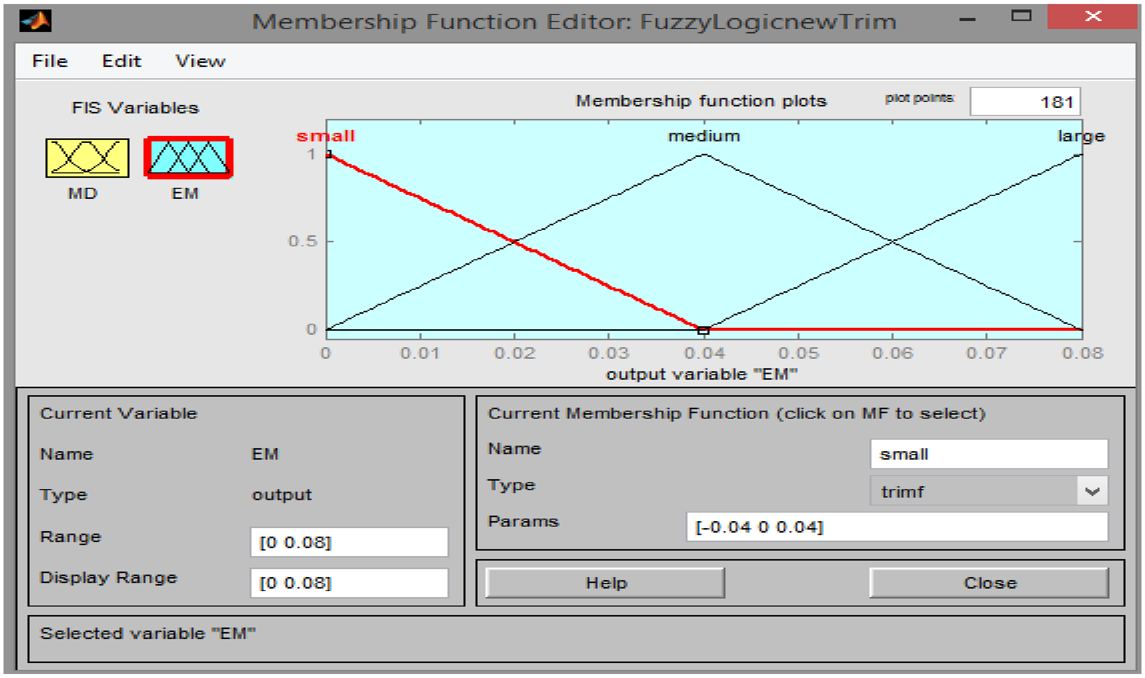
Name small

Type trimf

Params [3.75e-06 4.5e-06 5.25e-06]

Ready

Figure 3.13: Fuzzy Logic Toolbox Command Window of input in triangular shaped



Current Variable

Name EM

Type output

Range [0 0.08]

Display Range [0 0.08]

Current Membership Function (click on MF to select)

Name small

Type trimf

Params [-0.04 0 0.04]

Selected variable "EM"

Figure 3.14: Fuzzy Logic Toolbox Command Window of output in triangular shaped