UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS ◆

JUDUL: MODELING MAGNETO-RHEOLOGICAL DAMPER USING NEURAL NETWORK AND SIMULATED ANNEALING

SESI PENGAJIAN: 2012/2013

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MODELING MAGNETO-RHEOLOGICAL DAMPER USING NEURAL NETWORK AND SIMULATED ANNEALING

MOHAMAD LUQMAN ZAKI BIN MONSARIF

This thesis is submitted in partial fulfilment of the requirements
for the award of Bachelor of Mechanical Engineering

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JUNE 2013

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

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I hereby declare that the work in this report is my own except quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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DEDICATION

I specially dedicate to my beloved parents,
Hj Monsarif B. Hj. Kahar and Hjh. Siti Mariam Binti Hj. Othman
and those who have guided
and motivated me for this project
especially Siti Nur Atikah Bt. Abdullah

ACKNOWLEDGEMENT

First and foremost, the deepest sense of gratitude to the God, who guide and gave me the strength and ability to complete this final year project successfully. Infinite thanks I brace upon Him. I would like to give a lot of thank to my supervisor, Dr Gigih Priyandoko. He helps and supports me through the whole two semesters. He always encourages and guides me in order to finish my report. His practice of professional really helps me in order to work by myself mostly. I also would like to take those opportunities to say special thanks to both my parents. They really help me a lot in term of money, time and support. Other than that, a million thanks to my second reviewer who reviewed my thesis. Also a lot of thanks to all the panels during the presentation day. They give me idea to complete my report successfully. Also to all my friends who really helps in term of giving idea and always shared knowledge that lead to complete this thesis. Finally, to all individual either directly or indirectly helps me to complete this thesis. I think that I will never make it to finish in time without all their help. Thank you.

.

ABSTRACT

This thesis is study about modeling the Magneto-rheological damper using Neural Network and Simulated Annealing method. Five different values of current were used in order to modeling the MR damper, which are 0.0 ampere, 0.5 ampere, 1.0 ampere, 1.5 ampere and 2.0 ampere. In order to modeling the MR damper, the graph of simulation damper will be compared with the experimental damper. The results will get the Square Error for the simulation damper. Then, the Root Mean Square Error will be calculated to get the difference between the simulation damper and experimental damper. The results show that the lowest RMSE for the simulation damper were value 1.282457, while the highest RMSE is 13.18909. From the results also, the better current value to modeling the MR damper is using the MR damper with the lowest RMSE.

ABSTRAK

Tesis ini merupakan kajian tentang pemodelan peredam Magneto-rheological menggunakan kaedah Rangkaian Neural dan Penyepuhlindapan simulasi. Lima nilai-nilai arus yang berbeza telah digunakan untuk memodelkan peredam MR, yang 0,0 ampere, 0,5 ampere, 1.0 ampere, 1,5 ampere dan 2.0 ampere. Dalam untuk memodelkan peredam MR, graf peredam simulasi akan dibandingkan dengan peredam eksperimen. Keputusan akan mendapat Ralat Square untuk peredam simulasi. Kemudian, Akar Min Ralat Square akan dikira untuk mendapatkan perbezaan di antara peredam simulasi dan peredam eksperimen. Keputusan menunjukkan bahawa RMSE terendah untuk peredam simulasi ialah nilai 1.282457, manakala RMSE tertinggi adalah 13.18909. Daripada keputusan yang diperolehi juga, nilai yang lebih baik semasa memodelkan peredam MR ialah dengan menggunakan peredam MR dengan RMSE yang paling rendah.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Magneto-rheological (MR) fluid is composed of oil and varying percentages of iron particles that have been coated with an anti-coagulant material. When inactivated, MR fluid behaves as ordinary oil. When exposed to a magnetic field, micron-size iron particles that are dispersed throughout the fluid align themselves along magnetic flux lines. This reordering of iron particles can be visualized as a large number of microscopic spherical beads that are threaded onto a very thin string. One can picture this thin string stretching from one magnetic pole to the other and perpendicular to each paramagnetic pole surface. (Mehdi.A et al. 2002).

In this analogy, the spherical beads represent iron particles and the string represents a single flux line. One can picture many of these strings of beads placed closely together much like the bristles of a toothbrush. Once aligned in this fashion, the iron particles resist being moved out of their respective flux lines and act as a barrier to fluid flow. (James. P, 2001).

MR fluid can be used in three different ways, all of which can be applied to MR damper design depending on the damper's intended use. These modes of operation are referred to as squeeze mode, valve mode, and shear mode. A device that uses squeeze mode has a thin film (on the order of 0.020 in.) of MR fluid that is sandwiched between paramagnetic pole surfaces as shown in Figure 1.1(James. P ,2001).

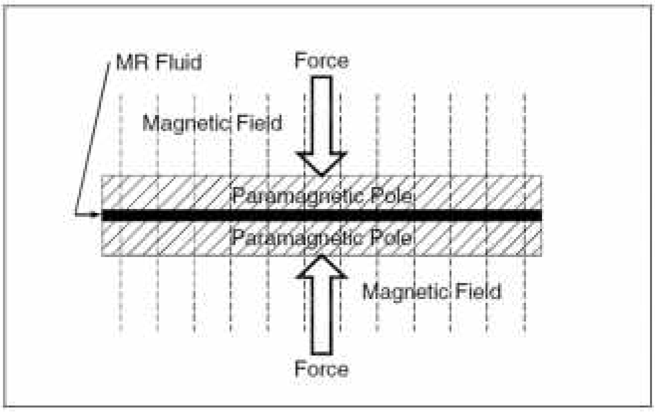

Figure 1.1: MR damper used in squeeze mode.[James. P ,2001]

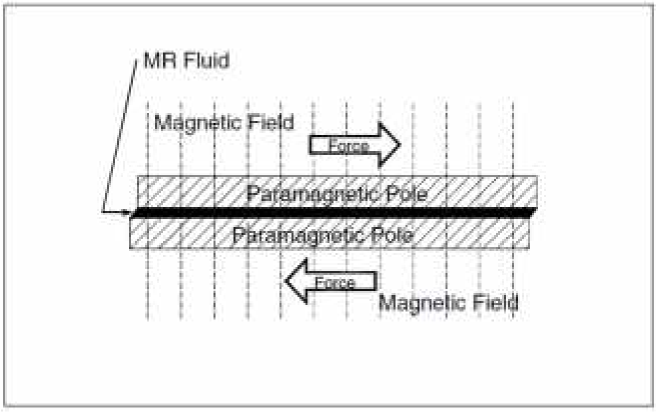

Figure 1.2 : MR fluid used in shear mode. [James. P ,2001]

An MR fluid device is said to operate in shear mode when a thin layer (≈ 0.005 to 0.015 in.) of MR fluid is sandwiched between two paramagnetic moving surfaces. Shear mode (see Figure 1.2) is useful primarily for dampers that are not required to produce large forces and for clutches and brakes. The last mode of MR damper operation, valve mode (see Figure 1.3), is the most widely used of the three modes. (James. P ,2001).

An MR device is said to operate in valve mode when the MR fluid is used to impede the flow of MR fluid from one reservoir to another. With the exception of a single hybrid MR damper design, all of the dampers that this project has been involved with operate in the valve mode. (James. P ,2001).

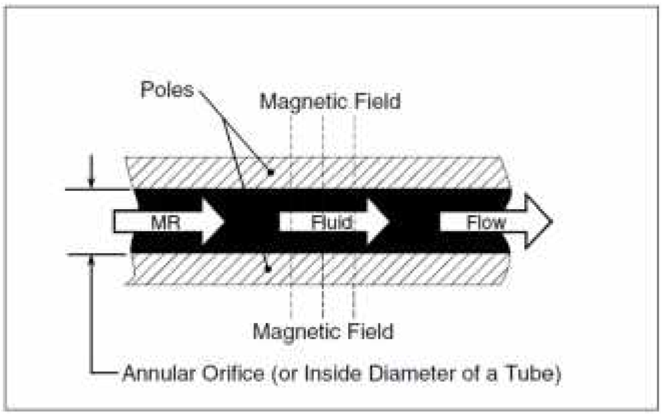

Figure 1.3: MR fluid used in valve mode. [James. P ,2001]

When MR fluid is used in the valve mode, the areas where the MR fluid is exposed to magnetic flux lines are usually referred to as “choking points” (see Figure 1.4). In the case of the damper depicted in Figure 4, MR fluid restricts the flow of fluid from one side of the piston to the other when the fluid is in the vicinity of the “choking points” shown. Varying the magnetic field strength has the effect of changing the apparent viscosity of the MR fluid. (James. P ,2001).

The phrase “apparent viscosity” is used since the carrier fluid exhibits no change in viscosity as the magnetic field strength is varied. Upon exposure to a magnetic field, the MR fluid as (a whole) will appear to have undergone a change in viscosity. As the magnetic field strength increases, the resistance to fluid flow at the choking points increases until the saturation point has been reached. The saturation point is the point where any increase in magnetic field strength fails to yield an increase in damper resistance. This resistance to movement that the iron particles exhibit is what allows us to use MR fluid in electrically controlled viscous dampers. (James. P ,2001).

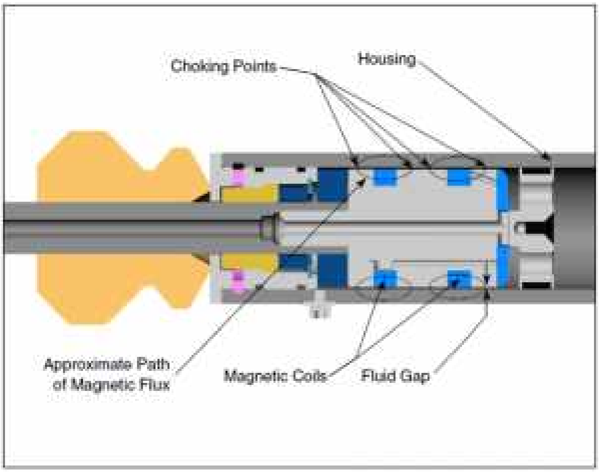

Figure 1.4: Typical MR damper. [James. P ,2001]

1.2 PROBLEM STATEMENT

According to Spencer,Dyke, Sain and Carlson (1996), a presently accepted definitions, a semi-active control device is one that has properties that can be adjusted in real time but cannot input energy into the system being controlled. A good damper can adapt with any kind of driving situation in any road condition. Therefore, the MR damper is the best candidates. Before that, we should create a model of MR damper to analyze the requirement is needed.

1.3 OBJECTIVES

The objectives of the project are:

1) To create modeling of magneto-rheological (MR) damper using neural network and simulated annealing.
2) To gain the smallest error that is possible using the neural network and simulated annealing.

1.4 SCOPE OF STUDY

1) Creating a simulation for modeling MR damper using neural network and simulated annealing.
2) Comparing the simulation result with the actual result.

CHAPTER 2

LITERITURE REVIEW

2.1 INTRODUCTION

In order to conduct a research, it is important to review on the aspects that related with topic. Therefore under this chapter, the theoretical about magneto-rheological fluid and magneto-rheological damper will be discussed here. Also, some previous studies including magneto-rheological also will be discuss. This is important in order to get further understanding towards the title.

2.2 MAGNETO-RHEOLOGICAL FLUID.

The magneto-rheological fluid (MRF) is a kind of traditional working medium applied to these devices, because its viscosity can change from liquid to semisolid or solid state within milliseconds under the electromagnetic field. The working model combine the mechanical structure and the electromagnetic field to improve the performance and describe the relationship among the damping force, velocity and the displacement of the devices, which have always been the main issues. An overview on the phenomenological models, which only represented two working models, valve model and parallel-plate model (Hongzhan LV et al. 2011).

2.2.1 Magneto-rheological fluid Properties.

A magneto-rheological fluid has its ability to switch back and forth from a liquid to a near-solid under the influence of a magnetic field. The term magneto-rheological comes from a combination of magneto (magnetic) and rheo, the prefix for the study of deformation of matter under applied stress.

A magneto-rheological fluid is a type of smart fluid in a carrier fluid, usually a type of oil. When subjected to a magnetic field, the fluid greatly increase its apparent viscosity, to the point of becoming a viscoelastic solid. The yield stress of the fluid when in its active state can be controlled very accurately by varying the magnetic field intensity.

According to Olabi. and Grunwald.(2006), magneto-rheological fluid (MRF) technology is an old newcomers coming to the market at high speed. Additionally, for products where is a need to control fluid motion by varying the viscosity, a structure based on MRF might be an improvement in functionality and costs. The operational modes of MR fluid can be classified into valve mode (flow mode), shear mode and squeeze film mode. This mode can be realized by applying a magnetic field at the flow passage of linear or rotary damper.

According to Kim and Park (1998), magnetic field at the passage was applied and the pressure difference between passages if effectively large, the damper can dissipate large amounts of energy. So, the valve mode damper was connected with two ports of pneumatic rotary actuator and applying magnetic field by moving a magnetic circuit.

Hitchcock. et al. (2005) stated that MR fluids generate a controllable damping force when its change it fluid appearance viscosity. This MR effect creates a dynamic performances characteristic that provides semi-active damping control where the change in damper force is entirely controlled by an input electrical current via a closed loop control system. A beneficial design features possible to MRF dampers is a fail-safe mode of operation. For a fail-safe MRF damper, any electrical system failure will result in a minimum required base viscous (passive) damper force characteristics.

Bosis, (2002), a typical MR fluids consist used by Rabinow consists of 9 parts by weight of carbonyl iron to one part of silicone oil, petroleum oil or kerosene. To this suspension, he would optionally add grease or other thixotropic additive to improve settling stability. In all of these devices one of the most important fluid properties is a low- off state viscosity. While in all of these examples having a MR fluid with high yield strength in the on-state is important, it is equally important that the fluid also have very low off-state. The very ability of an MR fluid to be effective at enabling a semi-active control strategy such as sky hook damping depends on being able to achieve a sufficiently low state.

Care must be taken in choosing fluid stabilizing additives to that they do not adversely affect off-state viscosity. Bosis (2002), the scale of fluid production necessary for even a modest automotive application is large. A single MR fluid device such as a damper on a single automotive platform model can easily require a total fluid volume production.

2.2.2 Magneto-Rheological Modes and Application

For every different fluid flow, the rheological stress is three different modes. They are;

a) Shear mode.
b) Valve mode.
c) Squeeze mode.

2.2.2.1 Shear mode.

The direct shear mode is used in brakes and clutches. The total force in the shear mode can be separated into a viscous (pure rheological) component F_r and a magnetic field dependent (magneto-rheological) component F_{mr}. Figure 2.1 shows the shear mode.

The simplicity and easy control makes it a cost effective choice for controllable exercise equipment. An MR fluid brake is currently being manufactured and sold as a controllable resistance element for programmable aerobic exercise equipment. (Olabi A.G et al 2007)

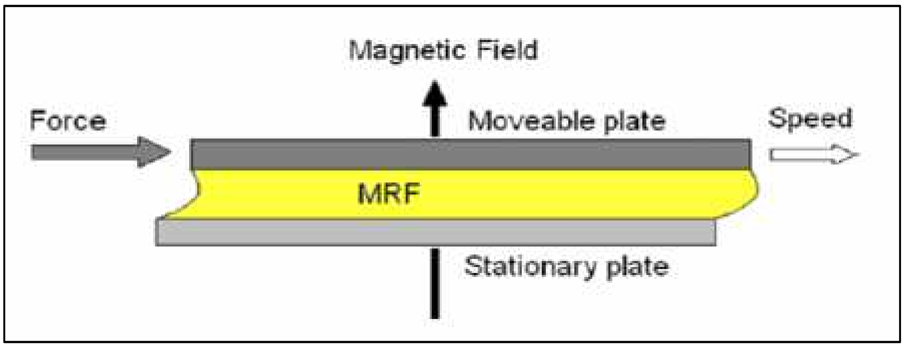

Figure 2.1: Shear mode. [Olabi A. G and Grunwald, 2007]

2.2.2.2 Valve mode.

The valve mode as an operational mode is used in dampers and shock absorbers. It is necessary to explain the difference between the observed pressure drop DP and the pressure drop calculated from rheological principles alone DP_r. This is the pressure drop due to magneto-rheological principles DP_{mr}. (Olabi A.G et al 2007).

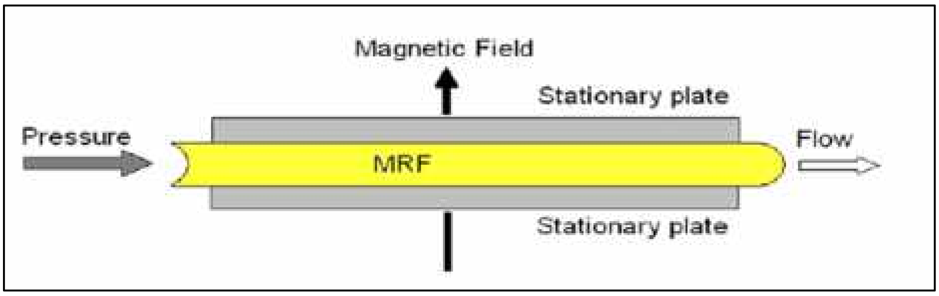

Figure 2.2: Valve mode. [Olabi A. G and Grunwald, 2007]

Figure 2.2 shows the valve mode for MR damper. It is clearly dependent on the yield stress developed in response to the applied magnetic field and to the above geometrical data, but there are also other factors which have an effect on this pressure drop, and the influence of these other factors are represented by the empirical factor f. The factor is found experimentally to be dependent on the proportion of the purely rheological pressure drop to the total observed pressure drop. (Olabi A.G et al 2007).

2.2.2.3 Squeeze mode.

This third mode, called the squeeze mode, has not been studied so thoroughly comparing with the direct-shear mode and the valve mode. Some small-amplitude vibration dampers use this mode. For small motions, this mode seems to offer the possibility of very large forces which can be controlled by the MRF effect. In one of the most recent theoretical evaluations of the squeeze-strengthen effect in magneto-rheological fluids the operation of this mode is described.

Figure 2.3 show the squeeze mode. It is suggested that a yield stress could be achieved which would be ten times as large as that which is possible with either the direct-shear or the valve mode. The higher yield stress under magnetic field means a higher ratio between on- and off-states. A stronger MRF effect in combination with advantages already described above would make MRF technology even more attractive and the technology of choice for the next generation of many more automotive and industrial applications. (Olabi A.G et al 2007).

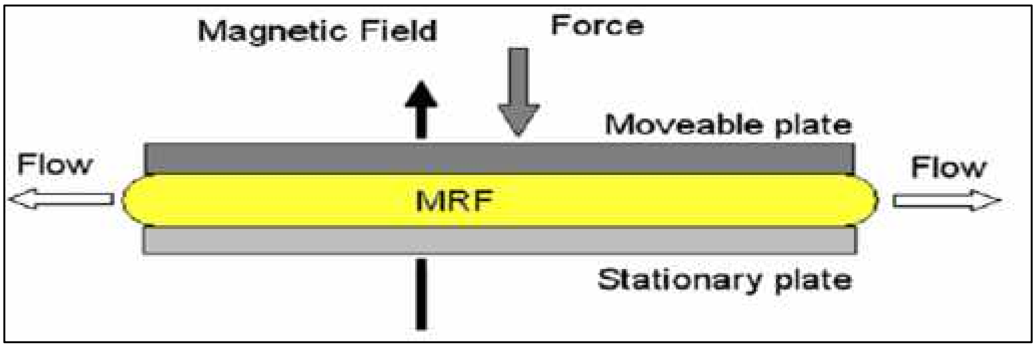

Figure 2.3: Squeeze mode. [Olabi A. G and Grunwald, 2007]

2.2.3 Components in Magneto-rheological fluid.

There are three basic components in magneto-rheological fluid. They are base fluid, metal particles and the additives.

Base fluid is actually acted as the carrier and naturally combines lubrication and damping features. If the MR fluid is applied without any magnetic effects (off state), they will behave like a base fluid. According to Olabi and Grunwald (2007), there are three different types of liquid that can be used as a base fluid and they are hydrocarbon oils, mineral oils or silicon oils. When the concentration of metal particles is very high, the base fluid will have a higher viscosity. This condition will make the fluid thicker. The fluid with the powder will have an increased velocity even though it was in the off-state.

Metals particles are said as the on-state. They usually look like a chain structure. Olabi and Grunwald (2007) said that this chain-like structure restricts the motion of the fluid and therefore changes the rheological behaviour of the fluid. Because of this resistance to flow caused by the chain-like structure, the Magneto-rheological effects was produced. The metal particles are usually made of carbonyl iron, or powder iron, or iron/cobalt alloys to achieve a high magnetic saturation. Larger torques in the on-state will be higher if only the particles is larger and the fractions of powder is higher but at the same time the viscosity of the MR fluid in the off-state will also be higher under these conditions.

The additives are actually the combination from stabilizers and surfactants. An additive is usually anti-corrosion. Olabi and Grunwald. (2007), highly viscous materials such as grease or other thixotropic additives are used to improve settling stability. Additives can act as the controller the viscosity of the liquid and the settling rate of the particles, the friction between the particles and to avoid the in-use thickening for a defined number of off-duty cycles.

2.3 MAGNETO-RHEOLOGICAL DAMPER APPLICATION.

Magneto-Rheological Fluid Damper has been used widely in a lot of different field. Kciuk. and Turcyn (2006), that during the past few years a number of commercially available products have been developed. They are;

a) Linear MR dampers for real-time active vibrational control system in heavy duty trucks.

b) Linear rotary brakes for low cost, accurate, positional and velocity control of pneumatic actuator systems.
c) Rotary brakes to provide tactile force-feedback in steer-by wire systems
d) Linear dampers for real-time gait control in advanced prosthetic devices.
e) Adjustable real-time controlled shock absorbers for automobiles.
f) MR sponge dampers for washing machines.
g) Magneto rheological fluid polishing tools
h) Very large MR fluid dampers for seismic damage mitigation in civil engineering structures.

2.3.1 Automotive and aerospace.

Automotive industry is the most common field that usually used Magneto-Rheological fluid in the car. Because of it cost which is quite highly in the market, therefore only a few of the car uses Magneto-Rheological fluid damper in their car. Most common car used is Audi R8, Chevrolet Corvette and Humvee.

If the shock absorbers of a vehicle's suspension are filled with MR fluid instead of plain oil and the whole device surrounded with an electromagnet, the viscosity of the fluid can be varied depending on driver preference or the weight being carried by the vehicle or it may be dynamically varied in order to provide stability control.

2.3.2 Building

A lot of civil engineering have try to do their best in order to find a new and very effective solution to face the especially the earthquake. Control systems to undergo the situation have unique requirements and constrain. Dyke et al. (1996) stated that during severe seismic events, the external power to a structure may be severed, rendering control schemes relying on large external power supplies in effective. Magneto-Rheological dampers are a new class of devices that mesh well with the requirements and constraints of seismic applications, including having very low power requirements.

2.3.3 Bridges

Usually, the longer the bridge is, the conditions can be even worst without some highly maintenance. According to Gordaninejad. et al 2000, stated that comparing to active and passive systems, semi active control can offer the combined advantages of both systems with its control flexibility and low energy requirement. Several semi active control strategies for MR fluid dampers have been applied to vibration control of civil structure.

2.3.4 Agriculture

Agriculture vehicle manufacturers are employing new semi-active cab suspensions using Magnetor-Rheological technology. The speed and simplicity of MR technology enables the use of low stiffness springs without the compromise between ride stability and can provide roll, isolation and pitch stability. Achen. et al. (2008) said that there are four types of tractor construction when it comes to suspension;

a) Unsuspended tractor.
b) Suspended cabin tractor.
c) Suspended front axle and suspended cabin tractor.
d) Fully suspended (front and rear axle) tractor.

2.3.5 Military

The U.S Army Research Office is currently funding research into using MR fluid to enhanced body armor. In 2003, researches stated that they were five to ten years away from making the fluid bullet resistant.(Tomizuka.M (2003).

2.4 MAGNETO-RHEOLOGICAL DAMPER

As a type of active or semi active controlling devices, the magneto-rheological dampers have become the research focus referring to these application fields such as aerospace, vehicles, biomedical instruments, structural damping and so on.

One of the more promising devices for vibration control applications is the magneto rheological damper. An MR damper, as shown in Figure 2.4, resembles an ordinary dashpot or linear viscous damper; however, it is filled with a special fluid and has one or more electromagnetic coils wrapped around the piston head. The proper magnitude of current supplied to the coils as mandated by a control algorithm produces an appropriate resisting force for the damper to mitigate vibration of the structure.

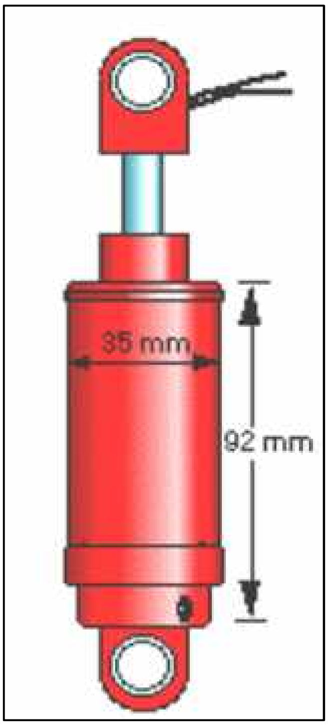

Figure 2.4: Magneto-rheological damper. [Schurter.K.C & Schurter. P. N.]

2.5 MAGNETO-RHEOLOGICAL DAMPER DESIGN

There is several type of damper that were used in industry or in automotive field. The damper consists of mono tube damper, twin tube damper and foot valve damper.

2.5.1 Mono tube and Twin Tube Magneto-Rheological Dampers

A mono tube MR damper (see Figure 2.5) is one that has only one reservoir for the MR fluid and also has some way to allow for the change in volume that results from piston rod movement. In order to accommodate this change in reservoir volume, an accumulator piston is usually used. The accumulator piston provides a barrier between the MR fluid and a compressed gas (usually nitrogen) that is used to accommodate the necessary volume changes. (James. P, 2001)

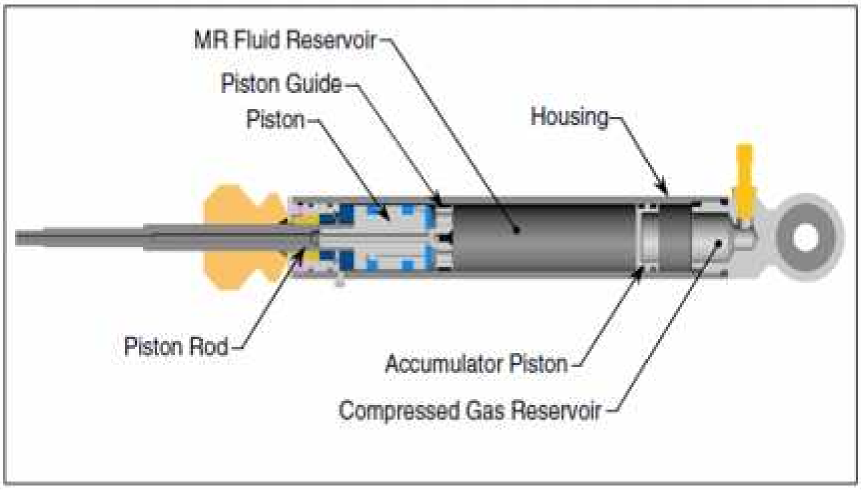

Figure 2.5: Mono tube MR damper section view.[James. P, 2001]

The twin tube MR damper is one that has two fluid reservoirs, one inside of the other. This configuration, which can be seen in Figure 2.6, has an inner and an outer housing. The inner housing guides the piston/piston rod assembly just as the housing of a mono tube damper does. This inner housing is filled with MR fluid so that no air pockets exist. To accommodate changes in volume due to piston rod movement, an outer housing that is partially filled with MR fluid occurs. (James. P, 2001).

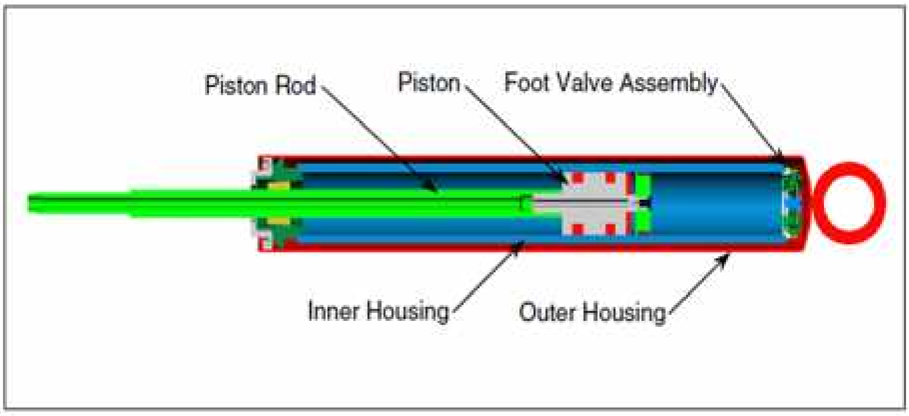

Figure 2.6: Twin tube MR damper. [James. P, 2001]

In practice, a valve assembly called a "foot valve" is attached to the bottom of the inner housing to regulate the flow of fluid between the two reservoirs (see Figure 2.7). As the piston rod enters the damper, MR fluid flows from the inner housing into the outer housing through the compression valve that is attached to the bottom of the inner housing.

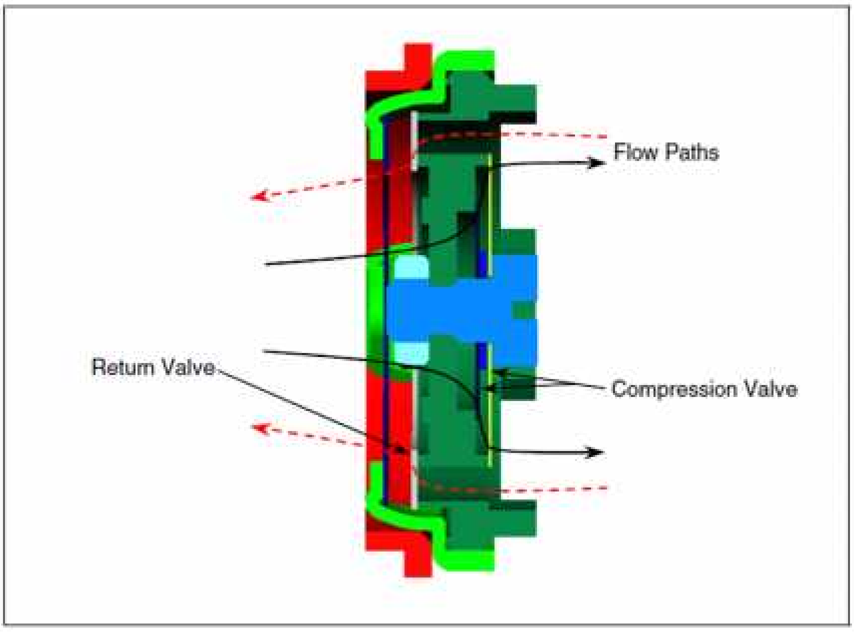

Figure 2.7: Foot valve. [James. P, 2001]

The amount of fluid that flows from the inner housing into the outer housing is equal to the volume displaced by the piston rod as it enters the inner housing. As the piston rod is withdrawn from the damper, MR fluid flows into the inner housing through the return valve. (James. P, 2001)

The damper should function properly as long as the following conditions are met: (James. P, 2001)

(1) The valving is set up properly;

(2) MR fluid settling is not a problem; and

(3) The damper is used in an upright position.

In order for a twin-tube MR damper to function properly, the compression valve must be stiff relative to the pressure differential that exists between either sides of the piston when it is in operation. The return valve must be very unrestrictive so that as little resistance to fluid flow as possible is provided.

With this type of MR damper, keeping the iron particles (which are an integral part of MR fluid) in suspension is a major concern since these iron particles can settle into the valve area and prevent the damper from operating properly. All MR dampers are affected by MR fluid settling, but this problem is particularly prevalent in the twin tube variety (James. P, 2001).

2.5.2 Bypass flow type

Sunakoda. K et al. (2000) stated that, bypass flow portion is a passage for MR fluids connecting two pressure chambers. The bypass flow is at the outside of the cylinder. In bypass type hydraulic dampers such as this, a cylinder is divided to two airtight pressure chambers by a piston with rubber O-rings. The MR fluid is flow from a high-pressure chamber to a low-pressure chamber through the bypass flow portion.

The bypass flow portion has an orifice and the MR fluid flow is narrowed rapidly at the orifice. Moreover, intense magnetic fields are applied to the MR fluid at the orifice by electromagnets. To simplify the analysis of the MR fluid in the magnetic field, a rectangular cross section is selected as the orifice shape. The electromagnet was form by copper wire wound around a C-shaped iron rod. The air gap between the ends of the C-shaped iron rod forms the rectangular cross section of the orifice. Thus, the length of the air gap of the electromagnet is equivalent to the thickness of the orifice that is penetrated by the magnetic flux. This method of magnetizing MR fluids has the advantages to the thickness that the MR fluid is rarely affected by the heat generated on the electromagnet. (Sunakoda. K et al. 2000).

2.6 MAGNETO-RHEOLOGICAL FLUID DAMPER ADVANTAGES

Kciuck . M and Turcyn . R (2006) concludes that MR technology has moved out of the laboratory and into viable commercial application for a diverse spectrum of products. This is because MR fluid damper offers;

a) Real-time, continuously variable control of:
   i. Damping.
   ii. Motion and position control.
   iii. Locking.
   iv. Haptic feedback.
b) High dissipative force independent of velocity.
c) Greater energy density.
d) Simple design (few or no moving parts).
e) Quick response time (10 milliseconds).
f) Consistent efficacy across extreme temperature variations (range of 140C to 130 C).
g) Minimal power usage (typically 12V, 1 Amp max current.
h) Fail-safe to battery backup, which can fail-safe to passive damping mode.
i) Inherent system stability (no active forces generated).
j) MR fluids can be operated directly from low-voltage power supplies.
k) MR technology can provide flexible, reliable control capabilities in designs.

2.7 HYBRID NEURAL NETWORK

The term “artificial neural networks” is a generic description for a wide class of connectionist representations inspired by the models for brain activity. The most common task of these models is to perform a mapping from an input space to an output space. A typical multilayered feed forward neural network is shown in Figure 2.8. It consists of massively interconnected simple processing elements (‘neurons” or “nodes”) arranged in a layered structure, where the strength of each connection is given by an assigned weight; these weights are the internal parameters of the network. (Dimitris C. et al. 1994)

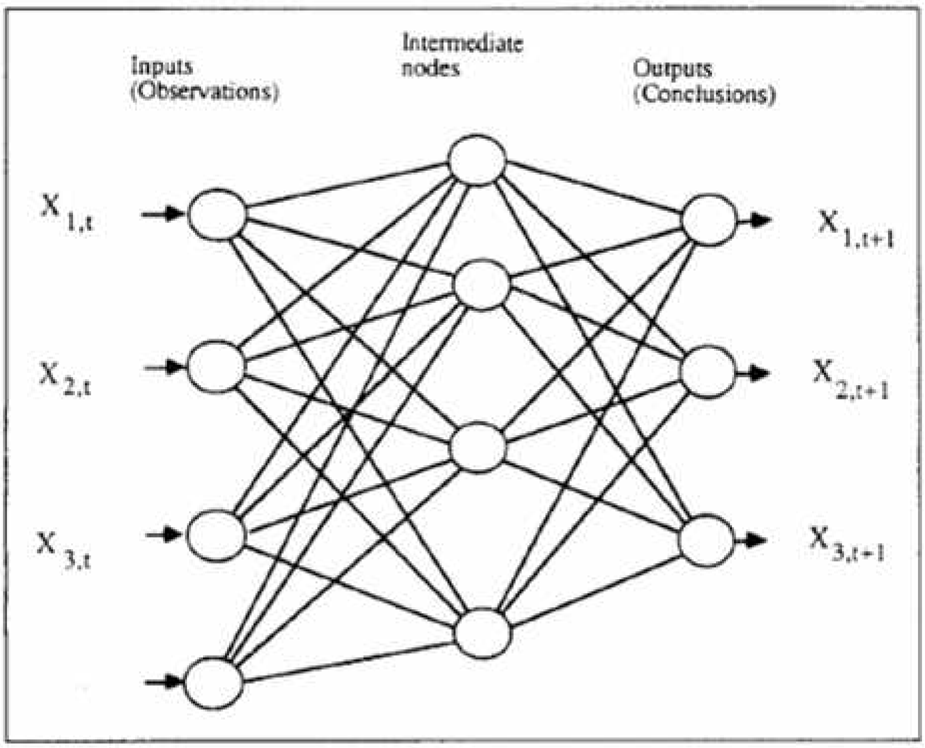

Figure 2.8: Multilayered feed forward neural network. [Dimitris C. et al. 1994]

The input neurons are connected to the output neurons through layers of hidden nodes. Each neuron receives information in the form of inputs from other neurons or the world and processes it through some-typically nonlinear-function (the "activation'' function); in this way the network can perform a nonlinear mapping. It has been shown that, under some mild assumptions, such networks, if sufficiently large, can approximate any nonlinear continuous function arbitrarily accurately (Dimitris C. et al. 1994).

These connectionist models have the ability to "learn" the frequently complex dynamic behavior of a physical system. Learning is the process where the network approximates the function mapping from system inputs to outputs, given a set of observations of its inputs and corresponding outputs. This is done by adjusting the network's internal parameters, typically in such a way as to minimize the squared error between the network's outputs and the desired outputs.

A standard neural network model was developed which, given as inputs observations of the state and manipulated variables, predicted the state of the system at the next sampling time. The state variables, particularly the biomass concentration, undergo changes of over and order of magnitude.

This large variation can cause problems when using neural network, so we define dimensionless biomass concentration *x* (Equation 1) and dimensionless substrate concentration σ (Equation 2) as:

$$x = \frac{k_1 . X}{S_{avg}} \tag{1}$$

$$\sigma = \frac{S_{avg} - S}{S_{avg}} \tag{2}$$

Where S_{avg} is the average value of the substrate feed concentration S_{in}. note that the scaling is linear, and should therefore have no effect on a squared error criterion. (Dimitris C. et al. 1994)

The desired network's outputs were the dimensionless biomass concentration and substrate concentration *x* and σ respectively. A sigmoid with output ranging from (-1, +1) as given by in the Equation 3, was chosen as activation function.

$$O_k = \frac{1 - e^{-(\Sigma jWjk.oj + b_k)}}{1 + e^{-(\Sigma jWjk.oj + b_k)}} \tag{3}$$

Here, o_k represents the output of neuron *k*, w_{jk} the weight from neuron *j* to neuron *k* which multiplies neuron's *j* output, and b_k the bias of neuron *k*.

For the hybrid neural network model, the squared prediction error over both process variables (biomass and substrate concentration) and for all training patterns *N* was minimized as with the standard neural network model:

$$MSE = \frac{1}{N}\sum_{i}^{N}[(x_i - x_i')^2 + (\sigma_i - \sigma_i')^2] \quad (4)$$

The neural network's output (cell growth rate *u*) does not appear explicitly in the Equation 4. (Dimitris C. et al. 1994)

One such method is the error back-propagation algorithm (Werbos, 1974; Rumelhart et al., 1986), which is essentially a first-order gradient descent method. The ability to approximate unknown functions through presentation of their instances makes neural networks a useful and potentially powerful tool for modeling in engineering applications.

2.8 SIMULATED ANNEALING

For the parameters' identification problem in the MR damper model, it belongs to the complexly and nonlinearly restraint problem. By such the traditionally nonlinear algorithms as the Powell method of direction accelerating, many problems could be turning out when solving the problem. For example, the initial spots may be sensitive and the convergence is in local. The Simulated Annealing algorithm was developed in 80s' and 20 century. It's a stochastic optimal algorithm in overall situation and used to solve the problem in the large-scale combination optimization (Liu et. al., 2005; Zhao et. al., 2006).

The thought could be originated to the physics annealing process of the solid matter. The algorithm can be said as following: less than one initial temperature, and going with the reducing of temperature parameter, we can integrate the characteristic of the probability jumping and stochastically find the optimal solution in overall situation of the object function in the solution space. Its main characteristic is that: it doesn't only accept the optimal solution in the searching process, but also accept the worse solution in certain probability. The probability "P" is related to the temperature.

When the temperature is much higher in the initial stages of annealing, the probability of accepting the worse solution is much larger. Then, going with the gradually reducing of temperature, the probability also becomes smaller and smaller.

When the temperature is near to zero, the worse solution can't be accepted. So we could achieve the chance to avoid the local optimization by this mechanism (Domer et. al., 2003; Li et. al., 2005).

The goal of this process is to reach the lowest energy state. Physical substances usually move from higher energy states to lower ones, so minimization naturally occurs, but in this process there is always some probability that a transition to a higher energy state will occur. As the energy state naturally declines, the probability of moving to a higher energy state will decrease.

Metropolis et al. (1953) proposed an algorithm to simulate the annealing process, modeling the transition of a solid from an elevated temperature to thermal equilibrium. The analogy between the slow cooling of a solid and minimizing the cost function of a combinatorial optimization problem was not realized until it was suggested by Kirkpatrick et al. (1982), and independently by Cerny (1985). Kirkpatrick et al. (1982) developed this "simulated annealing" algorithm by substituting cost for energy and by executing the Metropolis algorithm at a sequence of slowly decreasing temperature values. This method was reported to perform well even in the presence of a high number of variables.

The simulated annealing (SA) implementation used in this simulation was taken from Goffe at al. (1994). While a complete description can be found there, a summary of this algorithm follows. Given the function $f(\mathrm{x})$ to be minimized, several initial parameters must be set, including T_0, the starting temperature; x, the starting solution vector of weights; and *V*, the step length for *X*. Both *X* and *V* are vectors of length n, the number of weights in the ANN. Note that *x* and *v* are elements of vectors *X* and *V*. for example, x_1 is the first weight in *X* and v_1 is the first element in *V*. We define $f(x)$ to be sum-of-squared errors that is produced by the vector *X*.

Equation 5 shows when taking the initial vector *X*, the weight is used for the ANN to calculate and save its f value as the current optimum and best optimum. A candidate *X* is then chosen by varying each x_1, by equation, where *r* is a random number drawn from a uniform distribution between (-1, +1).

$$x_i' = x_i + r^* v_i \tag{5}$$

From this new *X* the function value *f* is then computed (See equation 6). If *f* is less than *f*, *X* is accepted as new *X*. If this new *f* is the smallest solution so far, *f* and its corresponding *X* are saved as the best solution. If *f* is greater than or equal to *f*, the Metropolis criterion is used to test for acceptance. The value from equation 2 is computed and compared with *p*, a random number drawn from a uniform distribution between [0, 1]. If *p* is greater than *p*, the new point is accepted and *X* is updated with *X*, otherwise, *X* is rejected. (Randall, 2001)

$$p = e^{\left(\frac{f-f'}{T}\right)} \tag{6}$$

The process repeats for a user defined number of steps N_s through all element of *X*. N_s is set to the recommended value of 20 for our study. During this process, the step length *V* is adjusted so that 50% of all moves are accepted. After N_T times through the above process, *T* is reduced. An examination of equation 7, shows that a decrease in *T* will decrease the probability of accepting uphill moves. The reduction in *T* is calculated by the formula shown in equation 3. The value r_T is also user defined and set between [0, 1].(Randall, 2001)

$$T_1 = r_T * T_0 \tag{7}$$

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Chapter 3 will be discussing about all the method and software used in order to get the best frag of a magneto rheological. Also, all the previous data and the flow chart to get a good result also will be discussed here.

3.2 METHOD

Based on prior literature review and related theory, a computational analysis is done in order to prove the theory and to collect more information.

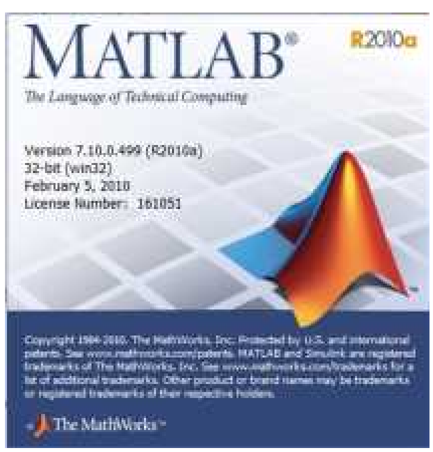

Figure 3.1: The Matlab software used

Simulation is a process obtaining a similar result compare to the actual result. In this study, in order to get similar result, we need to build a coding script and add up the formula of neural network and also simulated annealing. In this simulation, there are five main currents that were used which are 0A, 0.5A, 1.0A, 1.5A and 2.0A.

There are 12 weights in each current given. Then we need to change the weight given by any random value. The method used is called try and error. Each of every weight must be change in order to get the similar result. It may take some times to proceed with this method because there is no exact formula in order to change the value.

After getting the result, then the data from the result is obtained. From the data obtained, the root mean square error (RMSE) can be calculated. This data would tell how much error happen between the simulation result and the actual result.

3.3 FLOW CHART

Flowcharts here are to help in guidance the designing and documenting complex processes or programs. Like other types of diagrams, they help visualize what is going on and thereby help the viewer to understand a process, and perhaps also find flaws, bottlenecks, and other less-obvious features within it.

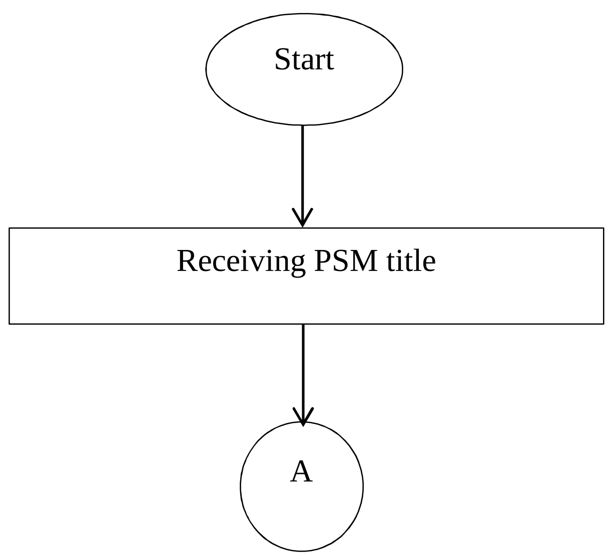

Figure 3.2: Flow Chart

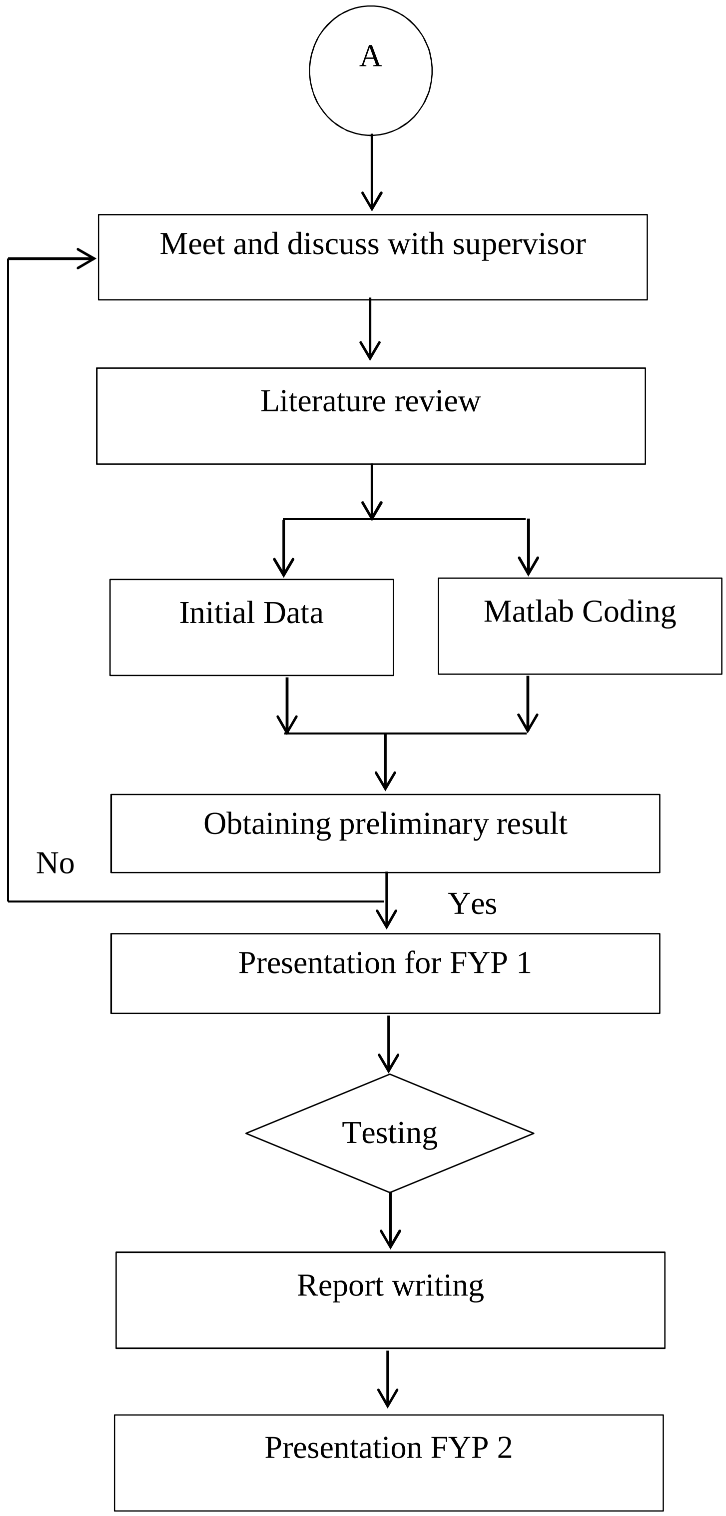

Figure 3.2: Continued

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

Under this chapter, all the result that already collected will be discussed here. Every parameter involved during the measurement will be stated. Also, under this topic all the equation used to calculate will be explained. All data were collected and analyze using MATLAB R2010. By using the software, the displacement, force and error graph can be identified. In this chapter, the experimental data will be compared with the data obtain by using the neural network and simulated annealing (NNSA) method to evaluate which one will be accepted by choosing the lowest root mean square error (RMSE).

4.2 SCRIPT

By using MATLAB, the coding was uses are as follow:

```
function [sys,x0,str,ts] = nn1(t,x,u,flag)

switch flag,
    case 0
    [sys,x0,str,ts]=mdlInitializeSizes;
  case 3
    sys=mdlOutputs(t,x,u);
  case 2
    sys = mdlUpdate(t,x,u);
  case { 1, 4, 9 }
    sys=[];
```

```
  otherwise
    %error(['Unhandled flag = ',num2str(flag)]);
end
%
function [sys,x0,str,ts] = mdlInitializeSizes()

sizes = simsizes;
sizes.NumContStates  = 0;
sizes.NumDiscStates  = 12;
sizes.NumOutputs     = 1;       % dynamically sized
sizes.NumInputs      = 5;       % dynamically sized
sizes.DirFeedthrough = 1;       % has direct feedthrough
sizes.NumSampleTimes = 1;

sys = simsizes(sizes);
str = [];
x0=[0.00064 0.00111 0.001 0.0001 0.001 0.0001 0.1 0.5412 0.381
0.000001 0.0000001 0.000001];
ts  =[-1 0];                    % inherited sample time

function sys = mdlUpdate(t,x,u)
    A = 0.00000001;
    T = 1.3806503*10^23; % Boltzman constant

    tempX(1)=x(1)-A*exp((u(3)-u(4))/T);
    tempX(2)=x(2)-A*exp((u(3)-u(4))/T);
    tempX(3)=x(3)-A*exp((u(3)-u(4))/T);
    tempX(4)=x(4)-A*exp((u(3)-u(4))/T);
    tempX(5)=x(5)-A*exp((u(3)-u(4))/T);
    tempX(6)=x(6)-A*exp((u(3)-u(4))/T);
    tempX(7)=x(7)-A*exp((u(3)-u(4))/T);
    tempX(8)=x(8)-A*exp((u(3)-u(4))/T);
    tempX(9)=x(9)-A*exp((u(3)-u(4))/T);
    tempX(10)=x(10)-A*exp((u(3)-u(4))/T);
    tempX(11)=x(11)-A*exp((u(3)-u(4))/T);
    tempX(12)=x(12)-A*exp((u(3)-u(4))/T);

    x(1)=tempX(1);
    x(2)=tempX(2);
```

```
    x(3)=tempX(3);
    x(4)=tempX(4);
    x(5)=tempX(5);
    x(6)=tempX(6);
    x(7)=tempX(7);
    x(8)=tempX(8);
    x(9)=tempX(9);
    x(10)=tempX(10);
    x(11)=tempX(11);
    x(12)=tempX(12);
    sys=x;

function sys = mdlOutputs(t,x,u)

    x(13)=(u(1)*x(1))+(u(2)*x(4))+(u(3)*x(7))+x(10);
    x(14)=(u(1)*x(2))+(u(2)*x(5))+(u(3)*x(8))+x(11);
    x(15)=(u(1)*x(3))+(u(2)*x(6))+(u(3)*x(9))+x(12);
    x(16)=(2/(1+exp(-2*x(13))))-1;
    x(17)=(2/(1+exp(-2*x(14))))-1;
    x(18)=(2/(1+exp(-2*x(15))))-1;

    sys=x(16)+x(17)+x(18);
```

4.3 SIMULINK MODEL

Then from the MATLAB menu, we create new file called Model. Click File, New and Model respectively. After that we need to create a circuit which has the same simulation as RBF Network. Figure 4.1 shows the example of simulink model which has three initial values and an error.

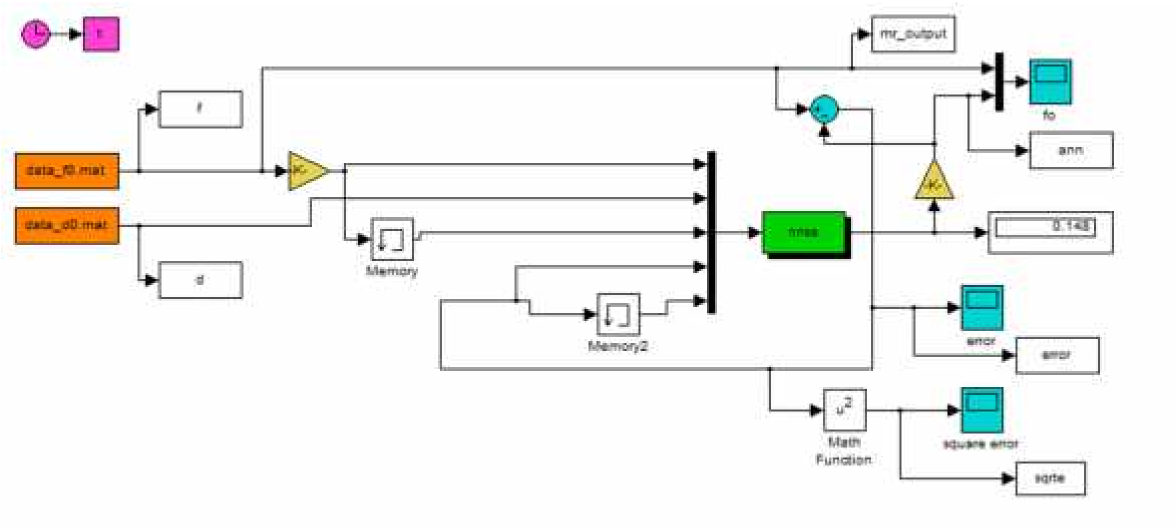

Figure 4.1: Simulink model

4.4 PRELIMINARY RESULT

The preliminary result is obtained from plotting graph. The blue line represents magneto-rheological (MR) output while green line represents the neural network (NN) output.

4.4.1 Plot (t,mr_output,t,nn_output)

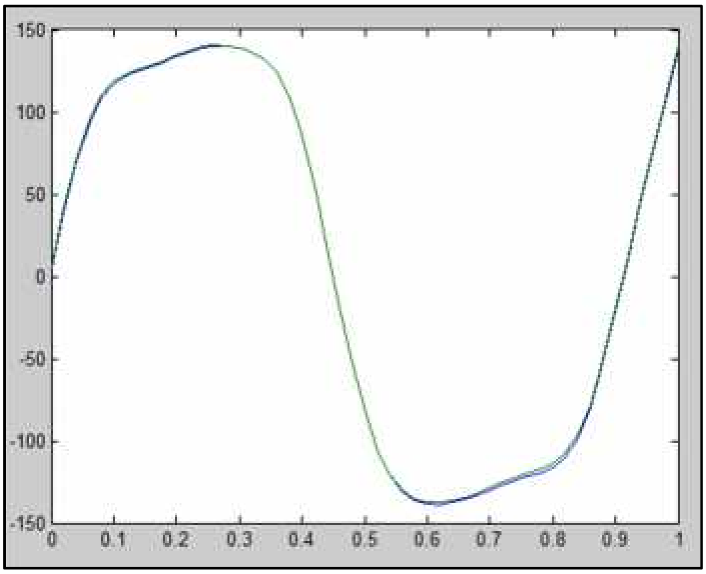

Figure 4.2: Time vs MR Output And Time vs NN Output Graphs

4.4.2 Plot (t,d)

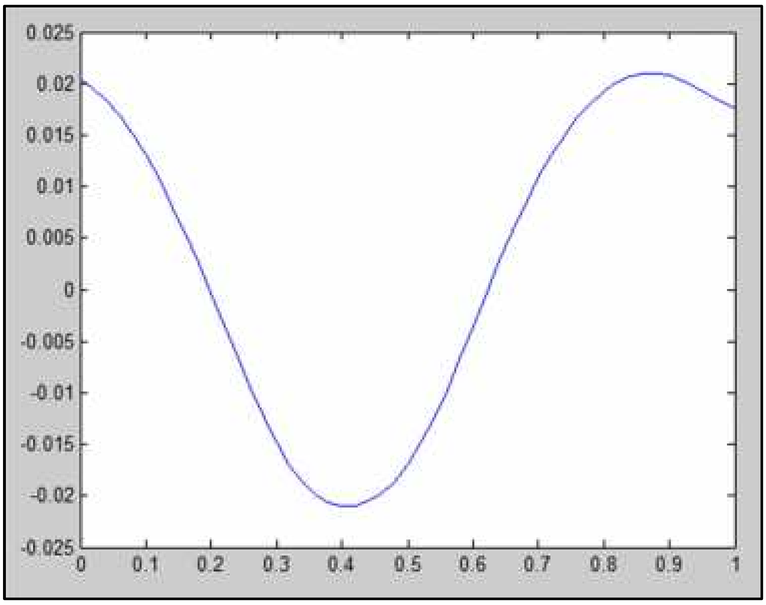

Figure 4.3: Time vs Distance Graph

4.4.3 Plot (t,v)

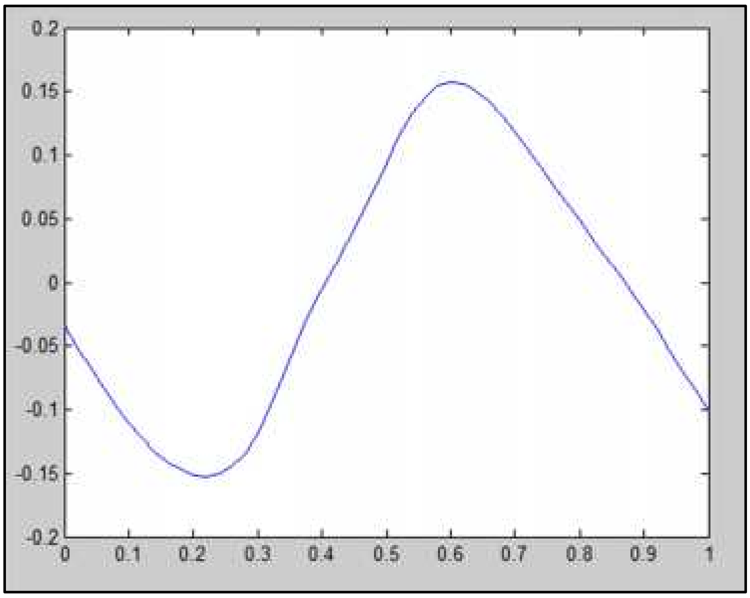

Figure 4.4: Time vs Velocity Graph

4.4.4 Plot (mr_output,d)

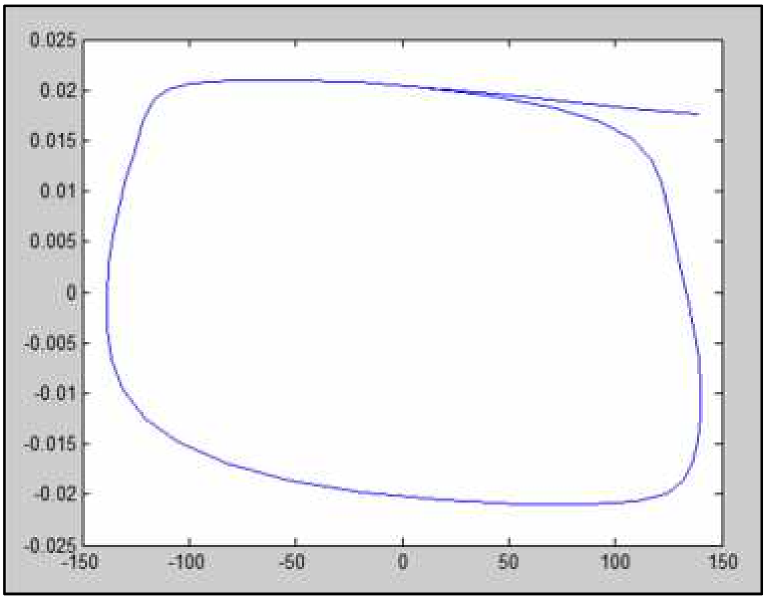

Figure 4.5: MR Output vs Distance Graph

4.4.5 Plot (d,mr_output)

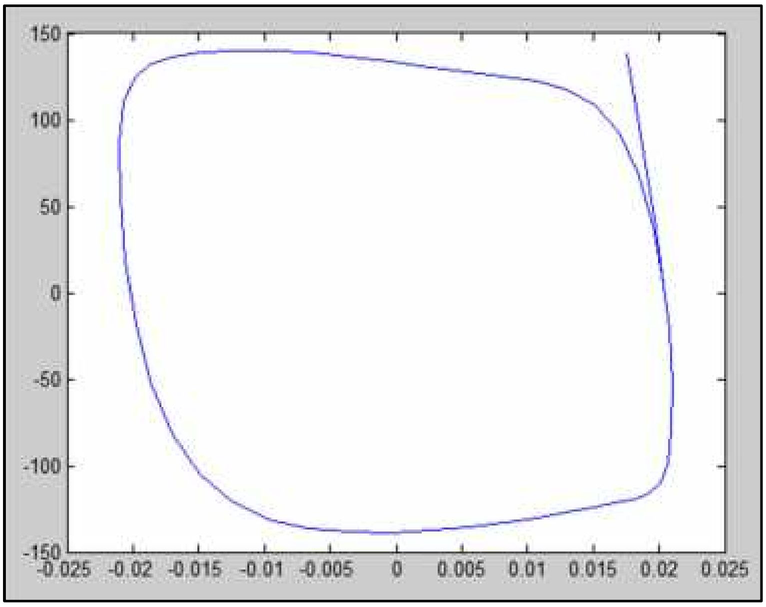

Figure 4.6: MR Output vs Distance Graph

4.4.6 Plot (v,mr_output)

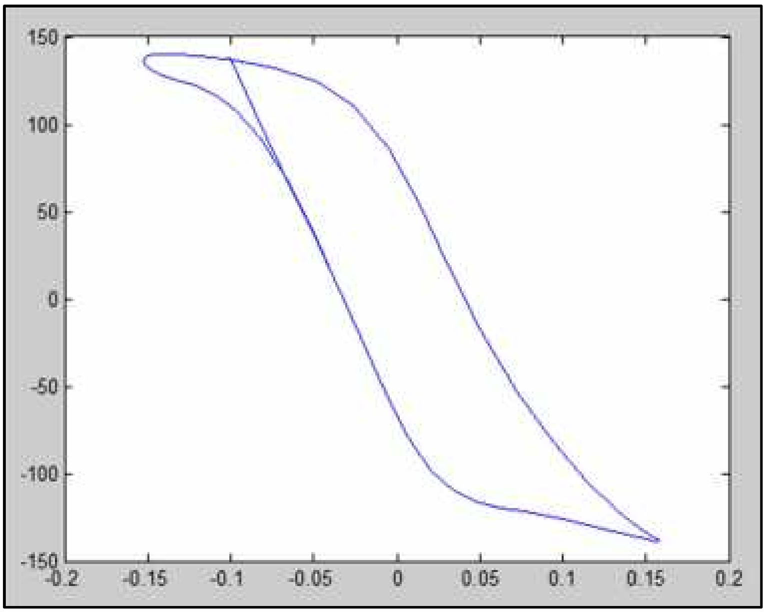

Figure 4.7: Velocity vs MR Output Graph

4.4.7 Plot (d,mr_output,d,rbf_output)

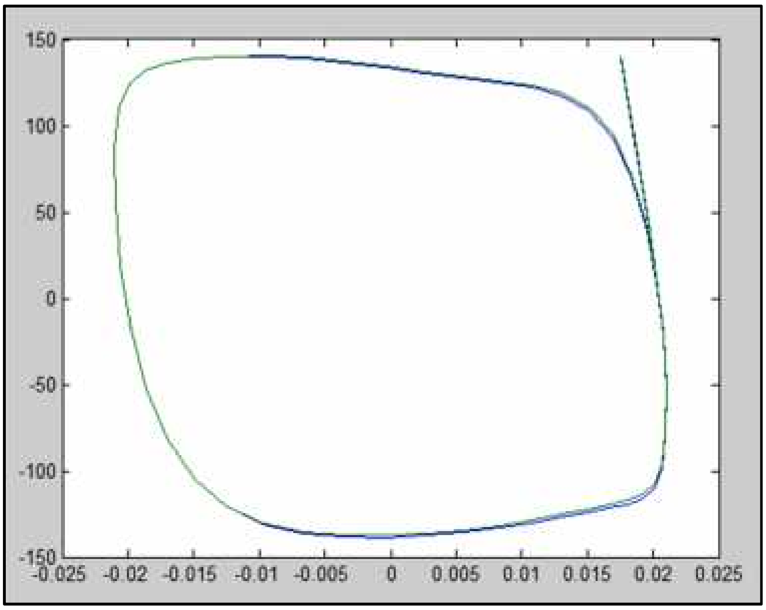

Figure 4.8: Distance vs MR Output And Distance vs RBF Output Graphs

4.4.8 Plot (v,mr_output,v,rbf_output)

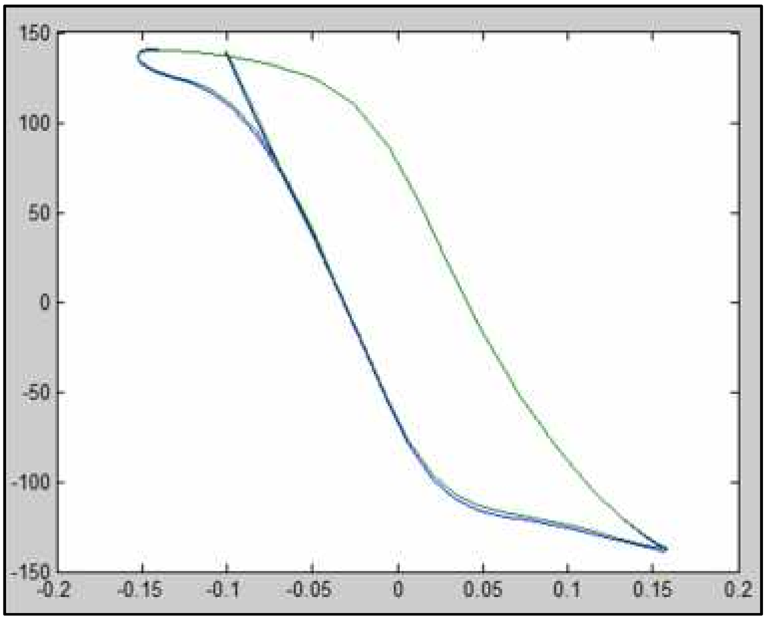

Figure 4.9: Velocity vs MR Output and Velocity vs NN Output Graphs

4.5 DATA ANALYSIS

The experiment is conducted by using a tensile testing machine. To obtain the experimental data, a direct current (DC) power supply is use to provide the current flow through the magneto-rheological (MR) damper. There are five value of current that were used in the experiment. The current given is 0A, 0.5A, 1.0A, 1.5A, and 2.0A. When the current is apply on the simulation, there will be four graph that will be discussed which is displacement, force, comparison between actual and simulation and error graph.

4.5.1 Simulation and Experimental Result for Current 0A

(a) The parameters graph for 0A damper

The parameter of experimental damper data is obtained from the experiment. The parameter used for these experiments is displacement and force. The results will only show the results data experiment by graph. The parameter of experimental damper data will be used as input in the simulation process. The figure 4.10 shows the displacement graph for 0.0 Ampere damper, the figure 4.11 shows the force graph, for 0.0 Ampere damper.

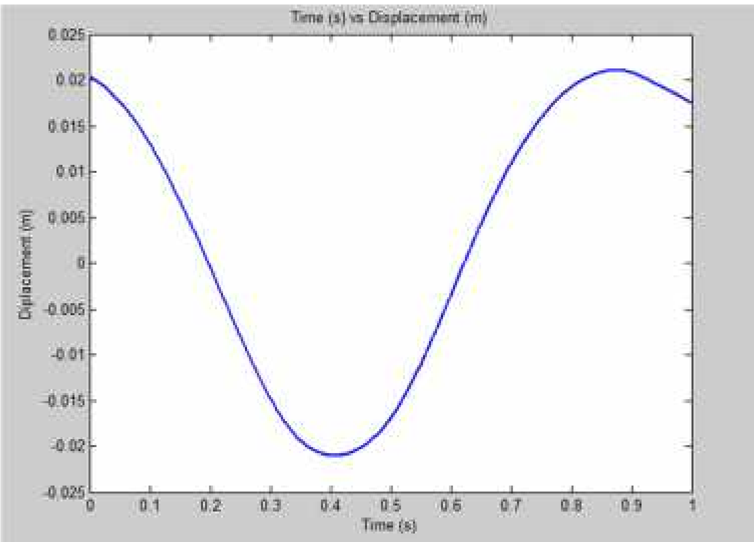

Figure 4.10: Displacement graph vs Time for current 0A

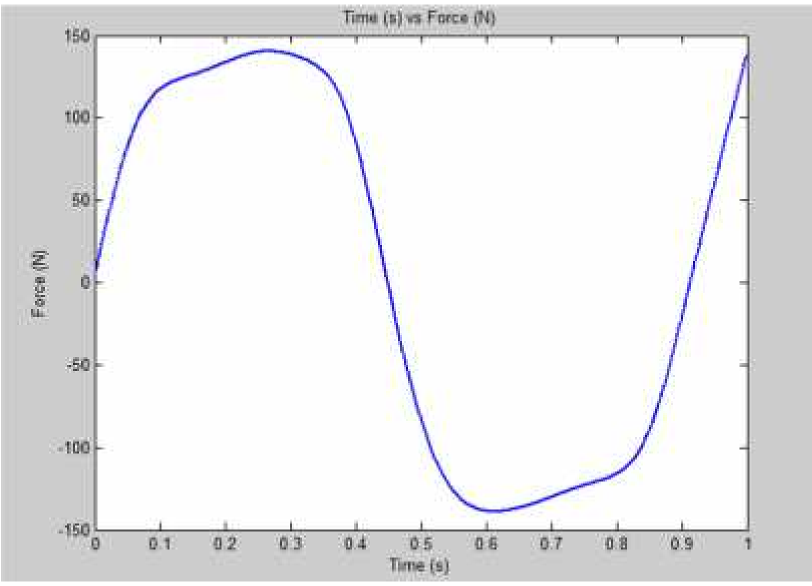

Figure 4.11: Force graph vs Time for current 0A

(b) The comparison graph between actual and experimental damper.

The comparison of the experimental and the simulation were obtained in term of the force graph. The Y-axis was represent the forces in Newton unit, while the X-axis were represent the time taken using second as a unit. The green line is the experimental damper data, while for the actual damper is blue line. The figure 4.12 shows the comparison graph between the experimental damper and simulation damper for 0.0 Ampere.

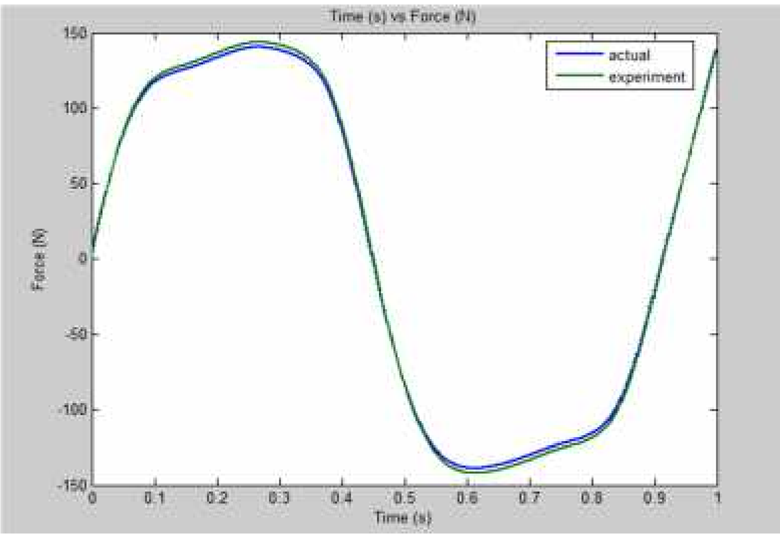

Figure 4.12: The comparison between actual (MR output) and experimental (NNSA output) graph for current 0A

(c) Square error for 0A damper

The results for square error will determine whether the method used which is neural network and simulated annealing can be used to modeling the MR damper. If the square error results from the simulation are small the modeling is successful. The data from the square error will be used to determine the value for Root Mean Square Error for the simulation damper. Figure 4.13 shows the RMSE for the 0A damper.

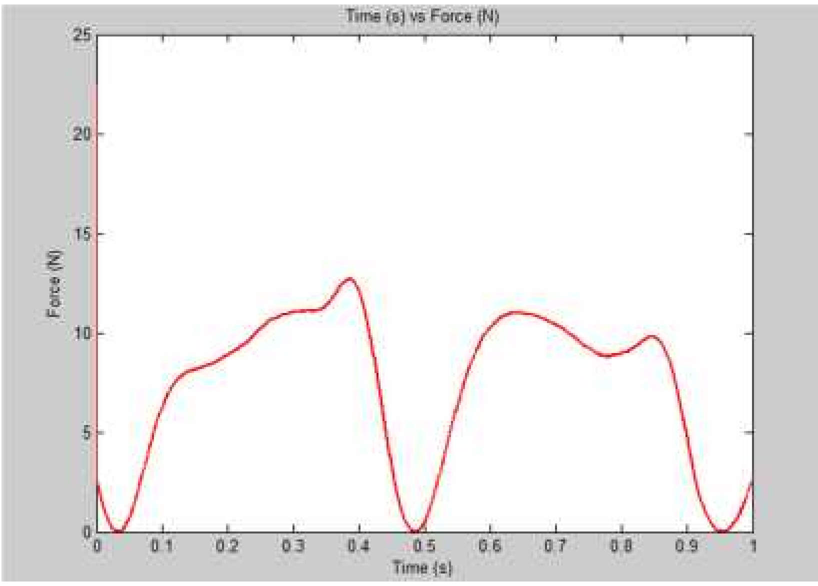

Figure 4.13: Error graph for current 0A

(d) Results for RMSE for 0A damper.

Root Mean Square Error is used to measure the difference or error between value from the experimental and the value from the simulation that being modeled. The Root Mean Square Error values will determine whether the neural network and simulated annealing method can be used to modeling the MR damper. To be precise, the RMSE were then being calculated using this formula:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(F_{actual} - F_{ANN})^2}{N}} = \sqrt{\frac{1.644695}{1001}} = 1.282457$$

4.5.2 Simulation and Experimental Result for Current 0.5A

(a) The parameters graph for 0.5A damper

The parameter of experimental damper data is obtained from the experiment. The results parameter from the experiment is displacement and force. The results will only show the results data experiment by graph. The parameter of experimental damper data will be used as input in the simulation process. The figure 4.14 shows the displacement graph for 0.5 Ampere damper, while the figure 4.15 shows the force graph for 0.5 Ampere damper.

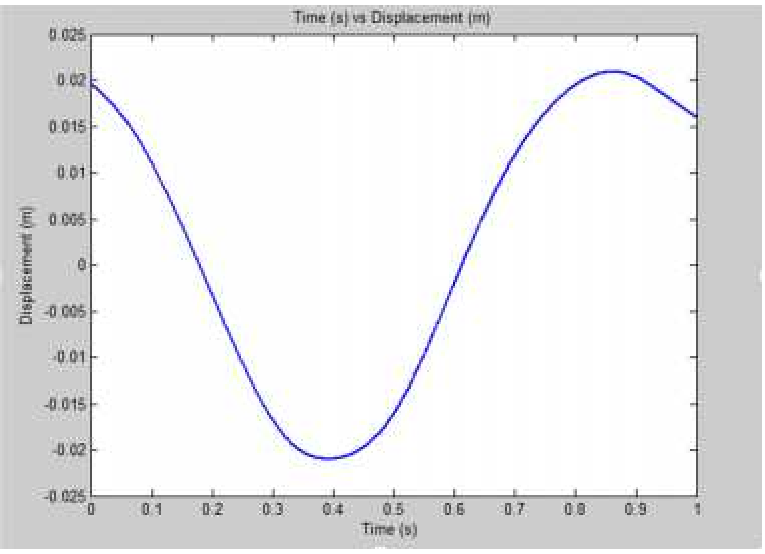

Figure 4.14: Displacement graph vs Time for current 0.5A

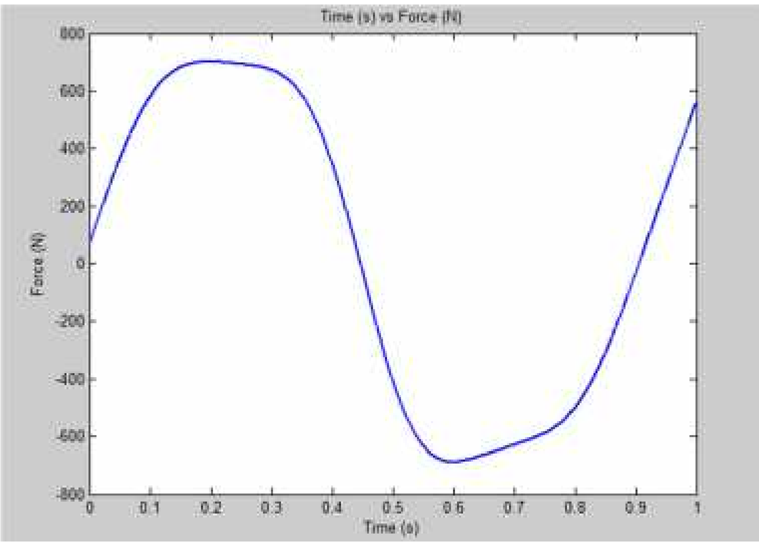

Figure 4.15: Force graph vs time for current 0.5A

(b) The comparison graph between actual and experimental damper

The comparison of the experimental and the simulation were obtained in term of the force graph. The Y-axis was represent the forces in Newton unit, while the X-axis were represent the time taken using second as a unit. The green line is the experimental damper data, while for the actual damper is blue line. The figure 4.16 shows the comparison graph between the experimental damper and simulation damper for 0.5 Ampere.

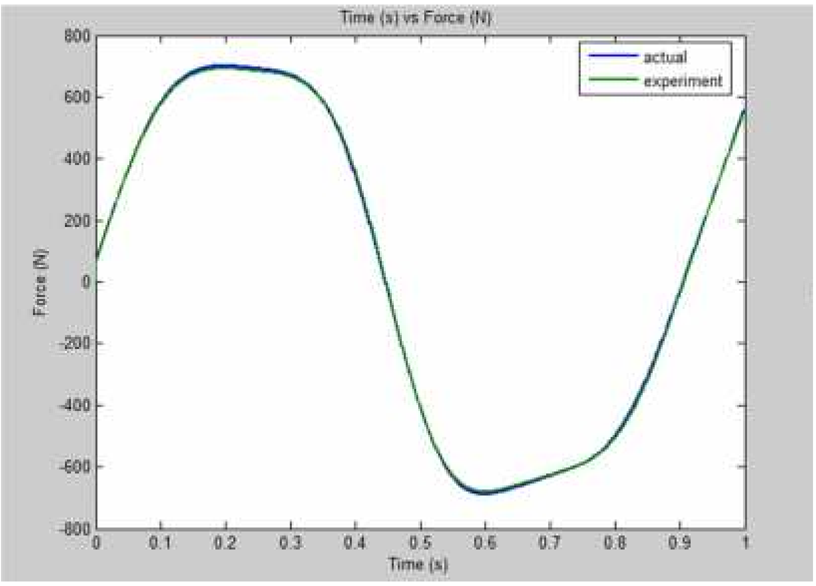

Figure 4.16: The comparison between actual (MR output) and experimental (NNSA output) graph for current 0.5A

(c) Square error for 0.5A damper

The results for square error will determine whether the method used which is neural network and simulated annealing can be used to modeling the MR damper. If the square error results from the simulation are small the modeling is successful. The data from the square error will be used to determine the value for Root Mean Square Error for the simulation damper. Figure 4.17 shows the RMSE for the 0.5A damper.

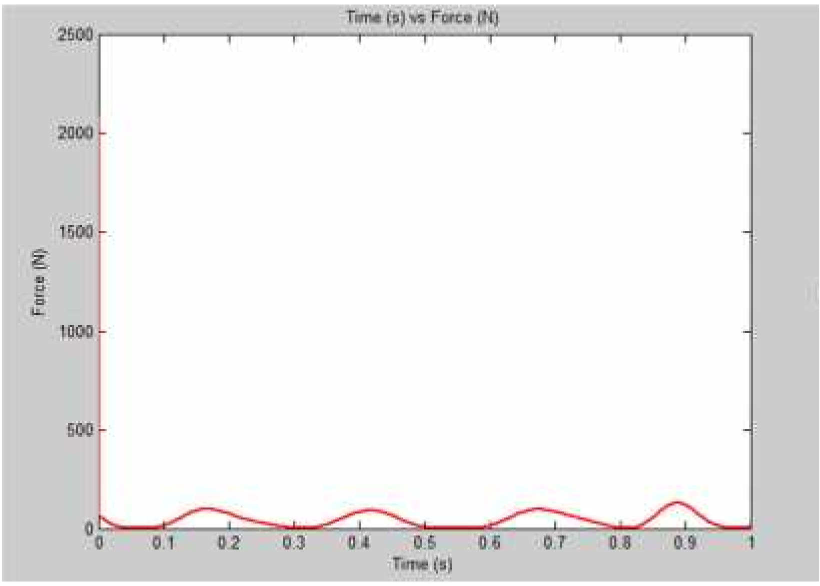

Figure 4.17: Error graph for current 0.5A

(d) Result for Root Mean Square Error for 0.5A damper

The RMSE value:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(F_{actual} - F_{ANN})^2}{N}} = \sqrt{\frac{43.15573}{1001}} = 6.569302$$

4.5.3 Simulation and Experimental Result for Current 1A

(a) The parameters graph for 1.0A damper

The parameter of experimental damper data is obtained from the experiment. The results parameter from the experiment is displacement and force. The results will only show the results data experiment by graph. The parameter of experimental damper data will be used as input in the simulation process. The figure 4.18 shows the displacement graph for 1.0Ampere damper, while the figure 4.19shows the force graph for 1.0 Ampere damper.

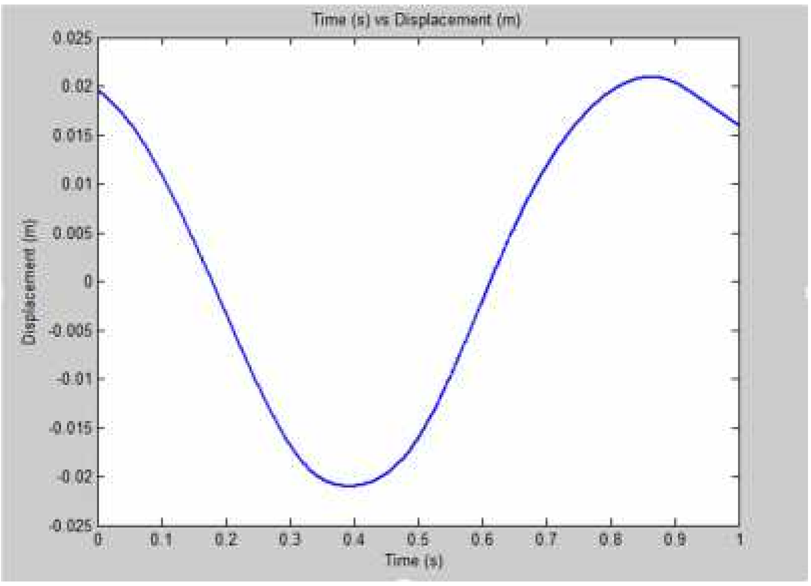

Figure 4.18: Displacement graph vs Time for current 1.0A

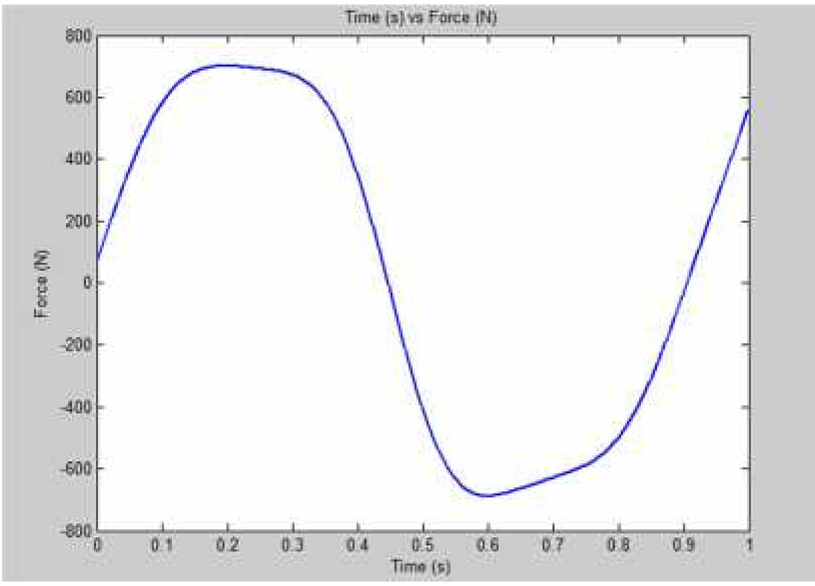

Figure 4.19: Force graph vs Time for current 1.0A

(b) The comparison graph between actual and experimental damper

The comparison of the experimental and the simulation were obtained in term of the force graph. The Y-axis was represent the forces in Newton unit, while the X-axis were represent the time taken using second as a unit. The green line is the experimental damper data, while for the actual damper is blue line. The figure 4.20 shows the comparison graph between the experimental damper and simulation damper for 1.0 Ampere.

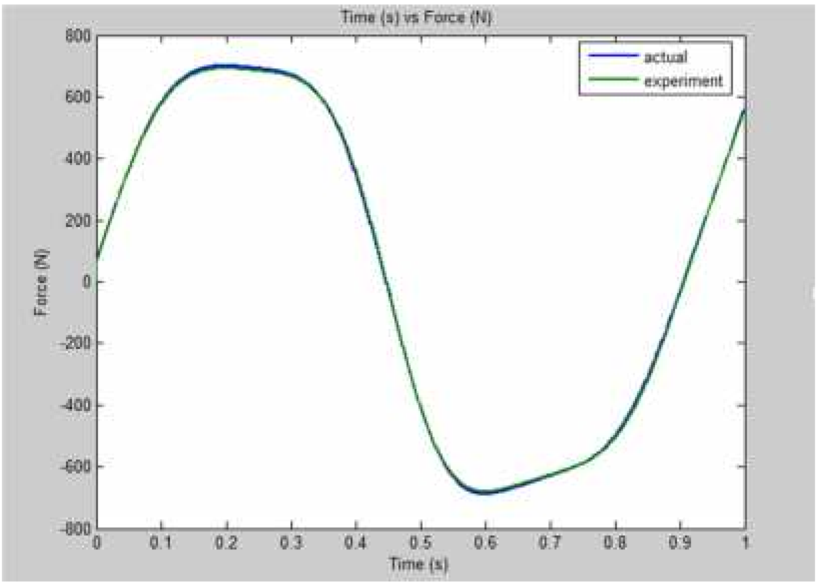

Figure 4.20: The comparison between actual (MR output) and experimental (NNSA output) graph for current 1.0A

(c) Square error for 1.0A damper

The results for square error will determine whether the method used which is neural network and simulated annealing can be use to modeling the MR damper. If the square error results from the simulation are small the modeling is successful. The data from the square error will be used to determine the value for Root Mean Square Error for the simulation damper. Figure 4.21 shows the RMSE for the 1.0A damper.

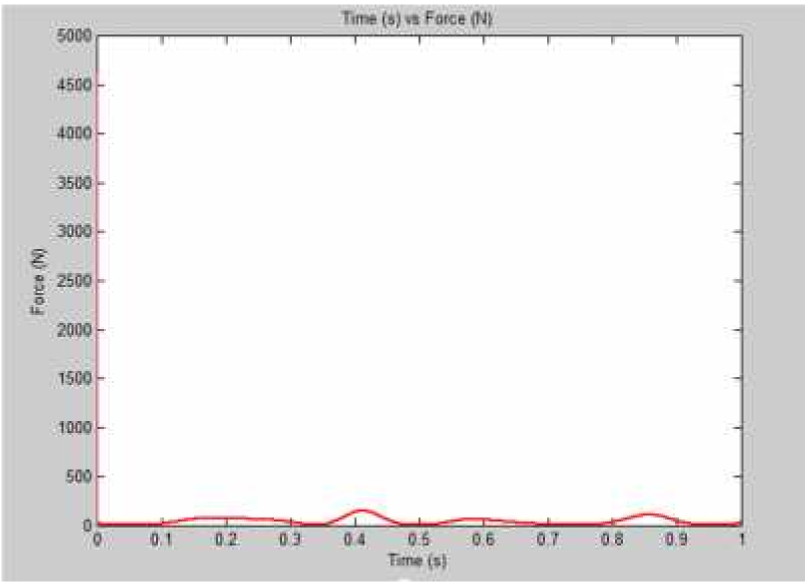

Figure 4.21: Error graph for current 1A

(d) Result for root mean square error (RMSE) for 1.0A damper

The RMSE value :

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(F_{actual} - F_{ANN})^2}{N}} = \sqrt{\frac{42.43644}{1001}} = 6.514326$$

4.5.4 Simulation and Experimental Result for Current 1.5A

(a) The parameters graph for 1.5A damper

The parameter of experimental damper data is obtained from the experiment. The results parameter from the experiment is displacement and force. The results will only show the results data experiment by graph. The parameter of experimental damper data will be used as input in the simulation process. The figure 4.22 shows the displacement graph for 1.5Ampere damper, while the figure 4.23 shows the force graph for 1.5 Ampere damper.

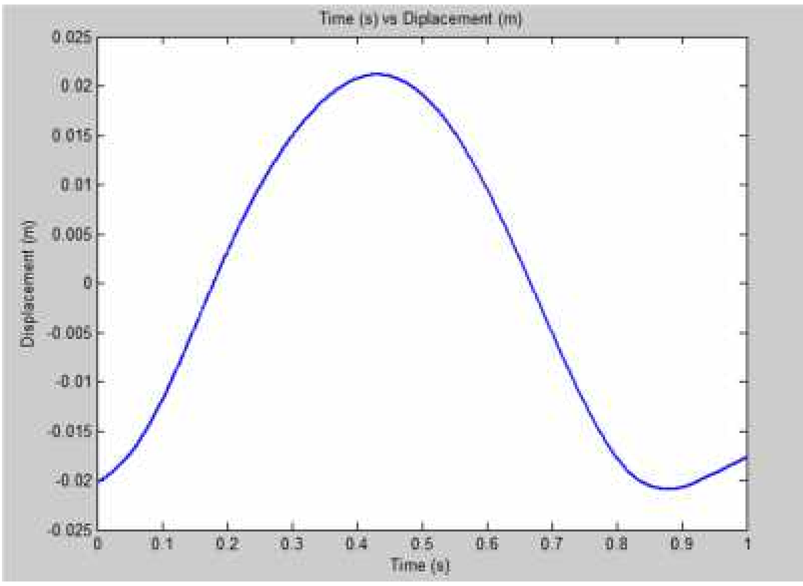

Figure 4.22: Displacement graph vs Time for current 1.5A

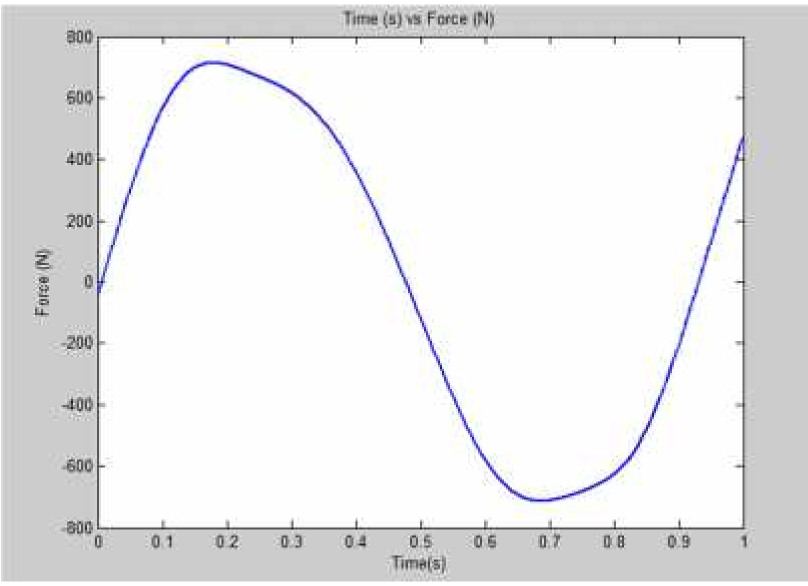

Figure 4.23: Force graph vs Time for current 1.5A

(b) The comparison graph between actual and experimental damper

The comparison of the experimental and the simulation were obtained in term of the force graph. The Y-axis was represent the forces in Newton unit, while the X-axis were represent the time taken using second as a unit. The green line is the experimental damper data, while for the actual damper is blue line. The figure 4.24 shows the comparison graph between the experimental damper and simulation damper for 1.5 Ampere.

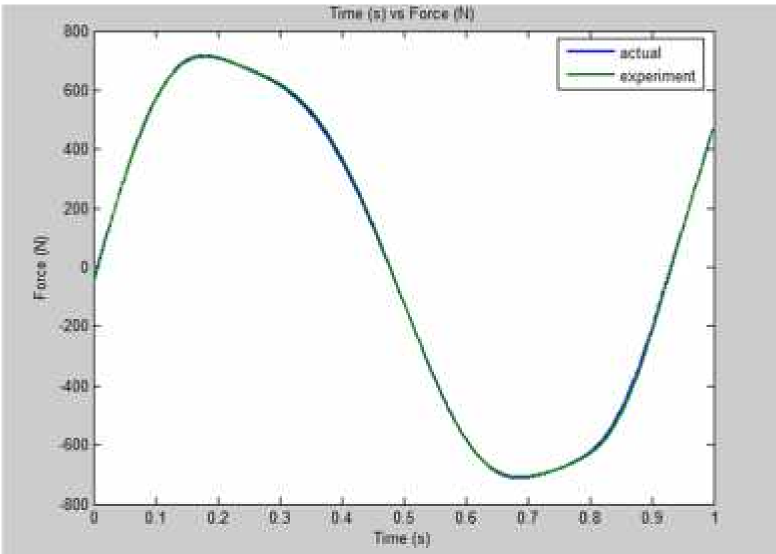

Figure 4.24: The comparison between actual (MR output) and experimental (NNSA output) graph for current 1.5A

(c) Square error for 1.5A damper

The results for square error will determine whether the method used which is neural network and simulated annealing can be used to modeling the MR damper. If the square error results from the simulation are small the modeling is successful. The data from the square error will be used to determine the value for Root Mean Square Error for the simulation damper. Figure 4.25 shows the RMSE for the 1.5A damper.

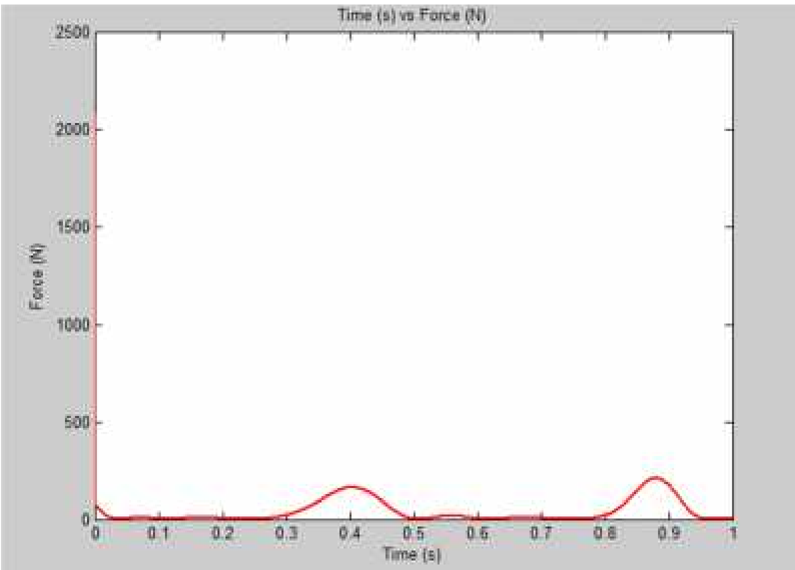

Figure 4.25: Error graph for current 1.5A

(d) Result for root mean square error (RMSE) for 1.5A damper

The RMSE value:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(F_{actual} - F_{ANN})^2}{N}} = \sqrt{\frac{41.45619}{1001}} = 6.438648$$

4.5.5 Simulation and Experimental Result for Current 2A

(a) The parameters graph for 2.0A damper

The parameter of experimental damper data is obtained from the experiment. The results parameter from the experiment is displacement and force. The results will only show the results data experiment by graph. The parameter of experimental damper data will be used as input in the simulation process. The figure 4.26 shows the displacement graph for 2.0Ampere damper, while the figure 4.27 shows the force graph for 2.0 Ampere damper.

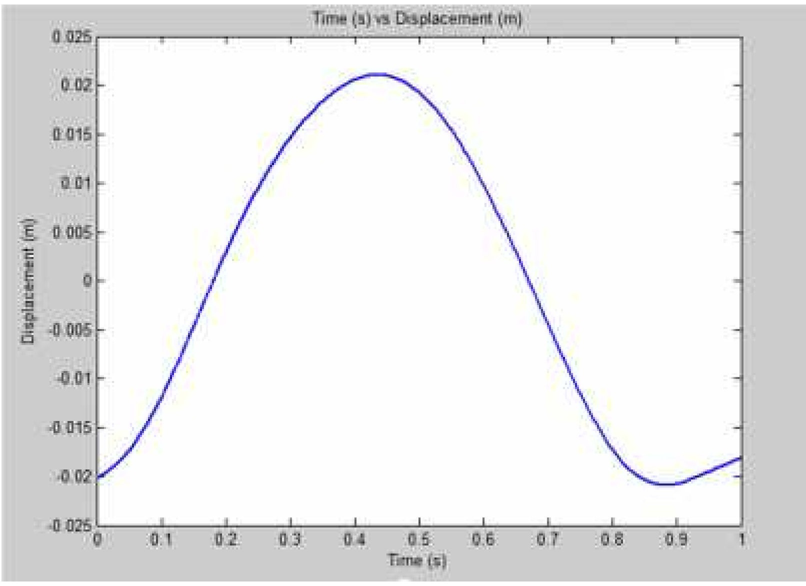

Figure 4.26: Displacement graph vs Time for current 2

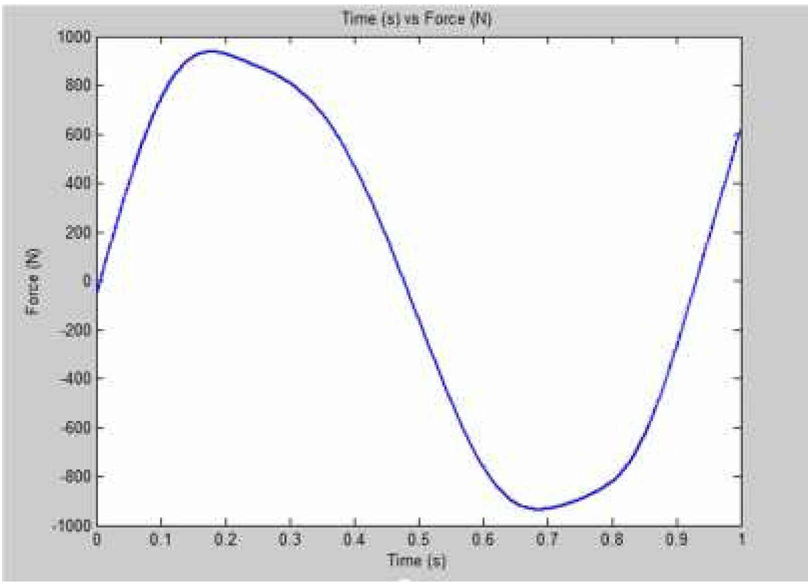

Figure 4.27: Force graph vs Time for current 2A

(b) The comparison graph between actual and experimental damper

The comparison of the experimental and the simulation were obtained in term of the force graph. The Y-axis was represent the forces in Newton unit, while the X-axis were represent the time taken using second as a unit. The green line is the experimental damper data, while for the actual damper is blue line. The figure 4.28 shows the comparison graph between the experimental damper and simulation damper for 2.0 Ampere.

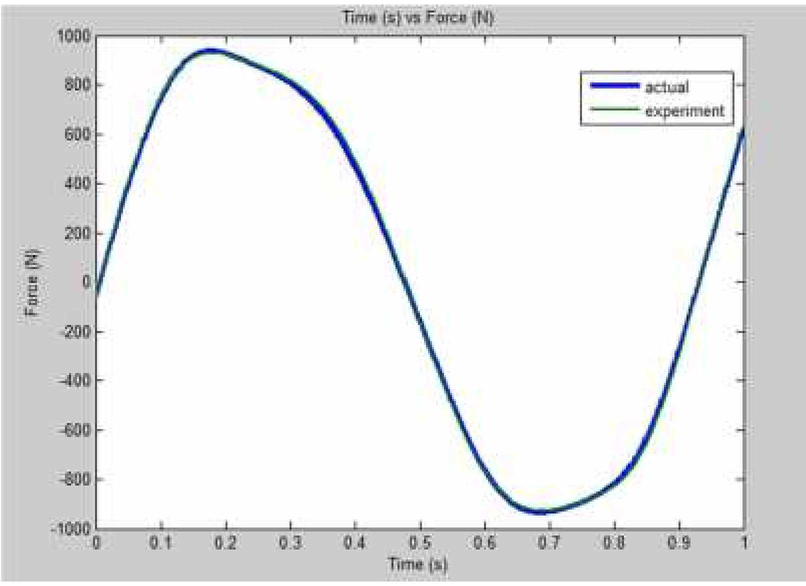

Figure 4.28: The comparison between actual (MR output) and experimental (NNSA output) graph for current 2A

(c) Square error for 2.0A damper

The results for square error will determine whether the method used which is neural network and simulated annealing can be used to modeling the MR damper. If the square error results from the simulation are small the modeling is successful. The data from the square error will be used to determine the value for Root Mean Square Error for the simulation damper. Figure 4.29 shows the RMSE for the 2.0A damper.

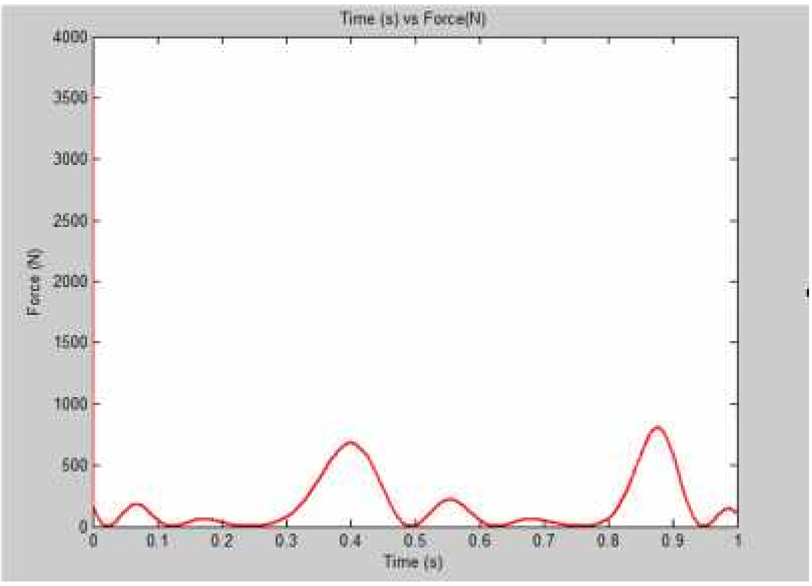

Figure 4.29: Error graph for current 2A

(d) Result for root mean square error (RMSE) for 2.0 A

The RMSE value:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(F_{actual} - F_{ANN})^2}{N}} = \sqrt{\frac{173.9522}{1001}} = 13.18909$$

Table 4.1 shows all RMSE value for each current flow. The smallest error is 1.282457 that is getting from 0A current while the largest error is 13.18909 from the 2.0A. As can see the 0 Ampere damper has the lowest RMSE value. This is because the MR damper is type of semi- active damper, this type of damper have the advantage of the requirement for low power requirement. While for 2.0 Ampere damper, the RMSE is higher because of the high power supply to the MR damper. The better parameter for modeling the MR damper using NNSA method is using the average current. The error is obviously still in a large margin compare to the other method that were using the same model. Thus, more simulation and tuning process should be done in order to achieve the smallest error that can be done using NNSA method.

Table 4.1: Overall RMSE value for all current from 0A until 2.0A

Current flow, A	Root mean square error, (RMSE)
0	1.282457
0.5	6.569302
1.0	6.514326
1.5	6.438648
2.0	13.18909

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

Under this topic, all the result and discussion before will be concluded under this topic. This chapter is to make it easier to understand the entire objective about the simulation done.

5.2 CONCLUSION

Modeling the MR damper can be done using variation of methods, and one of the methods is Neural Network and Simulated Annealing (NNSA) method. To modeling the MR damper using NNSA, the comparison is needed in order to determine whether the method can be used to model it as a real damper. The comparison between the experimental damper and simulation damper were made to modeling the MR damper. The comparison in this project is measure using the Root Mean Square Error of the simulation damper. The RMSE frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled. From the results, the lowest RMSE is the 0 Ampere damper which is 1.282457. The RMSE value is quite low, and it shows that the difference between the experimental damper and the actual damper using NNSA method is small. If the differences are small it indicates that the NNSA method can be used to modeling the MR damper.

5.3 RECOMMENDATION

Nowadays, the tuning process is just depends on try and error method. It will take times before the similar graph were obtain. There are more than hundred adjustments or tuning should be done in order to achieve the smallest error for the graph. So for the future research, there should be a formula or equations to determine the value of the weight (x) and also the learning rate (A) in the MATLAB coding's. Moreover, UMPs should provide the actual MR damper so the data obtain can be more accurate and the experimental simulation can be tested using NNSA method.

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