Characterization of Linear Motor

by

Mohd Hazmi Bin Husini

Dissertation submitted in partial fulfilment of
the requirement for the
Bachelor of Engineering (Hons)
(Electrical and Electronics Engineering)

DECEMBER 2012

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Characterization of Linear Motor

By

Mohd Hazmi Bin Husini

A project dissertation submitted to the
Electrical and Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(ELECTRICAL AND ELECTRONICS ENGINEERING)

Approved by

____

(AP Dr. Mohd Noh Bin Karsiti)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Mohd Hazmi Bin Husini)

ABSTRACT

Development of linear technology has increased recently for industrial purposes. In certain application especially in automation field, linear motor is more preferred compared to the conventional rotary motor. It is due to the advantages that linear motor can offer such as speed, position control, cost effective, no maintaining and many more. So, for student, linear machine can be considered as important as rotary machine and research, study and experiment should be encouraged by the university. From this project of Characterization of Linear Motor, the author as assigned to set up and configure the hardware and software of linear motor for testing and experimenting facility in university. The hardware components mainly are linear motor and motor driver from Copley Controls. The software used for to configure the motor driver for commutation modes is called CME 2 software from Copley Controls. After the installation of all components is completed, the character of the motor in different profiles is analyzed from the data obtain from the scope tools of CME 2 software.

ACKNOLEDGEMENTS

All praises go to Allah, our sustainer, without the grace and guidance, no effort could attain the success. I would like to express my gratitude to my supervisor, AP Dr. Mohd Noh Bin Karsiti and my co-supervisor, Mr. Saiful Azrin Bin Mohd Zulkifli for their invaluable assistance and technical guidance they contributed to this project.

I would like to thank all the technicians in the Electrical and Electronics Engineering department especially to Mr. Yasin Bin Baharuddin who have assisted me in completing this project. To all fellow colleagues, relatives and family, I am deeply grateful for all the help and support that they have given me.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1. Background Study

Motor can be considered very important in electrical machine. The character of motor that convert electrical energy to mechanical energy makes it more essential especially for industrial application [1] [4]. There are two motion type of motor which are rotary motor and linear motor. Each type of motor has own advantages and disadvantages in its application in the industry. Unlike linear motor, rotary motor is well established in the industry due to early research and development.

Recently, development and research of linear motion technology has increase in demand due to advantages of that the linear motion technology can promote. Linear motor is one of the developments of linear motion technology. The main difference of linear motor to the conventional motor is the rotor of the motor is linear in motion. The linear motor principle is still the same with the conventional rotary motor which is force exert from two different magnetic field [7].

Linear motion technology is not a new technology. There are many researches and developments of linear motor have been done before with a different type and configuration. In this study, linear motor will be tested and different profile of linear motor will be explored.

There are application of linear motor has been used nowadays such as Magnetic Levitation (MagLev) train. The linear motors provide forward driving force for the MagLev train and the conventional steel wheel and rail for train is replace by the floating train in the guided channel using the principle of magnet. Other applications of linear motor are food slicing and bottle capping in food industry.

Since the popularity of linear motor increase in recent year, there are a lot of machine manufacturers produce a linear machine as their product. So, there are many types of linear motor offered in the market for variety of application such as moving coil, moving magnet, AC synchronous design, AC induction design, linear stepping design, brushed and brushless design.

Consequently, due to the important of linear machine technology in the industry these days, it is good for students to have linear motor experiment facility in UTP so that they can have an experiment and hands on experience regarding the linear machine in their studies. There are a lot of experiment can be done in order to increase the knowledge of student in linear motor such as force control, positioning control and velocity control in different commutation methods.

In this project, installation of linear motor can be a platform to development and research studies of linear machine technology in UTP. This project also is much related to the Power Electronic and Electrical Machines courses and also related to the studies of applying linear machine such as robotic and manufacturing field.

1.2. Problem Statement

A brushless linear motor is work by injecting current into the phases at the right instant of time. When current is injected to particular phase, it will produce a magnetic field on the windings. This magnetic field will interact with the magnetic field of permanent magnet and force will be produced from the interaction from two magnetic fields. Hence, force that produced will move the mover linearly.

The process of injecting the current into phases of the winding is called commutation. The switching of current must be done on the right time to produce maximum force to the mover and accurate direction of the mover. In the brushless linear motor, permanent magnet is a moving part and the winding is stationery. For switching of current in the winding, electronic commutation which commonly referred to the motor driver is employed.

In certain industry application, the output of speed of the motor is very crucial especially in automotive industry. In contrast with linear motor, conventional rotary motor is mounted to the load using intermediate mechanical components such as gears, gearboxes and belts because the motor is circular in motion [2]. So, losses due to mechanical linkage may reduce the performance of the motor especially in terms of speed of the motor.

The introduction of linear motor may solve the problem of performance of motor. It is because linear motors do not have transition connection between the motor and the load and the load is connected directly to the motor. So, there will be no losses due to mechanical connection of transition components in the linear motor.

1.3. Objectives

The purpose of this final year project is to enable the final year students to manage and handle a project which will improve student skills in applying knowledge, finding ideas, solving problems and presenting result through guidance and help of supervisors and lecturers.

There are basically several objectives on the study of linear motor which need to be achieved at the end of final year semester.

1. Review the literature on linear motor.

2. Installing and configuring hardware and software of the linear motor and its components to become a system.

3. Testing the system.

4. Experimenting and verifying the position profile of the system

1.4. Scope of Study

In this project, elements and properties of electromagnetic and mechanical of linear motor will be covered. Comparison and evaluation of past and existing linear motor will be done as project reference. This project is conducted in duration of 2 semesters which in the first semester, the focus will be on literature and understanding on principle and its data sheet and also specification of the linear motor.

The first part of this project is to install the hardware components which are three-phase brushless linear motor and motor driver. The brushless linear motor is a Servotube Actuator (XTA3810) and the motor driver is Accelnet Panel ADP (ADP-180-18-S). The motor and drive is manufactured by Copley Controls Corporation [9] [10].

After hardware configuration is completed, software configuration will be applied where communication of linear motor and the driver need to be configured. Both components can communicate by using CME2 software [10]. In this stage, the configuration parameters such as motor, feedback, input and output, command input and faults is being set so the motor can run properly and achieved the desired output.

At a final stage, the signal waveforms in different factor need to be analyzed from observation of the signal waveform from the scope tool from CME 2 software.. Hopefully, the result from observation and analysis can define the characterization of the linear motor.

CHAPTER 2

LITERITURE REVIEW

2.1 Brushless Linear Motor

The generation of linear force conventionally is produced by the hydraulic and pneumatic system. The problem of hydraulic and pneumatic system is that they are complex and expensive. Other way to produce linear motion is from rotary machine that required mechanical equipment to convert rotary to linear motion. This will lead to extra cost for the installing and maintaining the mechanical equipment.

The introduction of linear machine provides an extra option in providing force in linear motion. The linear motor is more reliable and practical in linear automation because the motor provide direct switch from electrical energy to force energy in linear motion.

Linear motor is and energy converter which the motor is moving direct drive instead of rotating. Similarly to rotary motor, linear motor has the same principle of operation with different end effect. The study of linear motor is similar to the conventional rotary motor with some changes in the certain terms and elements which are angular dimension and displacement, torque and 360 degree commutation cycle of rotary motor is replaced with linear dimension and displacement, forces and distance between pole pairs of commutation cycle [3].

Basic principle of motor is when current-carrying conductor is placed in a magnetic field, it has force exert on the conductor [7], the magnitude of the force is given by,

$$\mathbf{F} = i\,(l \times \mathrm{B}) \text{ Newtons}$$
$$= ilB$$

The induced torque given by,

$$\tau = rF \sin\theta \text{ Newton/metre}$$
$$= r\,(ilB) \sin\theta$$

Where,

i = current

l = length of the conductor

B = magnetic flux density

r = radius of the loop

θ = angle between r and F [6]

Since the linear motor is not in angular dimension, torque can be easily replaced by force. It is because linear motors do not have radius and the angle between the flux density, B and current, I is always 90 degree. So, the force of the linear motor can be calculated just the product of current, length and flux density [3].

Two main components of conventional rotary motor are stator and rotor [5] [6]. For the linear motor, the main components are forcer (motor coil) and magnet track [3]. Similar to brushless rotary motor, forcer and permanent magnet track have no physical connection. Unlike rotary motor, which the stator in static position and rotor is moving, linear motor can have either moving forcer and static magnet rail or moving magnet or static forcer. Having a moving forcer, it required flexible cable which can move along with the forcer. With a moving magnet rail, the load of the motor is increased due to the weight of the permanent magnet which is higher compared to motor coil [3].

In certain application, linear motor can give better advantage in term of reliability and losses. The linear motor can be coupled directly to reciprocating vertical or horizontal load. However, in rotary motor system, the motor's rotor is mounted to the load by using mechanical component such as gears and belts. Unlike linear motor, the load is connected directly to the motor. The absence of contacting part in linear motor offer lower inertia, lower friction losses and no backlash compared to conventional motor [2]. In addition, linear motor is able to operate in high speed due to low friction losses. Linear motors also offer high dynamic stiffness and low maintenance cost because of no mechanical linkage between load and motor [2].

However, linear motors have drawbacks of cogging effect. Cogging is a strong mutual attraction between iron core and permanent magnet [8]. So, the motor will vibrate at low speed. This effect can be eliminated by ironless linear motor[3]. Furthermore, linear motor is expensive due to the small volume of the motor and the price of the permanent magnet especially for long track linear motor. Heat also one of the disadvantages of linear motor. Since the motor is attached straight to the load, the copper losses of I^2R will cause the motor to heat up easily. Cooling system is required in application that sensitive to heat [2] [3]

2.2 Commutation Methods

Commutation is a process of switching current into the phases of a winding that result the movement of the motor. In brushed motor, the switching of current occur when a brushes contact with commutator as a motor moves. In brushless motor, electronics commutation which is a motor driver required in switching the current to the winding and it is more complex [11].

In brushless motor, the current in the winding must switch its polarity relative to the magnetic field of permanent magnet. The cycle of switching or commutation repeat every revolution in rotary motor. But, the cycle is repeated over a fixed distance in linear motor. A brushless linear motor needs a driver to supply current to the winding. In order the cycle is repeated over a distance, a feedback from position sensor is required to make the commutation work properly as shown in figure 1 [12].

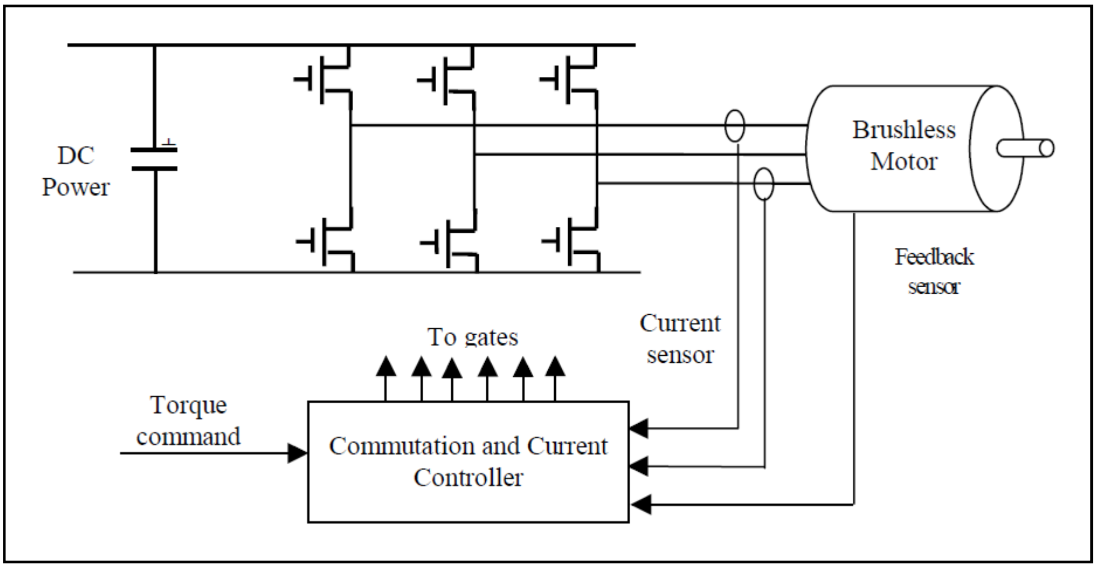


Figure 1 : Brushless Motor Drive System

In brushed motor, the commutation process is done by the brushed and commutator to provide switching to the winding in order to produce force or torque. This process can be done within the motor. The motor can be controlled by varying the supply to the motor. In brushless motor, external driver is needed to provide commutation process electronically. In order to control the motor, an amplifier and controller is needed.

In brushless motor, position sensor is very important for commutation process. The current will be injected to winding and vary in magnitude and polarity with reference of position sensor. The commutation cycle for brushless linear motor is repeated over fixed distance or stroke length of the motor.

There are three electronic commutation schemes to drive the brushless linear motor which are trapezoidal, six-step and sinusoidal commutation as shown in figure 2. Each of schemes has its own configuration and feedback [11].

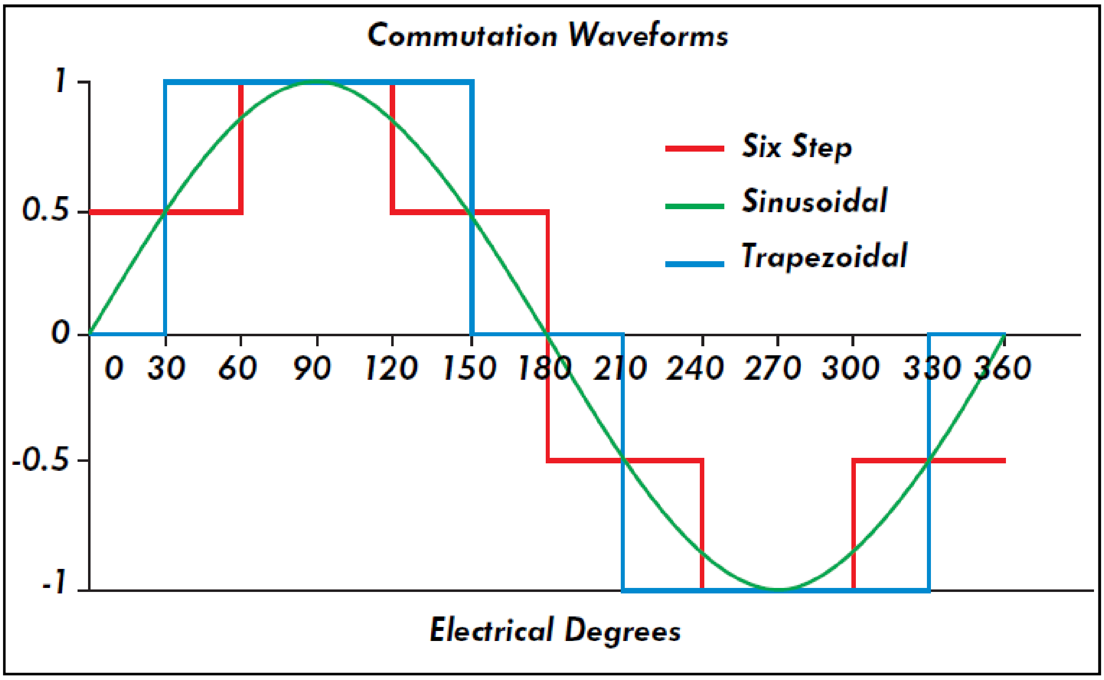


Figure 2 : Commutation Waveform

Trapezoidal commutation scheme is the simplest commutation and cheapest to implement it. It only needs digital hall devices to change the phase current sequence. When the phase current sequence is changes, motor will commutate. For the six-step commutation, it is similar to the trapezoidal but six-step has two current levels. Both of schemes has disturbance that will cause increase in temperature [11].

For the sinusoidal commutation, analogue hall device is used which will generate a sinusoidal waveform to commutate the motor. The generation of the waveform from hall device is referred to magnetic pole as the motor passes the magnetic pole of magnet. The sinusoidal waveform is best to used and motor will run smoothly and will drive more efficiently and produce less heat [11].

2.3 Tubular Motor

Linear motion always related by actuator. Before linear motor is introduced, mostly actuator is driven by rotary motor, hydraulic and compressed air (pneumatic). The Servotube Actuator is a linear motor that will offer optimum solution in automation application.

This motor will provide high speed and acceleration in motion than rotary motor with maximum velocity The motor also very cost-effective compared to motor that have application required flexibility and range of control [9].

With an internal dry bearing, this motor provides clean and quiet motion. In addition, this motor will required no maintenance and adjustment and also life span is greater than the conventional motor. This motor is applicable ideally for push, pull, lift material handling and packaging application [9]. Furthermore, the force of the motor can be obtained for the body or shaft of the motor as shown below.

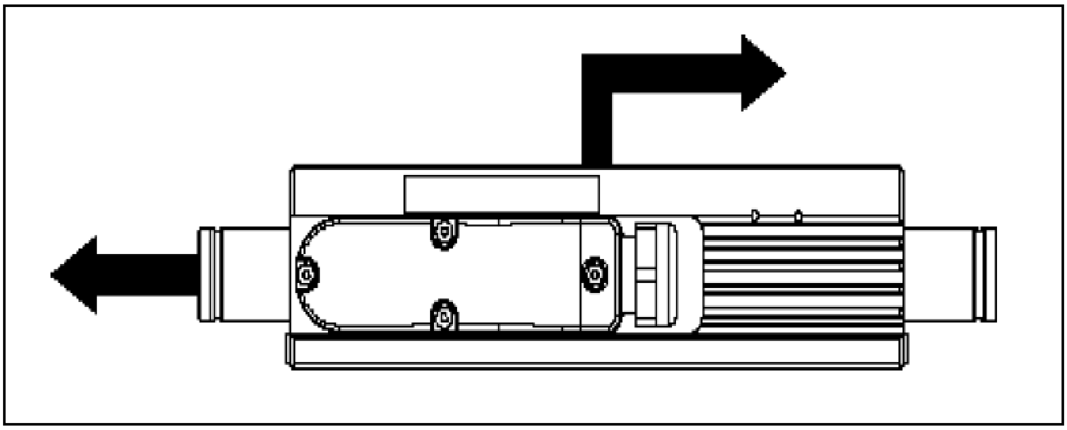


Figure 3 : Tubular Linear Motor's motion

The figure below is the basic construction of tubular linear motor. Commonly, the motor are brushless 3 – phase motor with a current will be injected to the motor forcer windings (U, V, and W) electronically for commutation process. The magnet tube is made of from a rare earth magnet and the arrangement of the magnet is shown on the figure below.

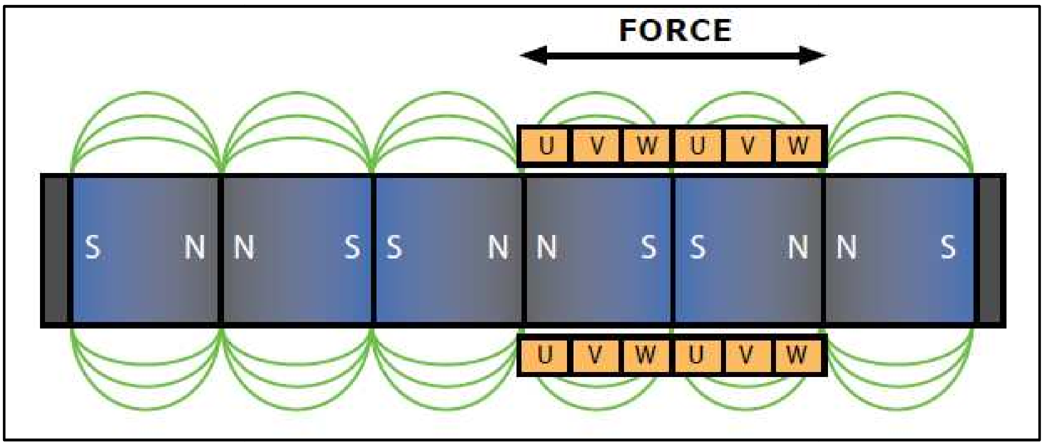


Figure 4 : Construction of Tubular Linear Motor

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

Throughout the entire project, progress of the project should follow the planned methodology to ensure the project is completed within the time constraint. In the project, the author is expected to understand the principle of linear motor by experimentation and testing method.

In the beginning of the project, research activities focus on understanding the principle of the linear motor. This can be done by trough study on several projects, articles, books and journals from previous research. All findings observed are recorded in the literature review of this project.

Then, the author is responsible to set up linear motor UTP has bought. The motor will be installed in the lab for experimenting purposes. The data sheet from the manufacturer will be understood before the linear motor and its components can be installed. After that, analysis activities of the motor profile should be done by testing and experimenting. Different modes and profiles should be reviewed in order to gain certain result.

3.2 Project Works

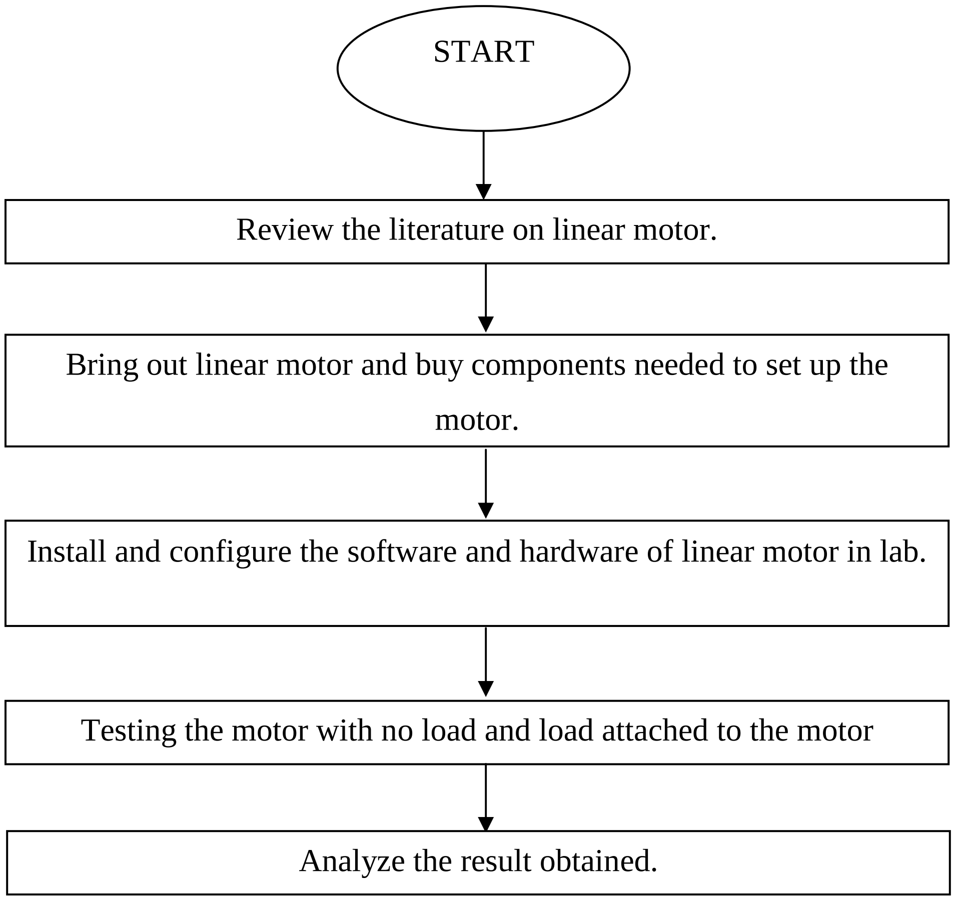


Figure 5 : Project Activity Flow Chart

In order to achieve the objective of the project, project flows as shown above must be pursued. The project has begins with review on literature about the linear motor and studies are done Servotube Actuator, Accelnet Panel ADP, CME software.

After all equipment is obtained, the installation of all components will be started in laboratory. All components will be installed in plate base for permanent installation. All components will be tested to ensure the effectiveness of the motor after the connection on linear motor is completed.

At the same time, CME 2 software will be installed at the laboratory and the communication between computer and Accelnet Panel ADP will be connected. After configuration of hardware and software has finished, the testing and experimenting can be done on the desired modes and profiles.

3.3 Tools Required

3.3.1. Servotube Actuator

From previous discussion, Servotube Actuator is linear motor that has linear in motion. Recently, linear motor is widely use in automation field due to its direct translation of linear motion in linear application. Linear motor also offers better performance, free maintenance and adjustment and longer lifespan to be compared to the conventional rotary motor. This type of motor is brushless linear motor which has motor driver works as commutation controller. This motor is powered by direct current (DC) to the motor driver and three phase supply to the Servotube Actuator [9].

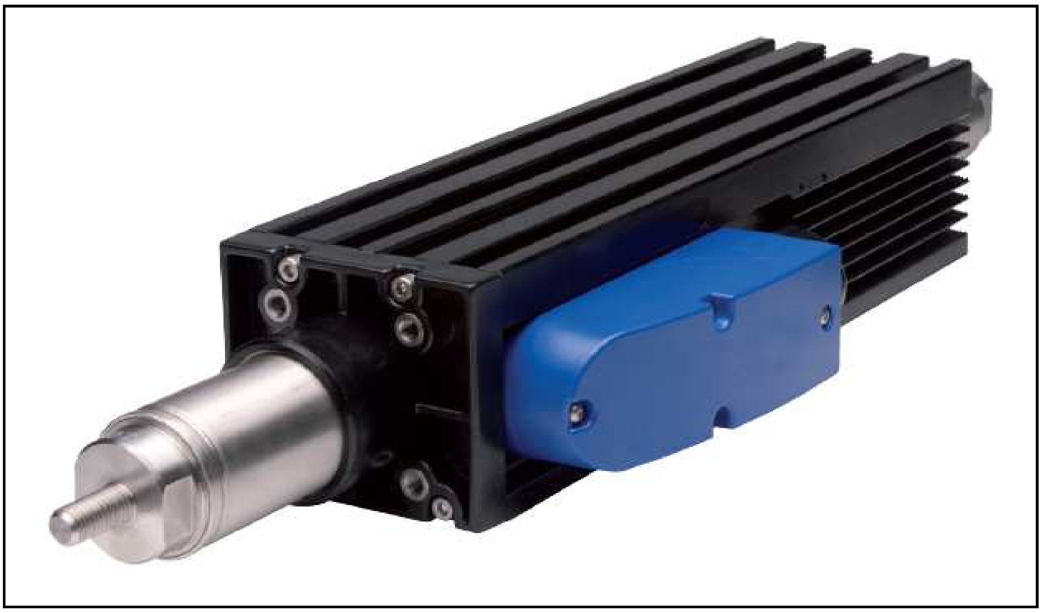


Figure 6 : Servotube Actuator

3.3.2. Accelnet Panel ADP

Accelnet Panel ADP is a brush or brushless motor driver which powered by DC. Accelnet can have different modes of controlling position, velocity and torque of a motor. Accelnet can be a stand alone driver after certain modes wanted to be used is programmed to the driver [10].

Figure 7 : Accelnet panel ADP

3.3.3. CME 2 Software

CME 2 Software is java based software developed by Copley Control. The motor drive is set up to certain mode using MCE 2 Software communicating by using RS-232 cable. All operation and modes needed to configure the motor driver are easily reached using this software.

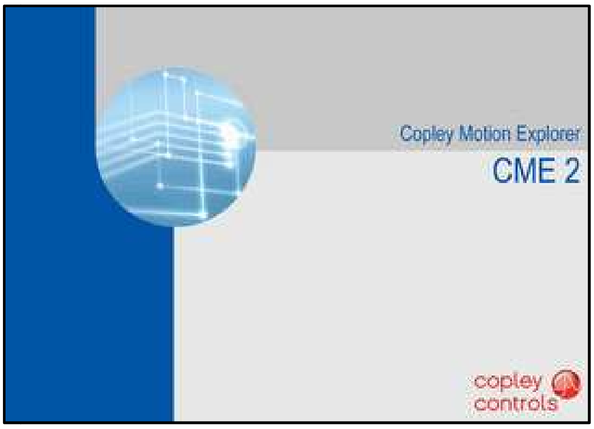


Figure 8 : CME 2 Software

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 System Installation and Configuration

In Installation and Configuration of the motor, 2 types of configuration need to be done to run the motor which are hardware wiring and CME 2 software configuration. First is setup a hardware configuration as shown below. After that, configuration of CME 2 software need be done to run the motor.

4.3.1. Hardware Wiring

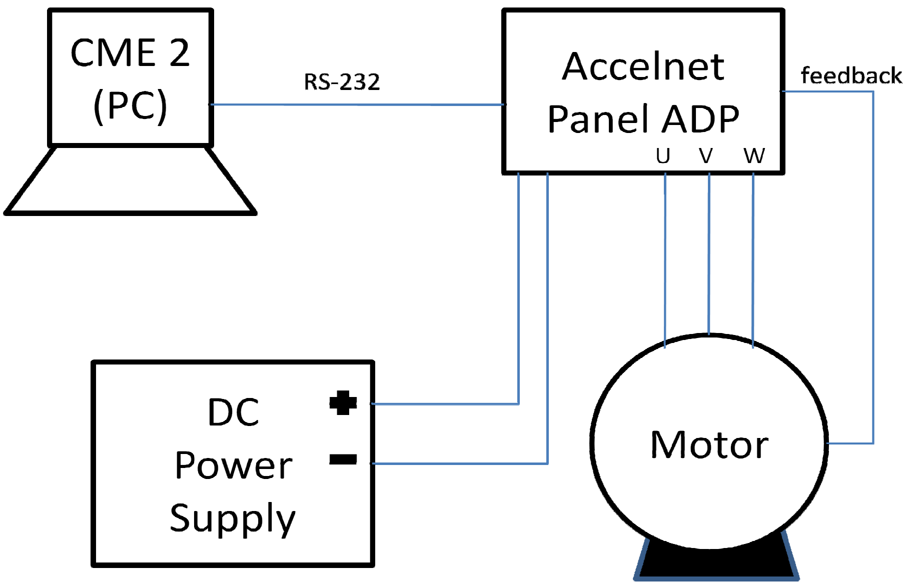


Figure 9 : Hardware Wiring Overview

CME 2 software and the Accelnet Panel ADP driver are linked via RS–232 port. RS-232 is connected to the COM port of PC with a D- Sub 9 pins, male connector and accept a cable with RJ-11 connectors for connection to the Accelnet RS-232 port (J6).

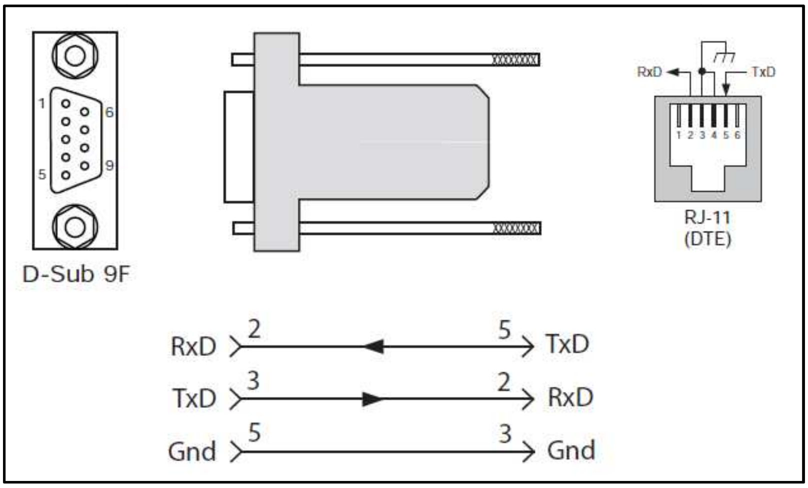


Figure 10 : RS-232 Connection

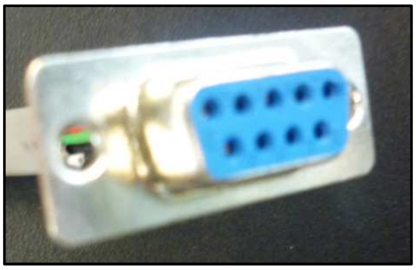


Figure 11 : D- Sub 9 pins, Male Connector

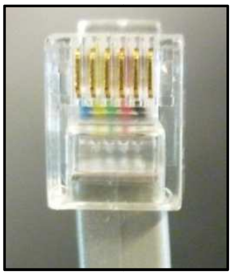


Figure 12 : RJ-11

Figure 13 : Accelnet RS-232 Port (J6)

Motor connection made up with 3 different types: phase, temperature sensor and feedback. The phase connection will carry the current from amplifier to drive the motor to produce a movement of the motor. The temperature sensor connection is a protection sensor to protect the motor from overtemperature which can cause damage to the motor. The feedback of the motor can be any such digital quad encoder, resolver, analog encoder or digital hall depending on the type of the motor.

The servotube actuator comes with two function cables which are sensor function cable and power function cable. These two cables will be connected to Accelnet driver. Motor will be supplied with AC power from Accelnet driver and motor feedback is provided to the Accelnet through sensor function cable. The senvotube actuator has a feedback of analogue encoder from position sensor.

The power cable of motor has 4 cores which are phase U, phase V, phase W and earth. This cable will be connected to Motor and Power Port (J1) port of Accelnet driver by using terminal block 6 positions connector. For the signal function cable, the cable will be connected to motor feedback (J2) port by using high density D-sub 15 position connector. The driver connection procedure can be referred in Appendices.

Motor phase cable will carry 3 –phase output current from amplifier. Since the motor is a brushless 3-phase motor, the current is produced by the PWM output of 3-phase MOSFET inverter. So, PWM will provide signal for commutation of the forcer coil electronically in right sequence to main the motion of the motor.

Before that, the amplifier Accelnet Panel has input power of 20Vdc to 180Vdc, transformer isolated. The amplifier is powered by external laboratory regulated DC power supply. Since the motor is uses only for testing and experimenting with no load attached to the motor, the supply voltage should be as low as possible to reduce the possibility of over temperature occur.

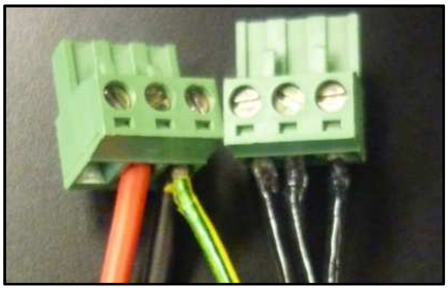


Figure 14 : Terminal Block, 6 Positions

Figure 15 : D-Sub, 15 positions, Male

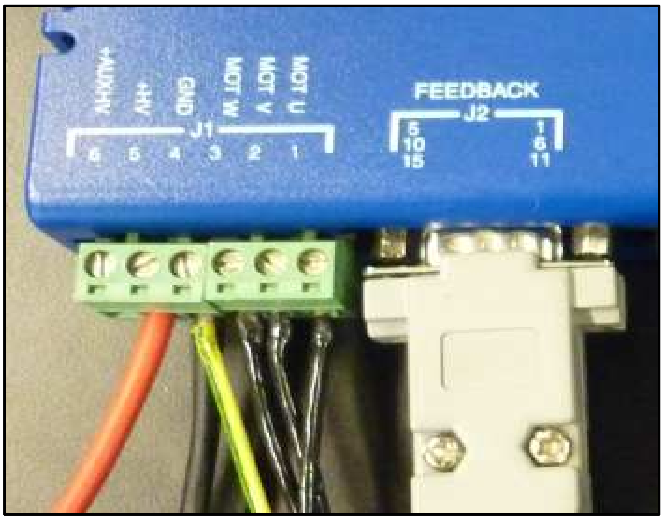


Figure 16 : J1 and J2 Accelnet Ports

4.3.2. Configuration on CME 2 Software

After hardware configuration is done, the next step is to configure the motor from the CME 2 software. Several basic steps should be followed in order to setup and tune the driver and motor. The procedures are listed below:

1. Prepare for setup by understand the safety and warning features in configuring the driver and motor. The wiring and connection is verified before start and make sure the motor is tied and no load attached to the motor. Power up the driver with minimum 20 Vdc.

2. Enter the basic setup parameter of the motor with reference of manual layout of motor and driver. Basic parameter will be shown in Figure below.

Motor Family:	Brushless
Motor Type:	Linear
Hall Type:	Analog
Hall Phase Correction:	Off
Use Halls for Velocity/Position:	Off
Use Back EMF for Velocity:	Off
Motor Feedback:	Low Frequency Analog
Load Feedback:	None
Multi-mode Port:	Emulated Motor Feedback
Operating Mode:	Position, Analog Input

Figure 17 : Basic Setup

3. Configure the motor, feedback and brake stop parameter with reference of the type of motor used which are linear or rotary.
4. Set an initial gains and limits of the motor. It can be done automatically by using calculate function in the software.
5. Configure digital input and output and command input of the motor.
6. Identify the fault if it occurred from error log screen. Analyze and correct the fault.
7. Run the motor in a move of jog mode. If the motor run in jog mode it can verify the driver can drive the motor.
8. Tune the motor’s control loop starting with the current loop, then the velocity loop and position loop. Before start tuning, make sure that the motor is mounted firmly and all the motor setting is verified accurately.
9. Configure homing parameters and perform homing optional test.
10. Test and analyze motion performance and sequence by using scope tool. Scope tools also can be medium to monitor and diagnose the performance of the motor.

4.2 System Testing

After the hardware and software configuration is done, all the internal and external components in the whole system are ensured works very well. All the wiring connection must be correct as in data sheet and all faults is cleared before the motor can run.

4.3.1. RS-232 Communication

Before CME 2 software configuration is done, the RS-232 communication between Accelnet Panel and PC COM port is confirmed. Before that, the software must be installed first and the amplifier must be powered up. If the amplifier could not connect to the PC COM, notification of communication error will appear as shown in the figure below.

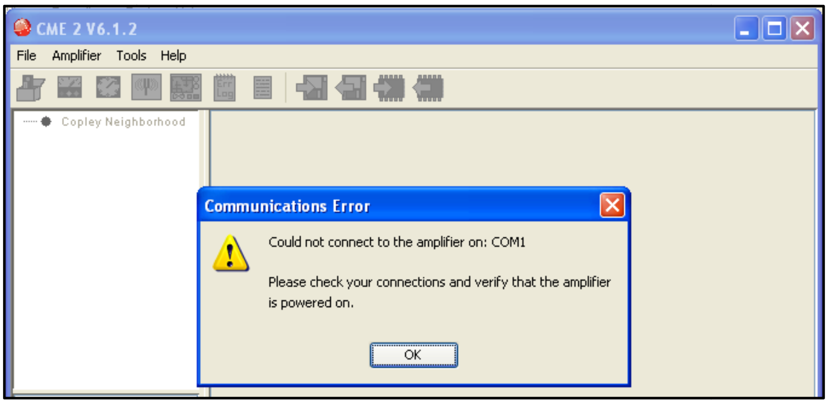


Figure 18 : Communication Error

This error can occur when the amplifier is not powered on or cable connection is wrongly connected. The communication problem between the Accelnet and the CME 2 may be caused by the RS-232 connection. After the connection is checked again, two cables are swapped with Rx of RS-232 are connected to Rx of RJ-11 as shown in figure below. The Rx of RS-232 should be connected to Tx of RJ-11. This wrong connection can be identified by using a device called PC Cable Tester. After the correction is done, the CME 2 software and the Accelnet driver now can communicate.

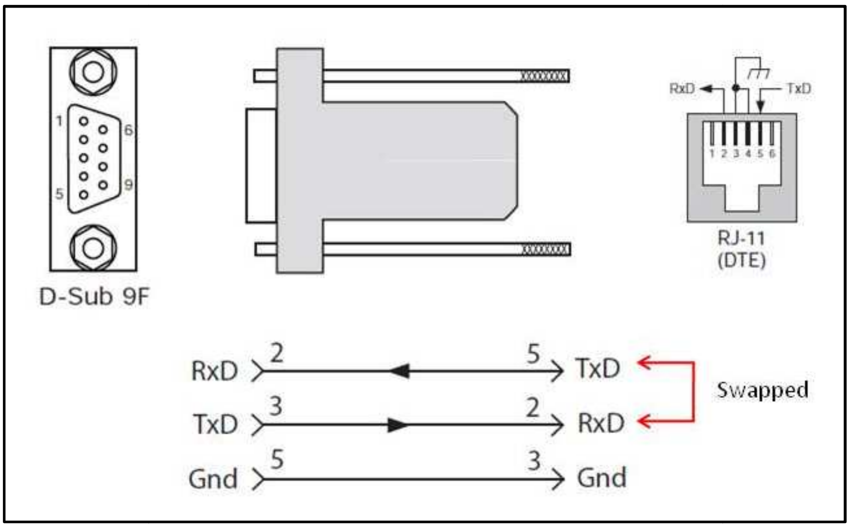


Figure 19 : Cable Swapped

Figure 20 : PC Cable Tester

4.3.2. Faults Configuration

After the PC COM port (CME 2 Software) and Accelnet Panel is connected, the procedure to setup the amplifier and motor must be followed in order. After 5th step is followed, fault is occurred. There are 2 faults occur which are under voltage fault and feedback error fault. Faults will be shown in error log screen as shown in figure below. Under voltage fault happens when the bus voltage drop below the voltage limit. This fault can be cleared after bus voltage return to its voltage range.

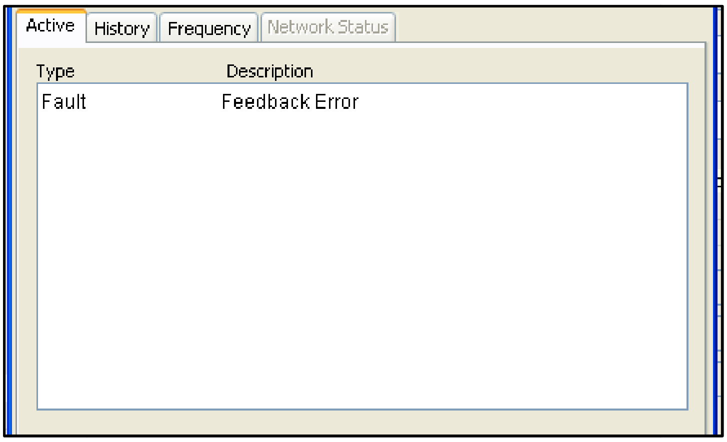


Figure 21 : Error Log Screen

Feedback error fault is a quite complicated fault because it can happen in 3 different reasons. First, the fault occurs if over current situation occur on output of internal 5Vdc supply to power up the feedback. It can be corrected if the feedback current returns to its operating range. The operating range for voltage and current is 5Vdc with tolerance of 0.25Vdc and 15mA with tolerance of 5mA respectively. The voltage and current of internal supply is verified manually using multimeter. The result is the voltage and current supply from the amplifier is 5.0436Vdc and 18.8mA. So, voltage and current is supplied to the amplifier within the operating range. Hence, no over current condition is detected on internal power supply of amplifier to power the encoder feedback.

Second, the fault occurs when feedback signal from analogue encoder is not connected or out of range and can be cleared if the signal stay within the operating range. This is a likely reason of the feedback error fault occur and will be examine in detail later in the report. Analogue encoder feedback in this system is position sensor of servotube actuator. Lastly, the reason for the fault occur is due to the differential signal from incremental encoder is not connected. For this fault, it will not occur in the system since the system not use an incremental encoder.

4.3.3. Position Sensor (Analogue Encoder)

The servotube actuator is built with position sensor. Position sensor will act as a position feedback analogue encoder to the motor. So, no external encoder required in providing a feedback to the motor. The position sensor output is analogue which a sin and cos signal. Four different signals is produced by the sensor which are sin(+), sin(-), cos(+) and cos(-). The build up of the analogue output is referred to the forcer phase.

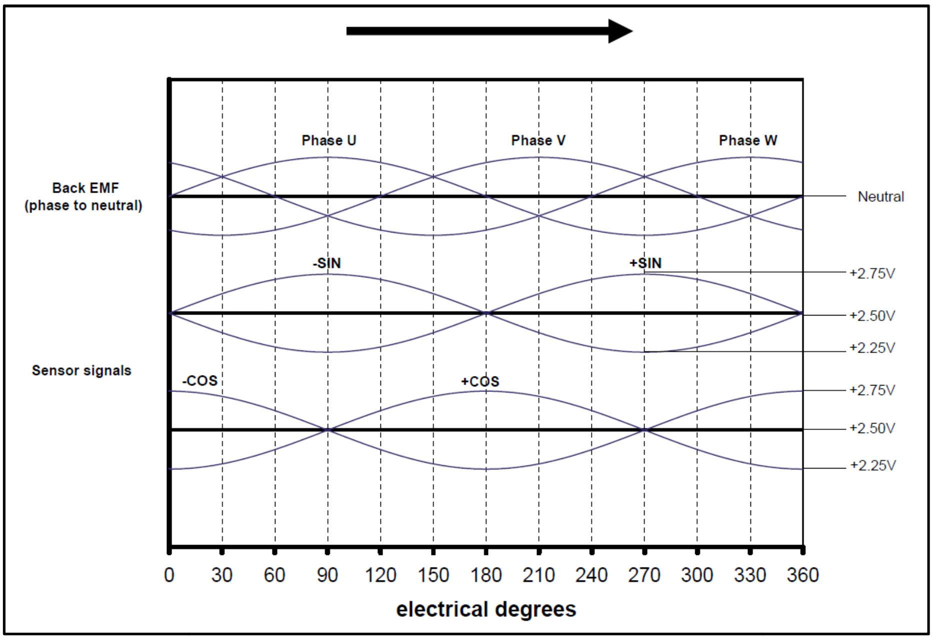


Figure 22 : Relationship between Forcer Phase Sensor Outputs

From the figure shown above, in one direction of motion (as shown by the arrow), sin(+) and sin(-) signals is in phase with phase U but in different direction. For motion shown (motion to the right), sin(-) signal is in phase with phase U and in opposite direction (motion to the left), sin(+) is in phase forcer phase U.

For the cos(+) and cos(-) is in same shape with sin(+) and sin(-) signals but shifted 90 degrees or quarter cycle. Other differences, at zero degree, cos signal start with maximum amplitude and sin signal start with zero amplitude.

One of the reasons the feedback error fault occurred is due to analogue encoder is not connected or out of tolerance. So, the signal strength and the waveform of the signal sensor may cause a feedback error fault. The position sensor output can be verified by examine the waveform of the signal using digital oscilloscope. The position sensor must be powered up and the tube is moved to obtain the signal. Two probes of channel 1 and channel 2 is tab to the signal output cable so that two different signal is obtain in the oscilloscope.

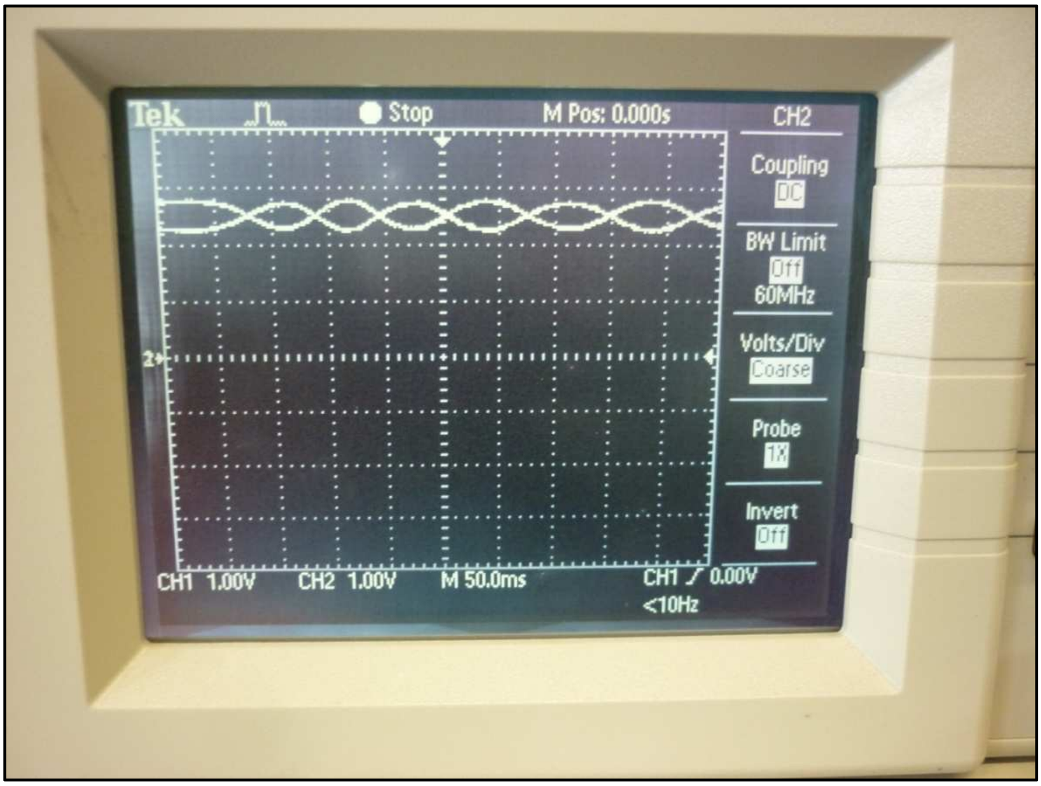


Figure 23 : sin(+) and sin(-) Signals

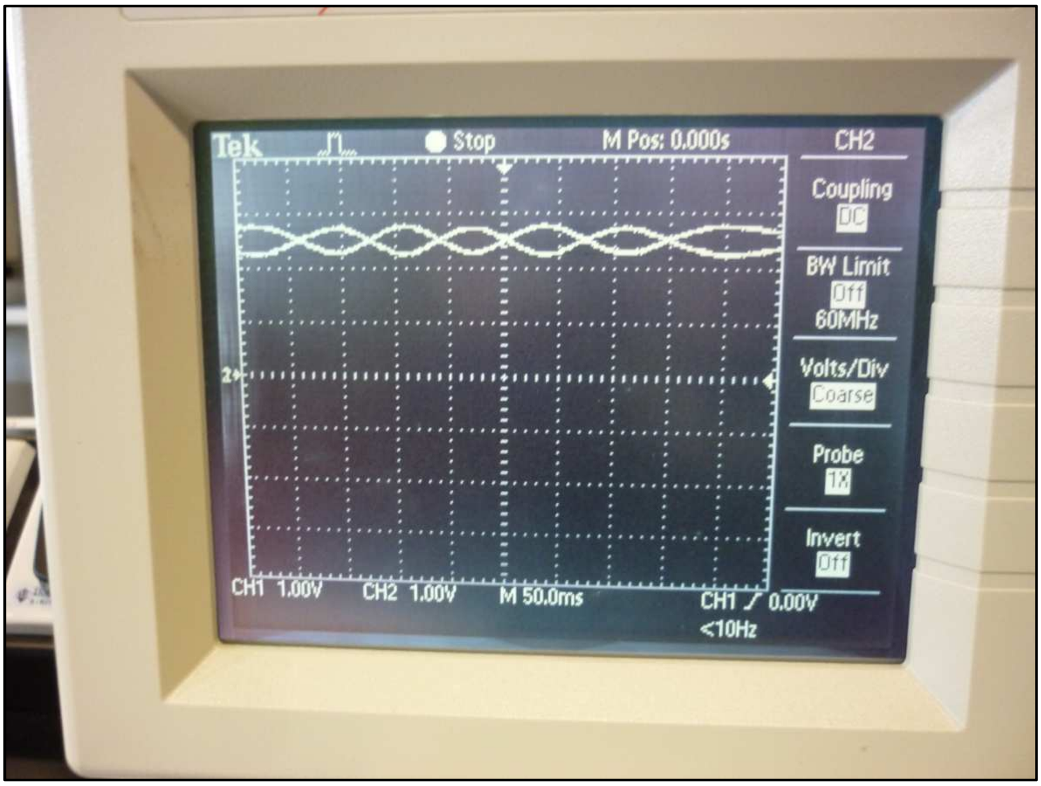


Figure 24 : cos(+) and cos(-) Signals

From the figure above, it shows that the sensor signal provide a shape of the signals same with the expected signals. The signals strength also is same as expected signal strength of maximum, minimum and zero position amplitude of the signals which is around 2.75V, 2.5V and 2.25V respectively. So, the signal waveform and strength is verified and it not causes a feedback error fault.

The feedback error fault may be caused by over current condition at the internal 5Vdc supplied by the amplifier to power the analogue encoder (position sensor). From the specification of the encoder, the supply voltage is in range of 4.75Vdc to 5.25Vdc and the supply current in range of 10mA and 20mA. From the examination of the supply voltage and supply current of amplifier using multimeter, the voltage and current are within the range which is 5.0436V and 18.8mA. So, no over current condition is detected on internal power supply of amplifier to power the encoder feedback.

4.3.4. Amplifier Firmware version and CME 2 Software Version

Amplifier’s firmware is a permanent software programme stored at the amplifier flash memory. Since the motor and amplifier is not been used for a long time, the amplifier flash hold an outdated firmware which is version 1.36. Since the CME 2 software is new version software which is version V6.1.2, the amplifier firmware and the CME 2 software may not be compatible. So, the new amplifier firmware version 1.9 is downloaded and stored at the amplifier flash memory as shown in figure below.

Figure 25 : Latest Amplifier Firmware Version and CME 2 Software Version

After a new version of amplifier firmware is stored, the software setup is done again and all the steps to setup the amplifier are followed from the beginning. No fault occurred after the setup is done and the motor can be run properly. This means that the CME 2 software is compatible with the amplifier firmware.

4.3 System Experiment and Verification

After the motor can be run, performance of the motor is examined and monitored through a CME 2 scope tools. The scope tools can provide a Function Generator and Profile Generator to drive the servotube without require any external impulse or control generator.

From the movement of the motor, position profile of the motor is analyzed. Two waveforms data will be obtained from several experiments to conduct the position profile analysis which are commanded position and actual load position. The experiment will conduct based on 3 different parameters which are amplitude (position count), frequency and commanded function wave.

For the experiment regarding the amplitude of the waveform which is position parameter, several details need to known before the experiment can be proceed. The position unit is counts. The information is,

1 Pole (electric cycle) = 71.2mm

Counts per Pole = 4096 counts

1 Count = 0.01738mm

1mm = 57.53 counts

In the first experiment, with a constant Sine Wave function and frequency of 2Hz, different amplitude of the waveform is examined. Three different waveforms with amplitude of 1000, 2500 and 4096 counts are examined.

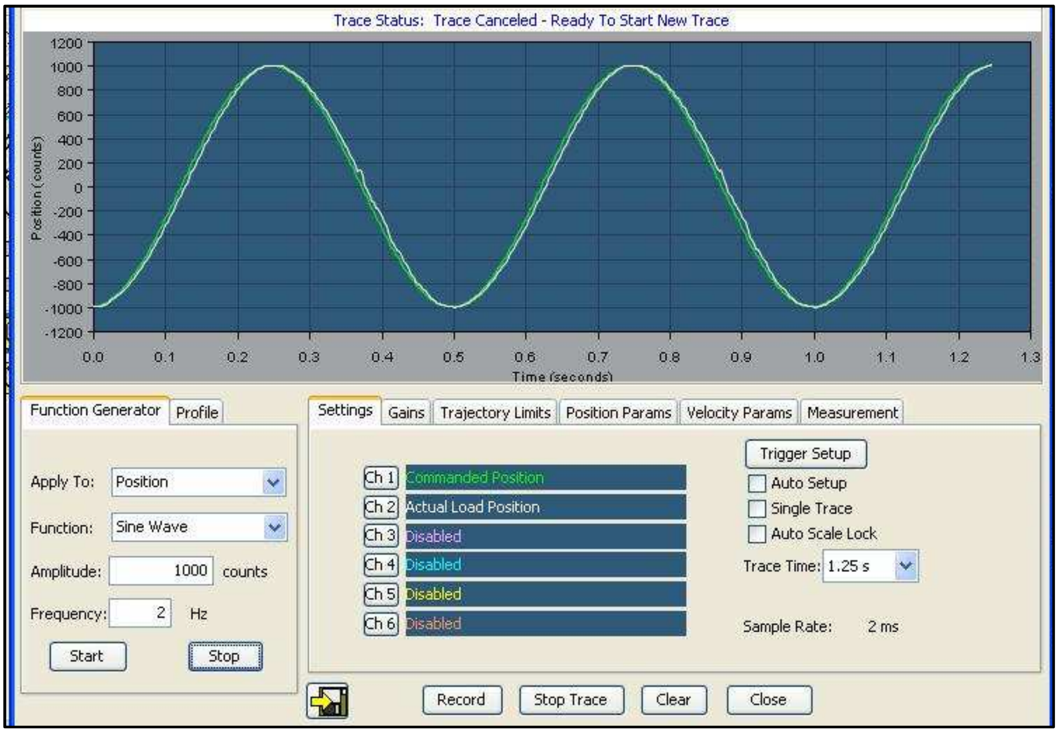


Figure 26 : Sine Wave, 1000 counts, 2Hz Waveform

From the figure shown above, the actual load position is in phase with the commanded position. With low amplitude or short position, the motor will move synchronously as the command input signal and the target position of 1000 counts is reached. The result if the amplitude is increased to 2500 counts is shown below.

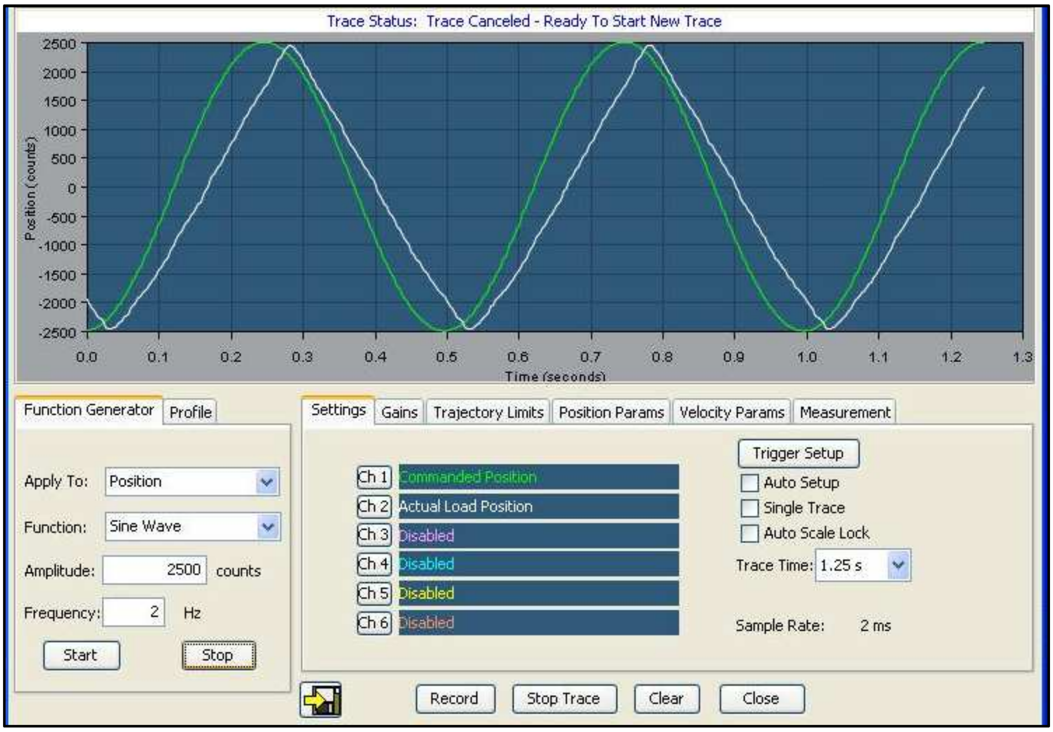


Figure 27 : Sine Wave, 2500 counts, 2Hz Waveform

For the amplitude of 2500 counts, the actual load position is still in phase with the commanded position signal. Both signals are only different in about 0.03s. In addition, the motor is moved in constant speed in both directions as referred to the actual load signal. The position of the motor before it changes direction is same as the commanded position. The result if the amplitude is increased to 4096 counts is shown below.

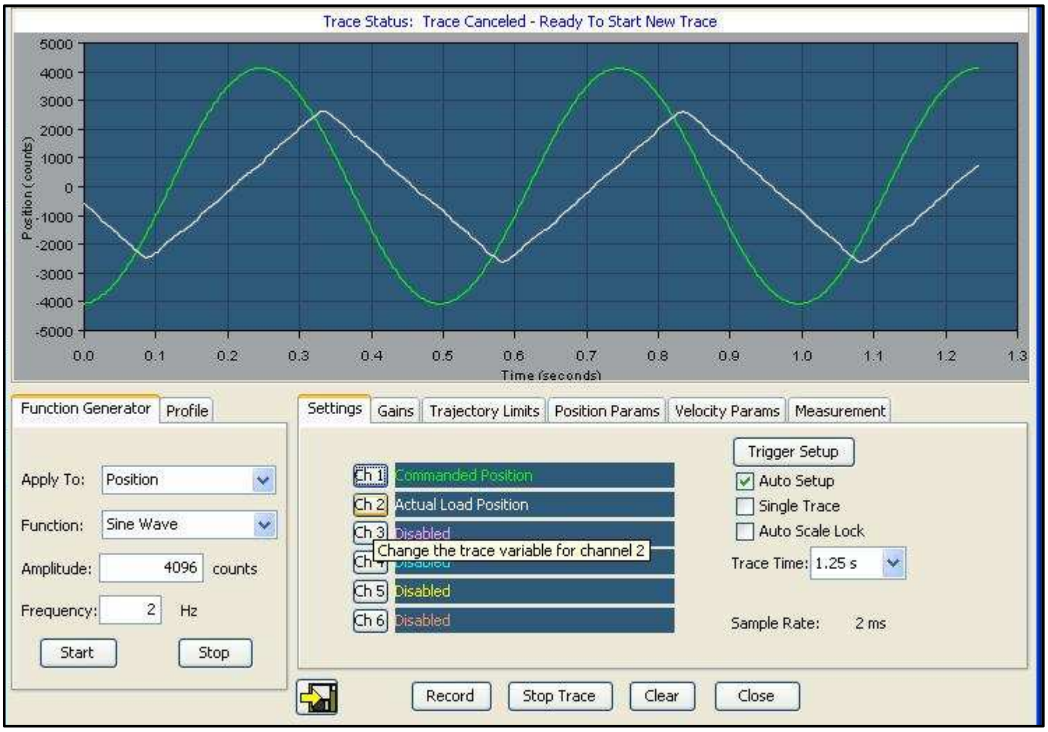


Figure 28 : Sine Wave, 4096 counts, 2Hz Waveform

From the observation of the waveform above, the motor is moved to the position same as 2500 counts and the motor move with a constant speed. The maximum position the motor can reach is about 2600 counts. The motor actual load position is still in phase to commanded position with a very small difference in time which about 0.08s. But, the obvious different is the motor travel in shorter position than the commanded position. In this experiment, for frequency of 2Hz, the motor only can travel to maximum position of 2600 counts.

For the next experiment, the frequency of the signal is reduced from 2Hz to 1Hz. The effect in reducing the frequency will be analyzed from the waveform obtained in this experiment.

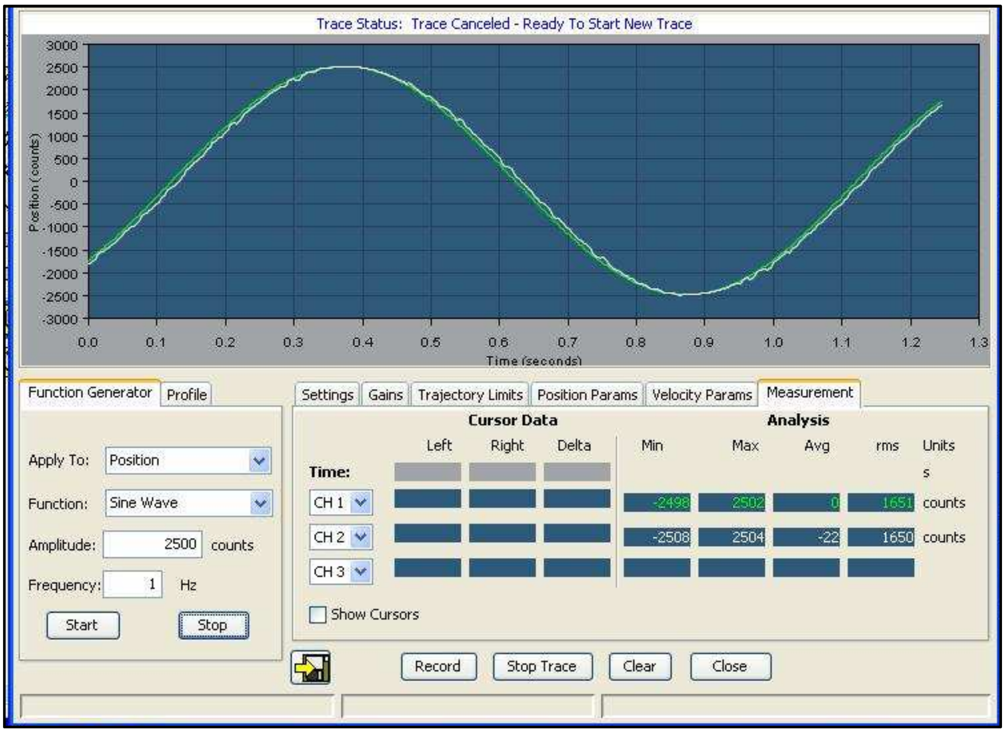


Figure 29 : Sine Wave, 2500 counts, 1Hz Waveform

For the amplitude of 2500 counts, the actual load position is in phase with commanded position signal and the target position of 2500 counts is reached. In comparison with the waveform of same amplitude but different frequency of 2Hz, in this result, there is no lag or delay between both waveforms. The amplitude of the signal is increased to 4096 counts and the result is shown below.

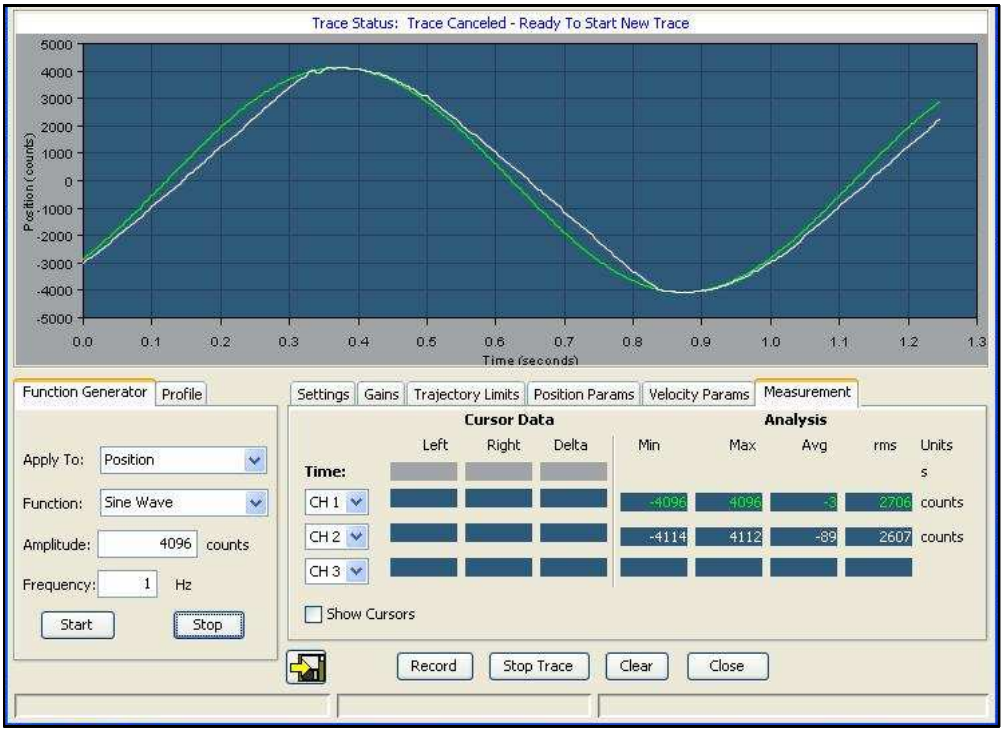


Figure 30 : Sine Wave, 4096 counts, 1Hz Waveform

From the result in the figure above, motor reach the commanded amplitude of 4096 counts. Both waveforms are in phase and no delay for the motor to reach the desired position. The amplitude is increased from 4096 counts to 6000 counts and the result will be shown in figure below.

Figure 31 : Sine Wave, 6000 counts, 1Hz Waveform

From the observation of the waveform above, the maximum position the motor can reach is about 5200 counts. The motor actual load position is still in phase to commanded position with a very small difference in time which about 0.08s and the motor move in constant speed. In this experiment, for frequency of 1Hz, the motor only can travel to maximum position of 5200 counts. So, by reducing the frequency, the motor can travel in a longer distance. Hence, to increase a maximum position the motor can travel, the frequency must be reduced.

For the next experiment, the impact of using different signal function to the actual load position is analyzed. For the position profile, only two different signal functions can be used which are Sine Wave function and Square Wave (Step Response) function. So, in this experiment, the waveform of Square Wave function with a frequency of 1Hz and variation of amplitude is analyzed.

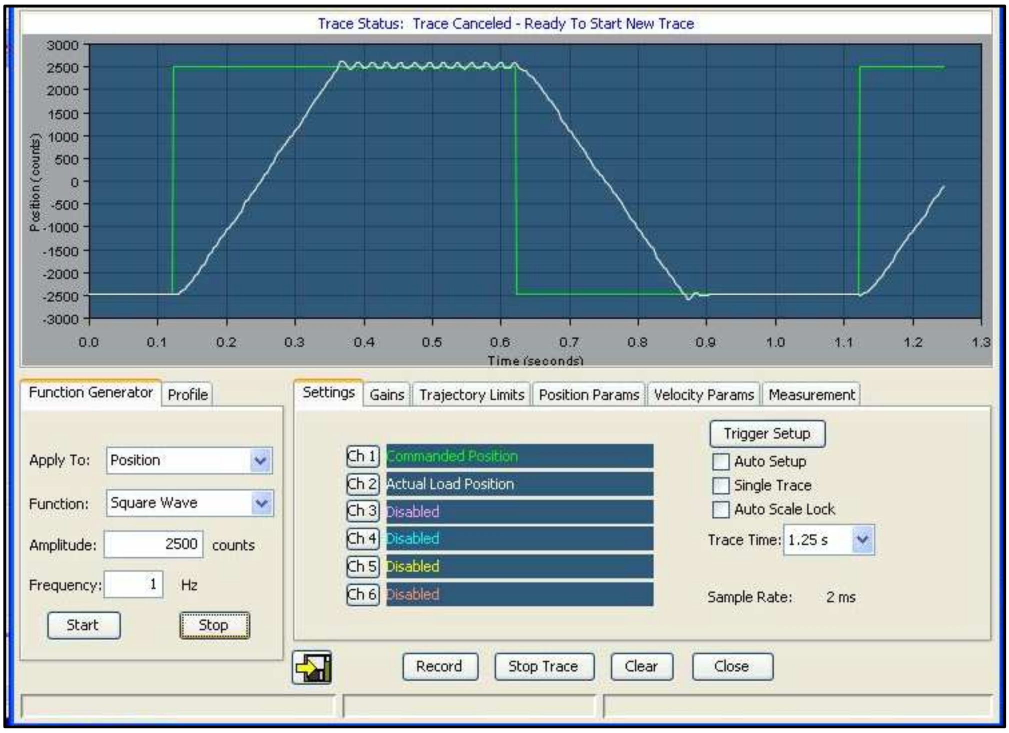


Figure 32 : Square Wave, 2500 counts, 1Hz Waveform

From the result in the figure above, the motor move with a constant speed to reach a desired position of 2500 counts. From the observation, after the motor reach a commanded position, the motor will stop at that position until the commanded signal change position direction. The amplitude is increased from 2500 counts to 4096 counts and the result is shown in the figure below.

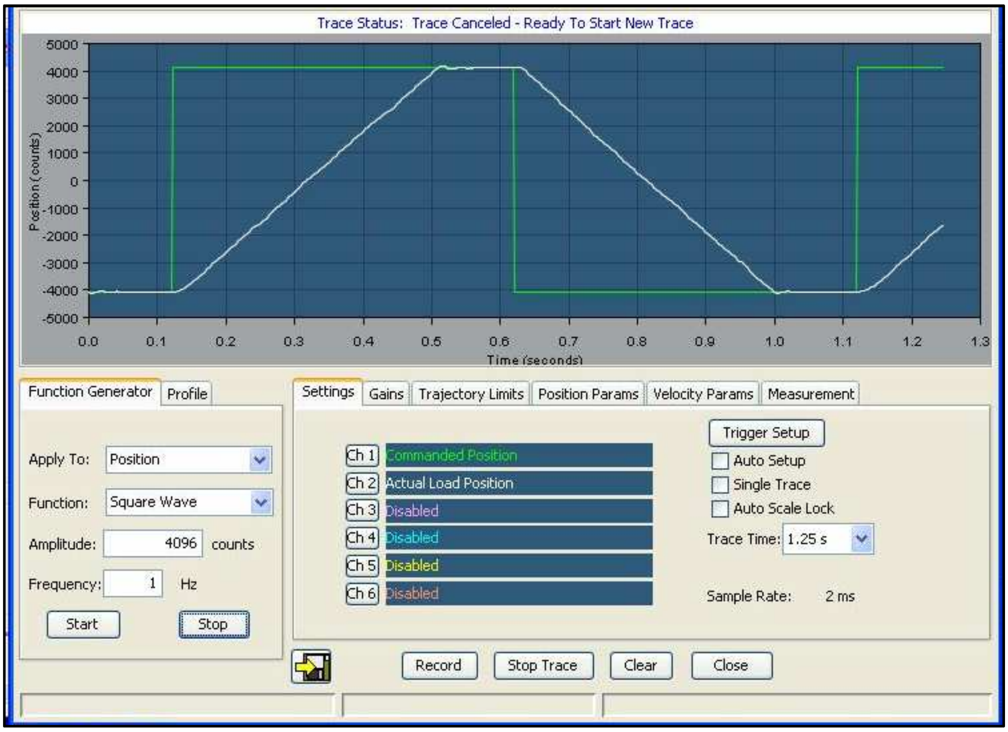


Figure 33 : Square Wave, 4096 counts, 1Hz Waveform

From the figure above, the motor reach the commanded position of 4096 counts and the motor run in constant speed. In addition, after the motor reach the commanded position, it will still stop but in shorter period compared to previous result. The amplitude is increased to 6000 counts and the result is shown below.

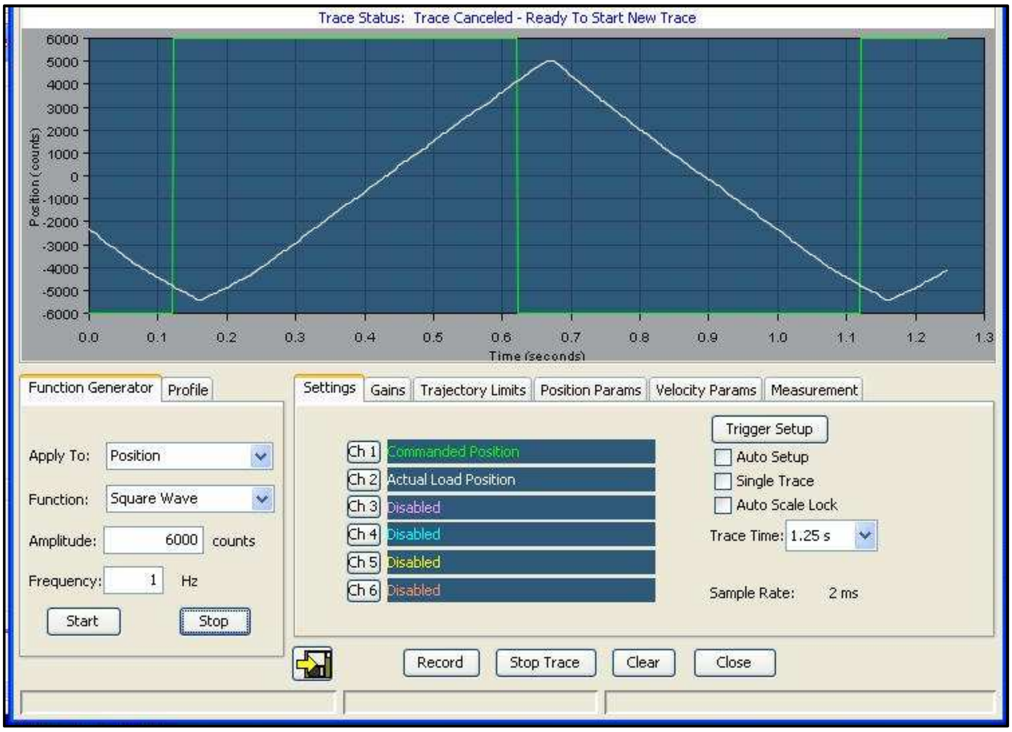


Figure 34 : Square Wave, 6000 counts, 1Hz Waveform

Form the result above, the motor is run to a maximum position of 5200 counts and the motor move in a constant speed. In addition, the motor will not stop before it changes direction. From the observation, by changing the function signal to square wave, the motor will move in constant speed to reach the commanded position and it will stay in that position before the commanded signal change in position direction. It will stay if the commanded position is lower than maximum position the motor can reach.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Based on the reading material on the usage of linear machine in the industry, there are al lot of proven cases where linear machine technology has increased in popularity due to advantages that linear motion has offered especially in linear motion application.

Hardware and software configuration will be completed at the end of the project. The Servotube actuator is connected with Accelnet Panel ADP and the controlling modes is configured by CME 2 software

From analyzed result, the conclusion is the maximum speed of the motor can limit the distance travel by the motor. From the commanded signal, by increasing the amplitude or position the signal with constant frequency will increase a speed of the motor. So, to improve the position of the motor, the velocity limitation of the motor must be increase.

5.2 Recommendations

5.2.1. Prime Mover for Linear Generator

Since the generator is machines that convert mechanical energy to electrical energy, linear motor output motion can be a prime mover to a linear generator. So, for further project of designing new prototype of linear generator, this linear motor can provide a mover to that generator with simple fastener need to be constructed to tie both shafts of motor and generator.

5.2.2. Construct a New Motor Amplifier

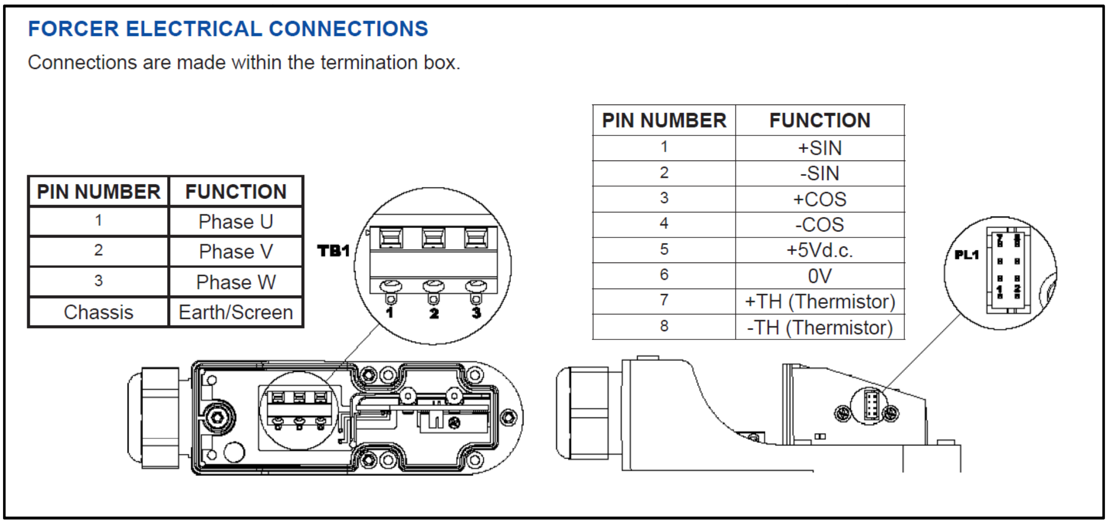
Electronic commutation for brushless motor is more complex than commutation of brushed motor due to existence of electronic components in the external motor driver. But it can produce the many commutation method for the motor for different applications. So, designing the motor driver for commutation process of certain application, it will help to increase an understanding and expertise in the commutation process especially electronics commutation.

5.2.3. Design a New Prototype of Linear Motor

In order to increase understanding in linear motor in terms of magnetic flux distribution, arrangement of permanent magnet, stroke length, winding connection and many more related to motor machine, designing and building the prototype of linear motor for new application can be a good future recommendation since a lot of new technology of linear motor has developed recently by manufacturer with different designs and applications.

APPENDICES

APPENDIX 1



FORCER ELECTRICAL CONNECTIONS

Connections are made within the termination box.

PIN NUMBER	FUNCTION
1	Phase U
2	Phase V
3	Phase W
Chassis	Earth/Screen

PIN NUMBER	FUNCTION
1	+SIN
2	-SIN
3	+COS
4	-COS
5	+5Vd.c.
6	0V
7	+TH (Thermistor)
8	-TH (Thermistor)

Figure 35 : Forcer Electrical Connection

APPENDIX 2

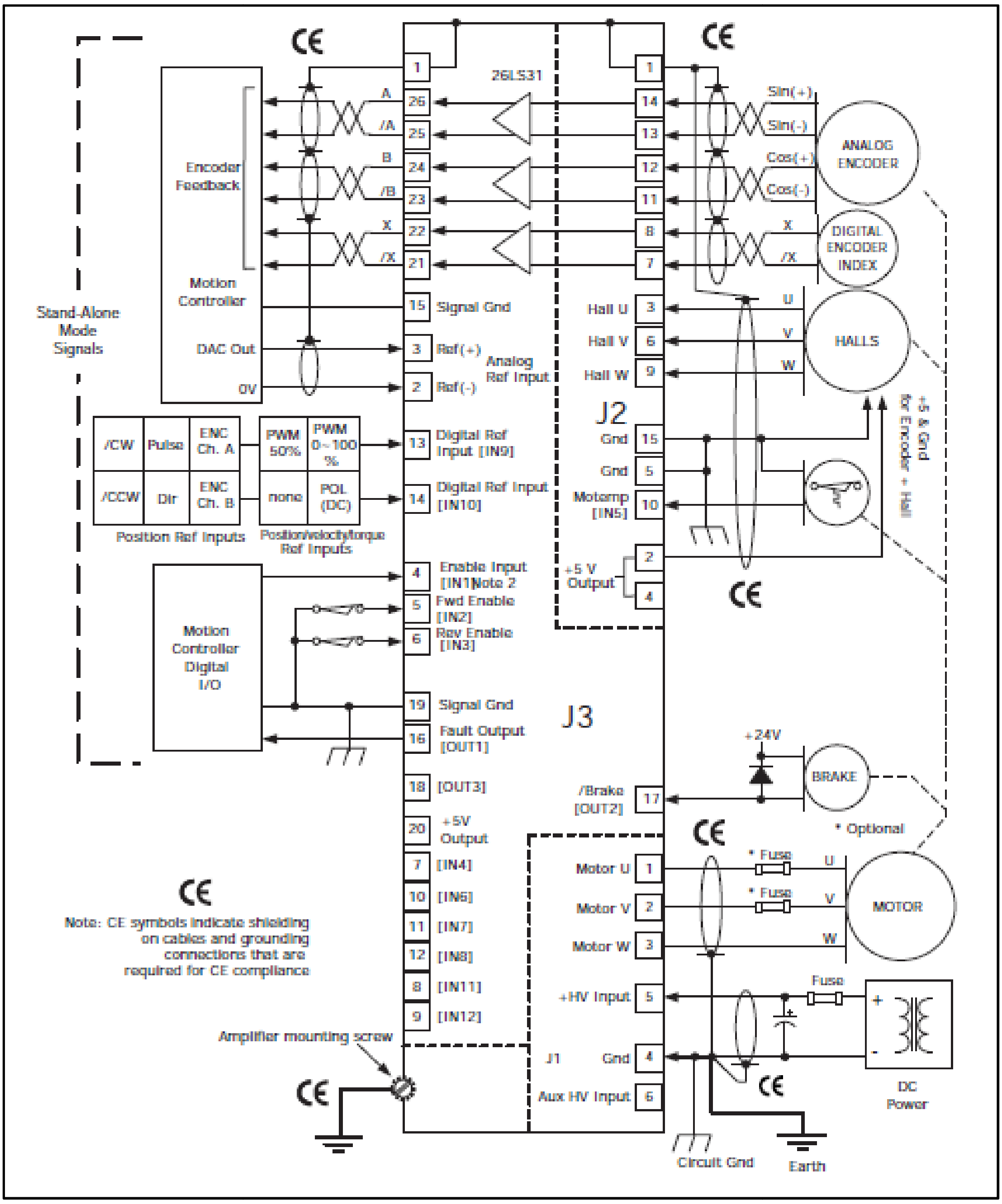
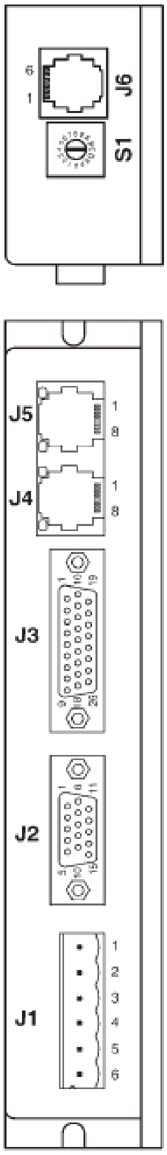


Figure 36 : Drive Connection for -S Option

APPENDIX 3



J6 RS-232

PIN	SIGNAL
1	No Connection
2	RxD
3	Signal Ground
4	Signal Ground
5	TxD
6	No Connection

J6 CABLE CONNECTOR
RJ-11 style, male, 6 position
Cable: 6-conductor modular type

J4-J4 CAN BUS

PIN	SIGNAL
1	CAN_H
2	CAN_L
3	CAN_GND
4	No Connection
5	Reserved
6	(CAN_SHLD) [1]
7	CAN_GND
8	(CAN_V+) [1]

J4, J5 CABLE CONNECTOR:
RJ-45 style, male, 8 position
Cable: 8-conductor, modular type

J3 CONTROL SIGNALS

PIN	SIGNAL	PIN	SIGNAL	PIN	SIGNAL
1	Frame Gnd	10	[IN6] HS	19	Signal Gnd
2	Ref(-)	11	[IN7] HS	20	+5 Vdc (Note 1)
3	Ref(+)	12	[IN8] HS	21	Multi Encoder /X
4	[IN1] Enable	13	[IN9] HS	22	Multi Encoder X
5	[IN2] GP	14	[IN10] HS	23	Multi Encoder /B
6	[IN3] GP	15	Signal Gnd	24	Multi Encoder B
7	[IN4] GP	16	[OUT1]	25	Multi Encoder /A
8	[IN11] GP	17	[OUT2]	26	Multi Encoder A
9	[IN12] GP	18	[OUT3]		

J3 CABLE CONNECTOR:
High-Density D-Sub
26 Position, Male

J2 MOTOR FEEDBACK

PIN	SIGNAL	PIN	SIGNAL	PIN	SIGNAL
1	Frame Gnd	6	Hall V	11	Encoder Cos(-)
2	+5 Vdc (Note 1)	7	Encoder /X	12	Encoder Cos(+)
3	Hall U	8	Encoder X	13	Encoder Sin(-)
4	+5 Vdc (Note 1)	9	Hall W	14	Encoder Sin(+)
5	Signal Gnd	10	[IN5] Motemp	15	Signal Gnd

J2 CABLE CONNECTOR:
High-Density D-Sub
15 Position, Male

J1: MOTOR & POWER

PIN	SIGNAL
1	Motor U Output
2	Motor V Output
3	Motor W Output
4	Ground (HV, Signal)
5	+HV Input
6	Aux HV Input

J1 CABLE CONNECTOR:
Terminal block,6 position, 5.08 mm, black
Beau: 860506
RIA: 31249106
Weidmuller: 1526810000
PCD: ELFP06210
Weco: 121-A-111/06
Tyco: 796635-6

Figure 37 : Port & Pin Number for Drive Connection

APPENDIX 4

Table 1 : Analogue Encoder Cable Termination

Servotube Actuator (Sensor Cable)		**Accelnet Panel ADP (J2 Port)**	
Sensor Function	**Cable**	**Pin**	**Signal**
+SIN	Blue	14	Encoder Sin (+)
- SIN	Red	13	Encoder Sin(-)
+COS	White	12	Encoder Cos(+)
-COS	Brown	11	Encoder Cos(-)
+5Vdc	Yellow	2	+5 Vdc
0V	Green	5	Signal Gnd
+TH (Thermistor)	Pink	10	[IN5] Motemp
-TH (Thermistor)	Grey	15	Signal Gnd
Screen	Screen	1	Frame Gnd

Table 2 : Power Cable Termination

Servotube Actuator (Power Cable)		**Accelnet Panel ADP (J1 Port)**	
Power Function	**Cable**	**Pin**	**Signal**
Phase U	Black 1	1	Motor U Output
Phase V	Black 2	2	Motor V Output
Phase W	Black 3	3	Motor W Output
Earth	Green/Yellow	4	Ground (HV, Signal)

Table 3 : DC Power supply Termination

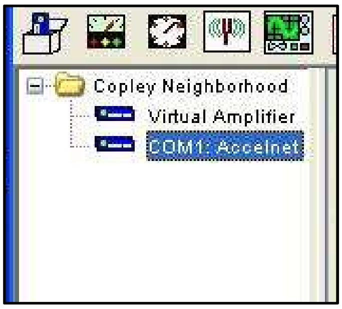
DC Power Supply		**Accelnet Panel ADP (J1 Port)**	
Supply Function	**Cable**	**Pin**	**Signal**
Positive (+)	Red	5	+HV Input
Negative (-)	Black	4	Ground (HV, Signal)

APPENDIX 5

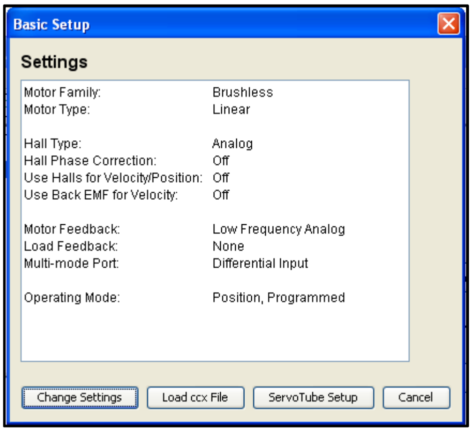
Configuration on CME 2 Software

1. Host Computer Requirements
    a. Minimum hardware requirement:
    - CPU : 1GHZ
    - RAM : 512 MB

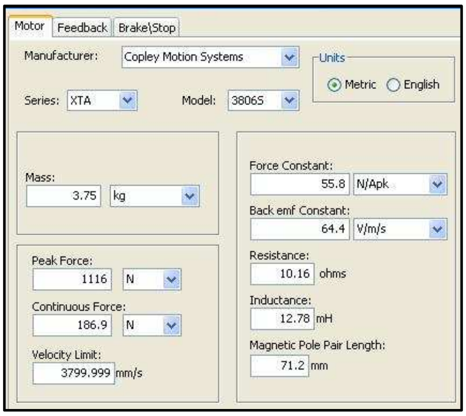
    b. Operating system: Windows XP, Vista and 7.
    c. Software: CME 2 Software Version 6.1 or higher.
2. Serial Communication parameters
    a. Communications Wizard (Select Device: Serial Ports).
    b. From available ports, select (remove) port that will be used for amplifier.
    c. Configure the Baud rate for selected port (baud rate: 115200).
3. Connect the amplifier
    a. Select the amplifier (COM1: Accelnet) from the list of amplifier available in Copley neighbourhood folder.



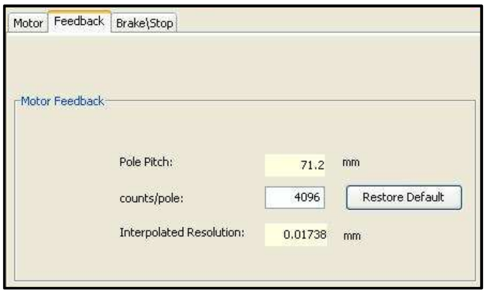
4. Basic Setup parameters
    a. Click Basic Setup icon and select ServoTube Setup.
    b. Set the Motor Option of Servotube (Model: XTA, Series: 3086S).
    c. Select the Operating Modes Option (Operating Mode: Position, Command Source: Software Programmed).
    d. Select Multi-mode Port (Multi-mode Port: Differential Input).
    e. Save the configuration.



5. Motor/Feedback Parameters
   a. Click the Motor tab to view the motor parameter.
   b. All the parameter is filled by default and verifies the parameter with reference of motor data sheet.



   c. Click the feedback tab to view the feedback parameters.
   d. Change count/pole if required and the default value is 4096 counts.



   e. Click Calculate to have software calculated loop gains and functions.
6. Input/output Parameter

   The input and output is set up by default. The change can be made by click the input tab or output tab.
7. Clear all the faults

8. Phase the motor by using auto phase tool
   Perform Motor Wiring Setup and Analogue Hall Setup.
9. Run a Jog Mode
   Clock to control Panel tab and Enable the Jog Mode to verify the amplifier can drive the servotube.
10. Auto tune the control loop
    Perform Current, Velocity and Position Loop Tune.
11. Analyze the performance of the motor using Scope tool.

REFERENCES

[1] Danielsson, O. (2003). *Design of Linear Generator for Wave Energy Plant*.Uppsala.

[2] J. Barrett, T. Harned, J. Monnich, *Linear Motor Basics*, Parker Hannifin Corporation.

[3] DeHart, S. Chopra, S. Daepp H. *Motors*

[4] Herman, I. *Electrical Transformers & Rotating Machines*. NewYork. Thomson

[5] Gieras, F. (2010) Permanent Magnet Motor Technology. Boca Raton.

[6] Mohd Nor, N. (2010). *DC Machine*. Electrical Machine 1

[7] Ibrahim, T. (2012). *Review on Electrical Machine*. Electrical Machine 2

[8] Lu, L. Yao, B. Chen, Z. Wang, Q. (2008). *Adaptive Robust Control of a Linear Motor Driven Precision Industrial Gantry With Improve Cogging Force Compensation*. Michigan.

[9] Dunkermotoren Linear System. (2011). *Models XTA3804-3810 Servotube Actuator*.

[10] Copley Controls. *Accelnet Panel AD*

[11] Aerotech. *Linear Motors Application Guide*

[12] Dal, Y. Jae, H. (1999). *About Commutation and Current Control Methods.* Virginia