# Test-Bed to Measure the Performance Criteria of Actuators

**Robotics Research Group, University of Texas at Austin**
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## 1. Introduction

In order to complete the actuator test architecture considering all the possible situations, a dynamic and nonlinear test environment was required. The Nonlinear Test Bed for Actuators (NTBA) was created to measure and record an array of physical properties during nonlinear load experiments. In order to simulate the most general situations during real operation of the actuator, two different types of loads (such as load motor with harmonic drive, and a non-linear load produced by a four bar linkages) can be applied. The NTBA will validate if the proposed prime mover criteria can be accurately obtain through experimentation and their usefulness in developing the operational performance envelopes. We will discuss the procedure to build the test bed and the capability of each component in the test bed to generate the required physical performance information.

## 2. Background

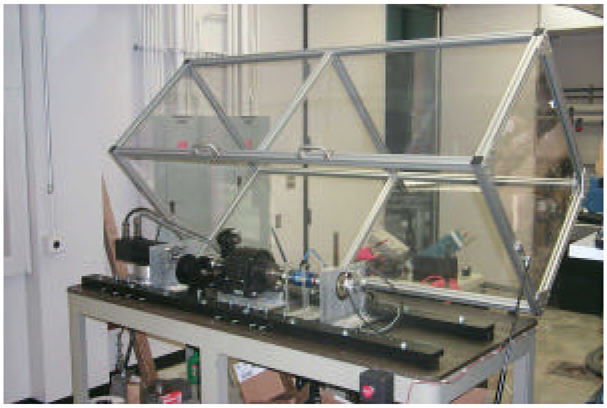


Figure 1. Nonlinear Test Bed

The Robotics Research Group (RRG) at the University of Texas at Austin developed the Actuator Endurance and Reliability Test-Bed to test an actuator under a static load such as a brake [1]. This test-bed measured torque and power using several fundamental test parameters and additional test conditions. RRG test beds can now measure actuator accuracy, repeatability, and stiffness. The test parameters obtained from the experiment were analyzed to determine the capabilities of the actuator in a steady state loading situation. The torque-speed curve obtained from experimental set-up showed the output curve limited by a fixed maximum temperature. Therefore, it did not create a basis to anticipate the failure of the test motor at an elevated internal motor temperature. This did not produce a complete description for the performance of the actuator. The torque-speed curve's shape varies at different temperatures. Connecting the torque-speed curves over varying temperatures creates a single 3D surface. The steady state performance of an actuator in this test-bed did not give us a complete picture for the use of actuators in specific applications such as for an electric car, the actuation of a trim tab in submarine, etc. Therefore, the nonlinear Test Bed is needed.

## 3. Overview of the Test Bed

RRG’s initial motivation for building the Nonlinear Test Bed was to find the performance envelope plots for Permanent Magnet Synchronous Motors, but the Test-bed had to be flexible enough to be used for a variety of prime movers as well as future research efforts involving Condition-Based Maintenance (CBM). Based on these objectives, the necessary operational characteristics of the test bed were specified. The maximum power is approximately 10 HP with a maximum speed up to 5000 RPM. All components are held rigidly against a variety of load profiles by long black steel rails. The rails have ½” threaded holes on the top to resist force in the vertical direction and ¼” holes in the side to resist force in the horizontal direction. The screws allow for adjusting the alignment.

The test bed is designed to overcome misalignments problems caused by manufacturing tolerances and to be modular. The supporting blocks have four threaded screws to transfer the force to the surface of the test bed by finding the height and angle with respect to the horizontal surface of the test bed. The screws for the supporting blocks and the screws for the rails operate to accurately position each component. Additionally, the rails are designed to be modular, so a multitude of configuration can be achieved as long as the height from the surface of the test bed to the rotational center is less than 6 *in*.

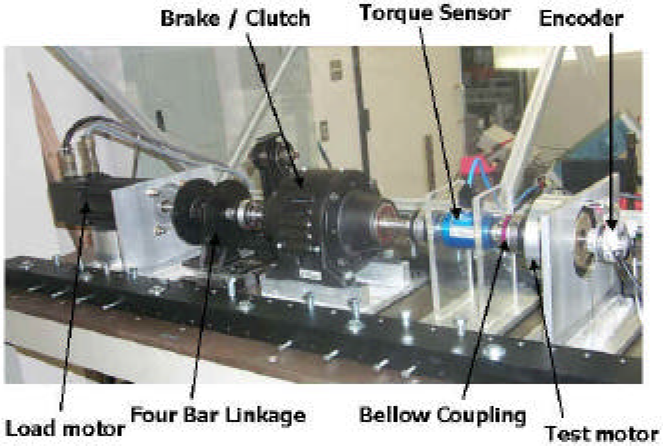


Figure 2. Mechanical Components

The test bed’s safety was an additional concern. To stop the operation of the test bed in the emergency situation, the emergency stop switch is built into the test bed. There are two power relays to disconnect the current to the amplifiers for the motors and an additional switch to stop the operation if the enclosure is opened. Also, the brake is on and the clutch is off by default to prevent the transfer of a large force from the load to the actuator under test. The large enclosure is built over the test bed while the system runs. Eventually this system will be used to test with large amounts of jerk motion so the potential for parts to fly off the system if they are not connected properly or break during testing is high. The enclosure will protect the user.

The mechanical component set-up for the test bed is shown in Figure 2. This test bed is for the dynamic test, so the load motor is used to generate the various load types. The four bar linkage creates the nonlinear periodic load. The special load type is selected to express the realistic situation for the given test motor. The brake and the clutch are one unit and they operate at the same time. That is, the brake is on and the clutch is off and vice versa. The torque sensor is needed to measure the torque between the load motor and the test motor. The encoders estimate the position, velocity and the acceleration. In addition, three bellows couplings are used to connect each component to the rest of the system. The couplings were carefully chosen to endure more than 40 Lf-ft in the rotational direction.

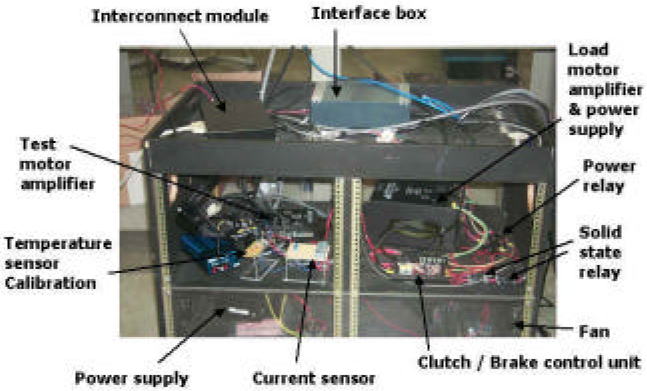


Figure 3. Electrical Components

Figure 3 shows the electrical component set-up for the test bed. The frame itself is made of the wood to avoid the electrical hazard. The interconnection module is for the connection lines between the motion controller and each mechanical component. There are many thick cable lines coming into the box so they should be assembled together tightly and nicely. The interface box is for the torque sensor. This unit sends the torque signal from the sensor to the controller. The motor amplifiers and power supplies needs the heat sink and cooling. During the testing, the amplifiers and power supplies will generate the large amount of heat so the four fans operate to reduce the heat. The solid state relay is used to control the brake and clutch operation. The current sensor will measure how much current flow through the wire from the amplifier to the test motor. Also, the temperature sensors are attached inside the test motor and the voltage signals transferred from temperature are scaled down by the calibration circuit. All of these components will be explained in detail later.

## 4. Components of the Test Bed

### 4.1 Test Motor Selection

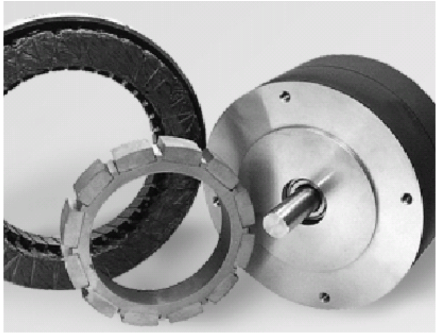


Figure 4. The PMSM Test motor

Permanent Magnet Synchronous Motors (PMSM) are very useful prime movers in the field of robotics because they have some distinct advantages compared to conventional DC motors that do not have permanent magnets on their rotors. PMSM are an attractive choice for heavy duty applications because large torque output can be obtained during high acceleration and deceleration rates. PMSM was chosen as the test motor for a practical robotic application. PMSM as the test motor specially has high torque and low speed compared with the motor used in manufacturing industries. The parameter values in the test motor are referenced from the ALPHA (Advanced Lightweight Prototype High-performance Arm) project of UTRRG in 1991 sponsored by the DARPA (Defense Advanced Research Project Agency) [2]. Fortunately, this test motor is obtained from the UTRRG Lab. The motor inside of the 2 DOF Knuckle Module to test the issues related to

| Parameter | Unit | Value |
|---|---|---|
| Model number | RBE | 03001-A50 |
| Horse power | HP | 2.65 |
| No load speed | RPM | 620 |
| Cont. stall torque | Lb-ft | ? |
| Peak torque | Lb-ft | 20.77 |
| Cont. current | Amps RMS | 7.6 |
| Peak current | Amps RMS | 17.2 |
| Rotor inertia | Lb-ft-sec^2 | 0.00058 |
| Weight | Lb | 7 |
| Static friction | Lb-ft | 0.1 |

Table 1. Test motor specifications

robotic fault tolerance through the fault tolerance test bed environment will be used to develop performance criteria from the Nonlinear Test Bed [3].

This PMSM as a test motor provided by Kollmorgen has Samarium cobalt rare earth magnets, three phase wye connection and built-in Hall Effect devices for electronic commutation. As looked at the Table 1, the maximum power is 2.65 HP, the synchronous speed is 620 RPM, and the peak torque is 20.77 Lb-ft. The continuous stall torque of this motor will be measured by experiment.

### 4.2 Load Motor Selection

In order to select the load motor, the various types of motors were investigated in terms of having a larger torque-speed curve range than the test motor. PMSM brushless DC motor was selected because it has a larger torque and speed range than any other type of motor. This load motor was also chosen because its inertia was small when compared with an induction, DC brushed motor. The Figure 5 shows Kollmorgen GOLDLINE series motors as a useful load motor in this experiment.

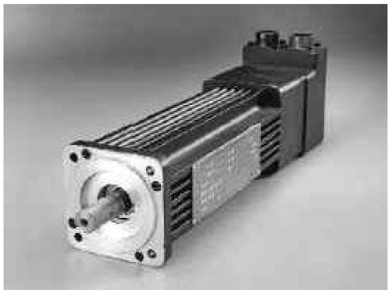
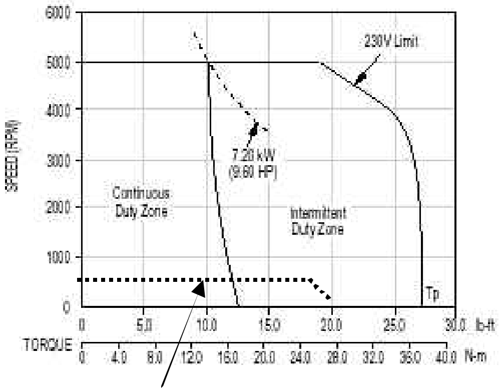


Figure 5. Load motor - PMSM



**Test Motor (RBE 03001-A50)**

Figure 6. Load motor (BE-406-C)

In Figure 6, the solid lines represent the load motor capacity and the torque-speed curves are divided as continuous and intermittent cases. The intermittent rates are unknown but the curves shows the performance of the motor capacity in intermittent zone is much improved by two fold. The torque-speed curve for the test motor is drawn in the figure. This two curves show the BE-406-C motor is appropriate as a load motor in this experiment due to the larger capacity for torque and speed than the test motor. Table 2 shows the specification of the load motor being used for this test. Notice the horsepower is almost 10 HP. The maximum speed is 5000 RPM and the maximum torque is 35.6 Lb-ft. It has very small inertia and needs 250 VAC in order to run the motor at maximum speed. However, the wall outlet voltage in UTRRG laboratory only provides 230 VAC so 5000 RPM is not possible. It is enough to test the test motor. The maximum current that the motor will need is quite large so the amplifier should be carefully selected.

| Parameter | Unit | Value |
|---|---|---|
| Model number | Goldline | BE-406-C |
| Horse power | HP | 9.6 |
| Speed at rated power | RPM | 5000 |
| Max speed | RPM | 5000 |
| Cont. stall torque | Lb-ft | 13.3 |
| Peak torque | Lb-ft | 35.6 |
| Cont. current | Amps | 27.2 |
| Peak current | Amps | 81.4 |
| Rotor inertia | Lb-ft-sec^2 | 0.000685 |
| Weight | Lb | 35.0 |
| Static friction | Lb-ft | 0.212 |
| Max voltage | Volts RMS | 250 |
| Price | $ | 2681 |

Table 2. Load motor specifications

### 4.3 Amplifier Selection

The amplifier is the electronic power converter that drives the motor according to the controller reference signals. The test motor and load motor in this experiment are permanent magnet synchronous motor, so Sinusoidal AC Brushless amplifiers are used. These amplifiers use encoder signals for commutation feedback. The amplifier drives the motor with sinusoidal currents, resulting in smooth motion. Hall effect sensors are needed for startup since the encoder provides only incremental position information and not the current angular location of the rotor relative to the stator.

| | |
|---|---|
| **Company** | Advanced Motion Control |
| **Part number** | SE30A40 |
| **Peak current** | 30 A |
| **Continuous current** | 15 A |
| **AC Supply voltage** | 45 ~ 270 VAC |
| **Price** | $995 |

Table 3. Test motor amplifier specifications

| | |
|---|---|
| **Company** | Advanced Motion Control |
| **Part number** | S100A40AC |
| **Peak current** | 100A |
| **Continuous current** | 50A |
| **AC supply voltage** | 85 ~ 270 VAC |
| **Price** | $1850 |

Table 4. Load motor amplifier specifications

Amplifier sizing is initially equating the power requirement of an amplifier to that of a motor. Servo amplifiers typically have both continuous and peak current ratings along with a maximum voltage rating. The peak current rating is available for acceleration/deceleration requirements for transient loads and is typically available for two or more seconds. Voltage and current ratings of an amplifier need to be matched with a motor's winding constants to yield the desired performance. The amplifier voltage and current ratings are determined from the maximum motor voltage, the maximum motor current and continuous motor current. It is recommended to select an amplifier with a voltage rating of at least 20% higher than the maximum voltage to allow for regenerative operation and power supply variations. The amplifier peak current rating should exceed the maximum motor current requirements.

The peak current of the test motor amplifier is 30 Amps which exceeds the peak current value of the test motor. Also the supply voltage that the amplifier needs is less than 270 VAC. The lab provides 120 VAC so the test motor amplifier will work for the motor.

In Table 4, the load motor amplifier is also selected by comparing the maximum peak currents of the motor and amplifier. The 100 Amps peak current of the load motor amplifier satisfies 81 Amps peak current of load motor. The supply DC voltage from power supply is 320 VDC

### 4.4 Power Supply Selection

The power supply is sized to match the amplifier and motor power requirements and typically includes a logic power supply along with regeneration circuitry. The power output rating of a power supply must exceed or equal the combined average power of all servo drives operating simultaneously. Taking into account motor and drive losses for permanent magnet servos, PS30A in Table 5 is chosen as a test motor power supply because peak current and supply voltage exceed the requirements of the test motor amplifier specification. The power supply for load motor is attached to load motor amplifier. The load motor amplifier (S100A40AC) has the power supply in the model so the input DC voltage directly supplies to the amplifier through the internally connected lines.

| | |
|---|---|
| **Company** | Advanced Motion Controller |
| **Model number** | PS30A |
| **AC supply voltage** | 45 ~ 240 VAC, 1 or 3 phase, 50 ~ 60 Hz |
| **Peak current** | 30 Amps for single phase AC input |
| **Continuous current** | 15 Amps for single phase AC input |
| **Price** | $350 |

Table 5. Test motor power supply specifications

### 4.5 Brake / Clutch Selection

In order to choose brake and clutch, we need to know how much torque and speed are governing the whole system. The maximum torque and speed handled by brake and clutch should be larger than the governed shaft torque and speed. The brake and clutch selection charts provided by the manufacturer help to choose the correct size of brake and clutch. The following equation will be useful to guide for selection of brake/clutch.

$$T = \frac{5250 \times HP \times K}{N} \tag{1}$$

where: $HP$ is the horse power for brake and clutch
$T$ is the torque in $Lb\text{-}ft$.
$N$ is the speed at brake and clutch location in RPM
$K$ is the motor overload factor for clutch

The overload factor is not used in brake selection. The no load speed of the test motor is 620 RPM, and the maximum power is 2.65 HP. Also, considering the motor overloading factor, K, is equal to 2, the acceptable torque for clutch is approximately 45 Lb-ft. The calculation for the static torque in brake does not include the motor overloading factor, so the torque is 22.4 Lb-ft. Therefore, EP-500 in

Figure 7. Foot mounted Brake/Clutch

Table 6 shows that both the 50 Lb-ft static torque for clutch and the 40 Lb-ft static torque for brake are larger than the values obtained from the equation (1). In addition, the maximum speed of the test motor is within the maximum range to be handled by brake/clutch module.

| **Manufacturer** | **Electro-Pack Size** | **Horse Power** | **Static Torque Clutch** | **Static Torque Brake** | **Max. RPM** | **D.C. Voltage** | **Price** |
|---|---|---|---|---|---|---|---|
| Warner Electric | EP-500 | 2 | 50 Lb-ft | 40 Lb-ft | 4000 | 90 | $1413 |

Table 6. Brake/Clutch specifications

### 4.6 Torque Sensor Selection

In order to fully measure the performance of an actuator and to enable torque control of the load motor, a torque sensor was needed. The torque sensor is required to have a torque, speed range, and a torsional stiffness higher than the operational range of the test motor. The procedures for choosing the right torque sensor are as follows. 1) Find the maximum average running torque. 2) Estimate the peak torque. 3) Check the extraneous loads. 4) Verify the speed rating. 5) Verify sensor accuracy. 6) Specify the power source. 7) Specify the output signal. 8) Choose the optimum torque sensor. According to the above procedure, the non-contact rotary torque sensor in Figure 8 is selected. Since the Nonlinear Test Bed is required to test a range of actuator sizes with their respective torque-speed curves, an **accurate** torque sensor was sought. Typical high quality industrial torque sensors are rated to 0.5% full scale accuracy. This means, for example, that if the torque sensor's full scale was 10 Nm, the output measurement will only be good to +/- 0.05 Nm. This is great if the operating point of the measured experiment is around 5-10 Nm. However, if the same sensor was used in an application with smaller torque magnitudes, the error would be a large percentage of the measured quantity. A balance between accuracy and economy was ultimately found in Surface Acoustic Wave Technology. Table 7 explains more about the specification of the torque sensor that we have chosen [7].

Figure 8. Torque sensor

Surface acoustic wave (SAW) technology is a relatively new when used for sensing torque. SAW transducers are similar in appearance to strain gages but they operate on a completely different principle. Each transducer has two sets of interdigital electrodes etched on a piezo-electric substrate. One is excited at ultrasonic frequencies and the other that receives this acoustic wave after it propagates along the surface of the shaft, converting back to an electrical signal. In a half bridge configuration, these sensors are temperature compensated, and have an accuracy that is superior even to the strain bridge (0.25% of full scale) [8]. A radio frequency coupling reliably transfers the sensor signal from the half bridge to a signal conditioning circuit. Since the radio frequency coupling is non-contact, the sensor is highly reliable. The change in torque is reflected in the change of frequency of the transducer signal. For this reason, signal conditioning circuitry is needed to convert the signal to a form that can be used by a controller (See Interface Box in Figure 9).

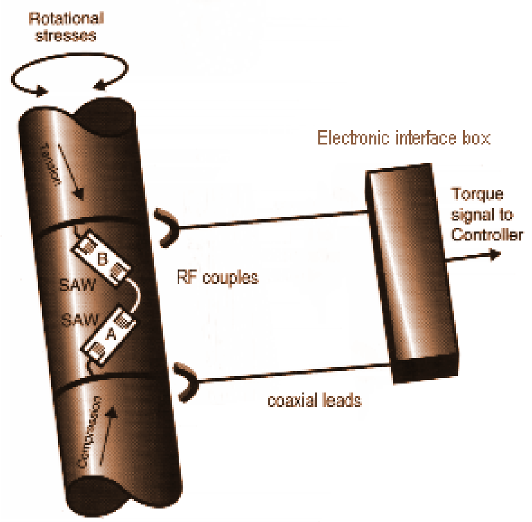


Figure 9. SAW transducer arrangement and electronic connection [7]

| Manufacturer | Model number | Max. Torque | Operational Speed | Accuracy | Analog torque output |
|---|---|---|---|---|---|
| WEN technology | E300RWT1-3 | 40Nm<br>= 29.5 Lb-ft | 15000RPM | +/-0.5% | +/-5V |

Table 7. Torque sensor specifications

### 4.7 Position Sensor Selection

The Test Bed required two encoders, one for the load motor and the other for the test motor. The load motor encoder was obtained from Kollmorgen and is embedded inside of the load motor. A through hole encoder is required for the Nonlinear Test Bed for accurate measurement of the output shaft position. BEI Technologies provided the test motor encoder. Both of the encoders are incremental optical encoders and have 2048 cycles per turn resolution. Figure 10 shows the test motor encoder. Table 8 shows the specifications of the load motor encoder. The specifications of the test motor encoder are contained in Table 9. The encoder signals provide feedback to control the position and speed for the operation of the motors.

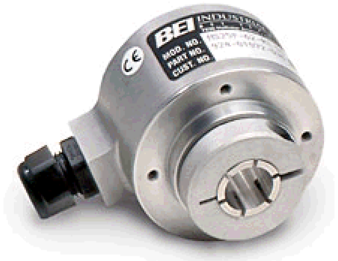


Figure 10. BEI optical encoder

| Manufacturer | Model number | Resolution | Number of channels | Max. Speed |
|---|---|---|---|---|
| Kollmorgen | BE1-406-C-94-064 | 2048 CPR | Dual with Index | 7500 RPM |

Table 8. Load motor encoder

| Manufacturer | Model number | Resolution | No. of channels | Max. Speed | Supply Voltage | Price |
|---|---|---|---|---|---|---|
| BEI Technology | HS25 | 2048 CPR | Dual with Index | 6000 RPM | 5 to 15 V | $455 |

Table 9. Test motor encoder

### 4.8 Current Sensor Selection

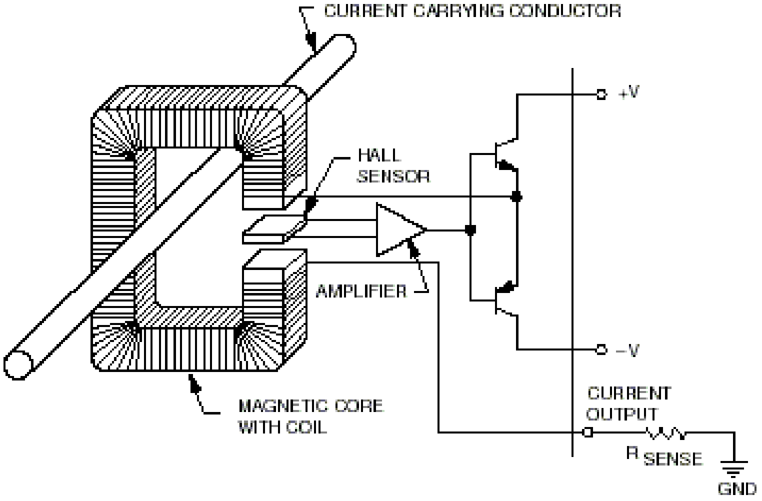


Figure 11. Schematic of closed loop current sensor [10]

Though current may be measured by inference using a known phase resistance and inductance and measuring the voltage across it, this inference is not accurate enough for a variable temperature environment like an actuator (both resistance and inductance change with temperature). In order to obtain a direct measurement of current, a current sensor was needed. Typical direct methods of measuring current include using a calibrated shunt resistor (measuring the voltage across it), an inductive coil, or a Hall-Effect current sensor. The shunt resistor offers simplicity but changes the phase resistance substantially. Both the inductive coil and Hall-Effect sensor use the magnetic field of the current-carrying wire to produce a voltage indicating the current. Between inductive and Hall-Effect current sensors, the Hall sensor offers faster response time (less than a micro-second). The Hall-Effect current sensor is also the industry standard, benefiting from the refinement of competition and low cost.

Hall-Effect current sensors come in two varieties: open loop and closed loop. Both have similar construction with a ferromagnetic core that provides a closed magnetic circuit in line with the Hall-Effect sensor. In the case of the open loop sensor, the Hall-Effect sensor produces a voltage proportional to the magnetic flux (and therefore the current) of the circuit. Since the measurement is passive, it is subject to drift and electromagnetic interference. A closed loop current sensor has an active inductive coil wrapped around the magnetic core providing an equal and opposite flux. A control loop is built into the sensor that continuously seeks to cancel the flux in the wire by generating an equal and opposite flux in the inductive coil (see Figure 11). The measured value of the current in the inductive coil is proportional to the current flowing in the phase being measured. The Hall-Effect sensor is only used as part of the control loop; it does not provide the output signal as with the passive variety. The close loop sensor is the superior choice in this application. Figure 11 shows a schematic diagram for a closed loop current sensor using Hall-Effect phenomenon.

Figure 12. Current sensor (CLN-25)

| Manufacturer | Model number | Nominal current | Peak current | Nominal output current | Accuracy at +/-15V | Sense resistor |
|---|---|---|---|---|---|---|
| FW Bell | CLN-25 | 25 A | 36 A | 25 mA | +/-0.5% | 218 Ohms |

Table 10. The specifications of closed loop current sensor

One current sensor is needed to measure the current in each phase of the actuator. Since the current is the same throughout the circuit these sensors may be located anywhere between the amp and the actuator. Inductive current sensors operate best when the wire being measured passes through orthogonal to the sensor. For this reason, an FW Bell closed loop current sensor was purchased (see Figure 12). These sensors route the current-carrying conductor through the hall sensor loop at a right angle. Table 10 represents the specification for the closed loop of current sensor provided by FW Bell.

### 4.9 Temperature sensor selection

In order to facilitate the measurement of criteria for an actuator, system testing must reflect temperature dependencies of the actuator system. A temperature sensor was needed to enable this testing. There are three types of temperature transducers that provide a temperature-dependant voltage signal. These are thermocouples, thermistors, and RTD's. All have similar geometries and are available in the temperature range that the PMSM phase windings will experience. EMF interference is one factor that helps in deciding the best temperature sensor for this application. Thermocouples are passive devices (not powered) that provide a small voltage signal due to the Seebeck Effect [1]. Since the signal is small it requires shielding from EMF noise and preamplification. These two factors made thermocouples the least desirable of the three options for this application.

Both thermistors and RTDs are temperature sensitive resistors. By placing them in a simple voltage divider circuit, they provide a simple clean signal. RTDs are superior both in accuracy (fractions of a degree) and in temperature range (up to 400 °F) than the thermistor, but they are more expensive. Since the application demands no more than +/- 1 degree of accuracy, and the upper range is well within the bounds of standard thermistors, a thermistor was chosen for temperature measurement.

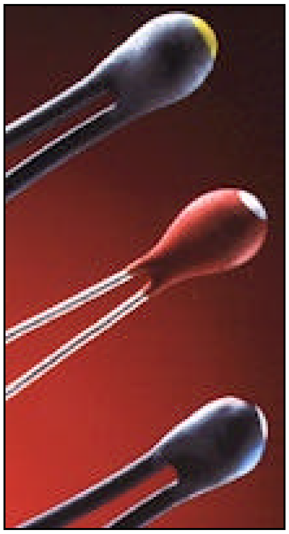


Figure 13. Thermistors [12]

## 4.10 Coupling Selection

The Nonlinear Test Bed chose the Bellows type of couplings to connect each component. The major characteristic of this specific coupling is high clamping forces to hold the shafts, so there is almost zero backlash. The way to hold the shaft is that the tapered conical sleeve slides inside the bore of the Bellows coupling and the outside shafts, and then by using the screws, the sleeve push into the body of the coupling. The tightening torque is 8 *Nm* and the stiffness of the coupling is 76000 *Nm/rad* in this application. The rated torque that can be handled by the chosen coupling is 60 *Nm* which is 44.3 *Lb-ft*. Also, the coupling is very light so it has very small inertia compared with the other type of couplings. The axial and lateral misalignment will be accommodated 1.5 *mm* and 0.2 *mm* respectively if necessary.

Figure 14. Bellows coupling [14]

## 4.11 Motion Controller Selection

Brushless motor operation, which PMSM belong to, is done by the commutation of current through three windings to the extent the rotor flux synchronizes with the stator flux. Commutation is implemented electrically with a drive amplifier that uses semiconductor switches to change current in the windings based on rotor position feedback. There are two common methods to vary the current supplied to the motor windings. The traditional method depends on the amplifier to commutate the current based on feedback and supplying to the motor. The second method is to use the motion controller to commutate the first two phases and to allow amplifier to determine the value of the third phase. Since the sum of the currents at any time is zero, the current in the third phase equals the inverse of the two currents. Figure 15 shows this operation. Galil’s motion controller has been chosen to use it for commutating in the motion controller because the load motor amplifier that the test bed has does not have the commutation logic in it.

| | |
|---|---|
| **Manufacturer** | Galil Motion Control |
| **Model name** | Optima Series, DMC-1840 |
| **System processor** | Motorola 32 bit microprocessor |
| **Communication interface** | PCI with bi-directional FIFO |
| **Digital I/O** | 8 Digital Inputs and 8 Digital Outputs |
| **Analog inputs** | 8 (+/-10V, 12 bit resolution) |
| **Minimum servo loop update rate** | 250 microsecond |
| **Maximum encoder feedback rate** | 12 MHz |

Table 11. The specifications of Galil motion controller

The Optima Series of Galil motion controller has many features that have the fast servo loop update rates as low as 62.5 microsecond/axis, 8 uncommitted and optoisolated inputs, 8 TTL outputs, and 8 uncommitted analog input channels with 12 ADC standard. Also, the controller has the non-volatile program memory with multitasking, faster command processing, and enhanced modes of motion. Table 11 represents the specification for the controller in detail.

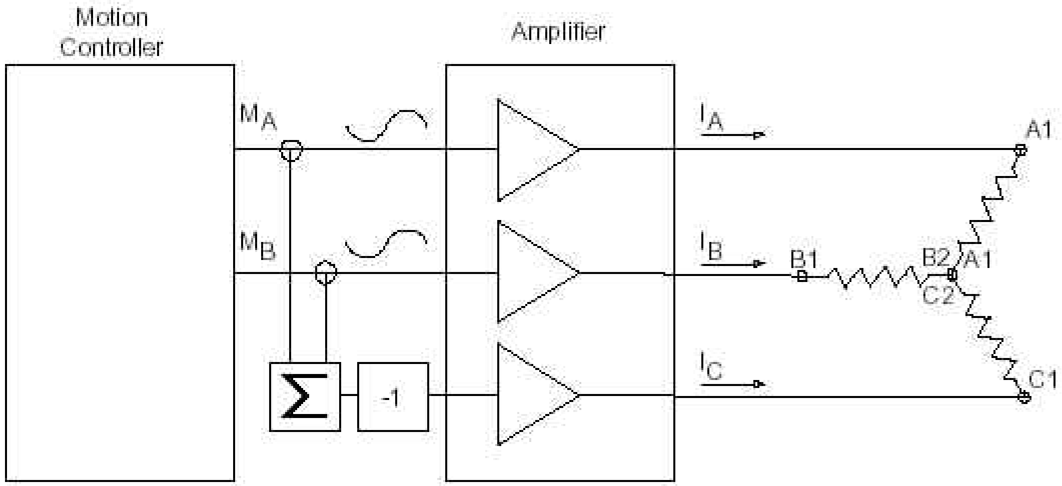


Figure 15. Commutation by motion controller

## 5. Operations of the Test Bed

Once the test bed has all of the required mechanical and electrical parts, signal wires are connected from controller to each component. The power lines for each piece of measurement equipment and amplifiers are connected with power supplies. Encoders and hall sensors need 5V, and their power is provided from the controller interconnection block. Current sensor needs +/-15V, so it has its own power supply. In addition, thermisters require +/-15V and the power is provided by the same power supply. Two power relays are used to disconnect the current flow if there is a power surge. Each of the power relays is connected in series between amplifier and power supply. A voltage divider circuit is also fabricated in order to take the voltage signals from the test motor. These signals are scaled down to +/-10V.

The sensor signals are sent to the motion controller through the interconnection block. There are eleven input signals that will be collected: three voltage signals, three current signals, four temperature signals, and one torque signal. The Galil motion controller has only eight input channels so a National Instrument's Data Acquisition Board will be used to take the additional signals. In the test motor, encoder and hall signals are needed for feedback to the amplifier. These signals are needed to complete the sinusoidal commutation loop to run the test motor. The load motor does not need to feedback the position signals and hall signals to the amplifier because the load motor commutates the current signals in the motion controller and not in the amplifier. The test motor amplifier ground is not isolated from the power line, so the grounds for the amplifier and motion controller are connected to the earth. Moreover, the one to one ratio of isolated power transformer is used to transfer the voltage range of between +/-76VDC to the voltage output range of 0VDC to 169VDC. Finally, in order to control the engagement of the brake and clutch, one of the digital output channels is used. This signal will be sent to the brake and clutch in an emergency case or during operational.

The Galil motion controller provides over 100 commands for specifying motion and machine parameters. Commands are included to initiate action, interrogate status and configure the controllers and filters. These commands can be sent in ASCII or binary. These Galil's commands help the user to generate, store and execute many complex application programs. Additionally, Galil provides DLL files to develop the program by using Labview, C/C++ or Visual Basic. All of these features will help us to build real time operation system with fast sampling and feedback update speed.

## 6. Conclusion

The Nonlinear Test Bed will provide test capabilities for a wide range of characteristics and many different actuators. Generally, test motor and load motor run at their maximum speed but torque capability of the test motor has not found yet. The performance of the test motor will be evaluated based on the test protocol for completion of one of the tasks for ONR all electric ship program.

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