Multidisciplinary Senior Design Conference
Kate Gleason College of Engineering
Rochester Institute of Technology
Rochester, New York 14623

Project Number: P12251

MOOG ELECTROMECHANICAL ACTUATOR TEST RIG

Brett Adams
Mechanical Engineering

Joseph Mazzara
Mechanical Engineering

Joshua Cocos
Electrical Engineering

Brad Adriaansen
Mechanical Engineering

Hussain Alabandi
Electrical Engineering

ABSTRACT

Electro-Mechanical Actuators (EMA) tend to fail without warning. As a result, there is a current interest in researching the failure modes of EMA in an effort to predict failures. The purpose of this project was to develop a test platform that will apply a passive load to resist the EMA's motion. The project will include development of a mechanical platform and a dSPACE control interface. The test platform was designed in a manner such that a passive load will be applied to resist motion in either direction of actuation from a neutral position. The platform was designed to handle a maximum EMA stroke of +/- 2 inches. If the EMA attempts to pass the two inch limit, safety cutoff switches will trigger and stop further actuation to prevent test rig damage. As loads in excess of 2,000 lb will be applied by the passive system, a safety enclosure was also designed to protect operators from any potential catastrophic failures.

BACKGROUND

The use of Electro-Mechanical Actuators (EMA) in place of hydraulic actuators in aircraft applications has received significant attention in recent years due to their lack of supporting hardware, thereby reducing mass, volume, and maintenance. However, this benefit is not without risk. The failure modes associated with current EMAs can often occur without sufficient notice. For EMAs to be widely-utilized fault detection and failure prediction methodologies must be an integral part of the Health & Usage Monitoring System (HUMS). State-of-health prediction in engineering systems is a rapidly evolving field that has a strong application to flight actuation.

This project seeks to build on the success of recent health classification research concluded by a MOOG employee resulting in a RIT Master's thesis in the spring of 2011. For this research an industrial grade EMA was installed in a test fixture with data acquisition and control capabilities. Tests were run with healthy and faulty bearings. The measurements were post-processed in a data-driven, Bayesian framework to accurately classify state-of-health.

At the conclusion of this work the EMA and test rig were deconstructed. It is this, Moog EMA, Controller LVDT, and Test Rig Base Platform have been offered for donation to be installed and commissioned at RIT for future flight actuator HUMS research projects.

DONATED EQUIPMENT

Figure (1) – Donated Penny & Giles LVDT

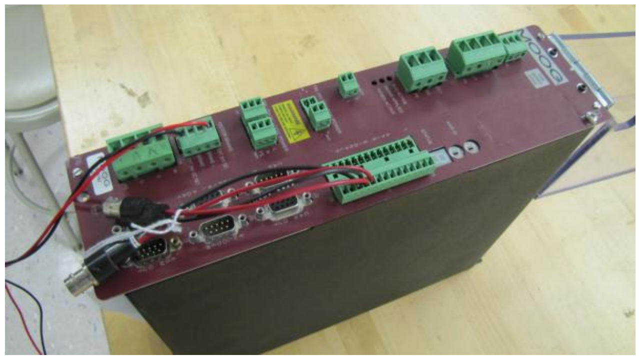

Figure (2) – Donated Moog T200 Controller

Figure (3) – Donated Moog Industrial EMA

Figure (4) – Donated Test Rig Base Platform

DESIGN PROCESS

The test rig is required to provide a passive load against EMA actuation and keep track of the EMA's actuation location from the neutral position. Two actuation options were investigated, and ultimately a +/- 2 inch cycle was chosen over a 0-4 inch cycle. The test rig must then supply loading in both the positive and negative actuation directions. Based on the position feedback from the provided LVDT, a control program was developed in dSPACE to communicate to the provided controller to tell the EMA how to respond. A mechanical cutoff switch system must be implemented to protect the test rig from any catastrophic mechanical failures.

EMA MOUNTING SYSTEM

The EMA mounting system was designed to utilize the EMA's "tunnion" design to allow for automatic alignment adjustment between the EMA and the main block as the EMA actuates. These trunnions were also designed to utilize the existing mounting locations within the donated base platform. The trunnions were to be constructed from AISI 1144 steel and mounted to the EMA with four M5 socket head cap screws. Two identical trunnions were required to mount the EMA.

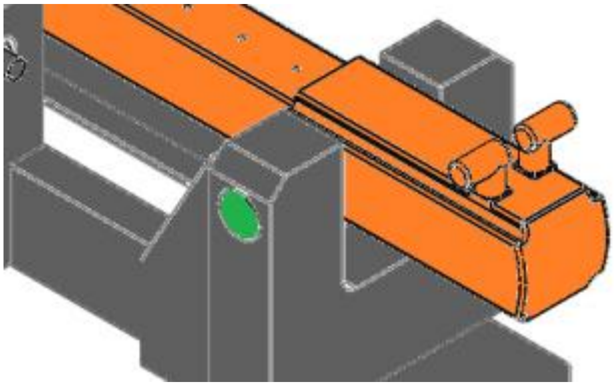

Figure (5) – Trunnion design concept

Note that in figure (5) the EMA is depicted in orange, and the trunnion is depicted in green. The test rig is colored grey. Through ANSYS structural analysis and fatigue loading calculations, the trunnions will have a factor of safety of approximately 16.

PASSIVE LOAD SYSTEM

The passive loading system was designed to provide a passive load to resist EMA motion in both positive and negative actuation directions. A spring system was devised to engage regardless of direction of EMA actuation. The system consists of two springs located to the left and the right of the test rig, in addition to brackets to support loads and a central shaft through each spring to both locate and support the load of the springs. The spring ends are captured by recessed plates with a central hole that will slide over the central shaft. These spring plates will experience compressive loads on the order of 1100 pounds. In order to engage the springs, sleeves were fitted over the central shaft, allowing the appropriate spring cup and bracket combination to be engaged for the direction of the EMA actuation. The central shafts will thread into a section of steel square tubing that the EMA rod end will also mount into. The section of square tubing will be supported by two bearing rods inserted into linear bearings that are already in the donated platform.

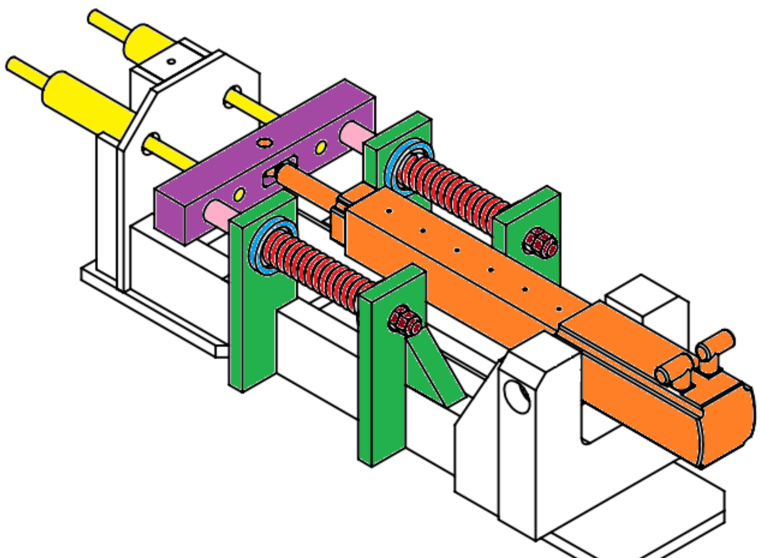

Figure (6) – Passive Load System concept

Note that in figure 6 the springs, brackets, spring plates, sleeves, square tubing, EMA, central shafts, and linear bearings & bearing shafts are depicted in red, green, blue, pink, purple, orange, brown, and yellow. Through various combinations of ANSYS analysis and fatigue loading analysis approximate factor of safety values were obtained.

Component	ApproxFS	Qty
Central Spring Shaft	14	2
Spring Shaft Sleeves	9	4
Square Tubing	4	1
Spring Plates	52	4
Brackets	2	4

Table (1) – Passive Load System FS

LVDT MOUNTING SYSTEM

The LVDT mounting system was designed such that the LVDT rod and barrel would always be in the readable range without the possibility of bottoming out under standard operating conditions. There were multiple possible designs to accomplish this and the chosen design will mount the LVDT barrel to the test rig with a bracket and the rod to the square tubing connected directly to the EMA with another bracket. This design will ensure that any misalignment with the EMA relative to the test rig will not affect the alignment of the LVDT rod and barrel. In addition, this design will allow the EMA to remain in place if EMA removal is desired.

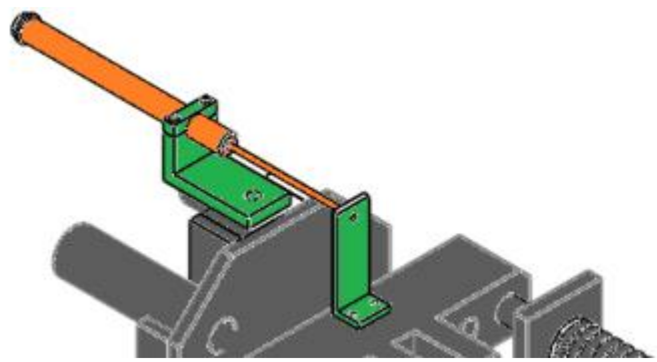

Figure (7) – LVDT Mounting System

Note that in figure 7 the lvdt rod and barrel are both depicted in orange while the brackets are depicted in green.

LVDT DEMODULATION PCB LAYOUT

In order for the LVDT to output a proportional voltage based its position, a LVDT signal conditioner must be wired in series with the LVDT device. This team chose to use the AD598 signal conditioner because of its cost benefits over a fully designed package. First, the ceramic DIP package, AD598AD, was purchased and used for prototyping. Using the calculations specified in the Analog Devices data sheet, resistors and capacitors were sized to match our specific Penny and Giles LVDT. The general schematic can be seen below in Figure 1:

Once this circuit was realized on the breadboard, it was powered using a 24V lab supply. The output was tuned by changing R2 so that the signal would swing from -8V to +7V over the entire physical range of the Penny & Giles LVDT.

Next a PCB layout was created using ExpressPCB software. This layout was sized to insure minimal area used. In order to interface with the LVDT device a five-pin pluggable terminal block was used. The male side featured screw terminals so that different LVDT devices could be swapped if necessary. The female side had through pins for easy soldering to the PCB. The output was channeled through a BNC output for use with coax cable. The power is supplied via an AC to DC transformer outputting 24VDC. This interfaces with the PCB via a barrel plug power jack.

Finally, in order to protect the circuit from hazardous noise, an aluminum box was purchased to enclose the PCB. Holes were made in the box to accommodate for the input and output ports. This final system is then mounted to the table for rigidity.

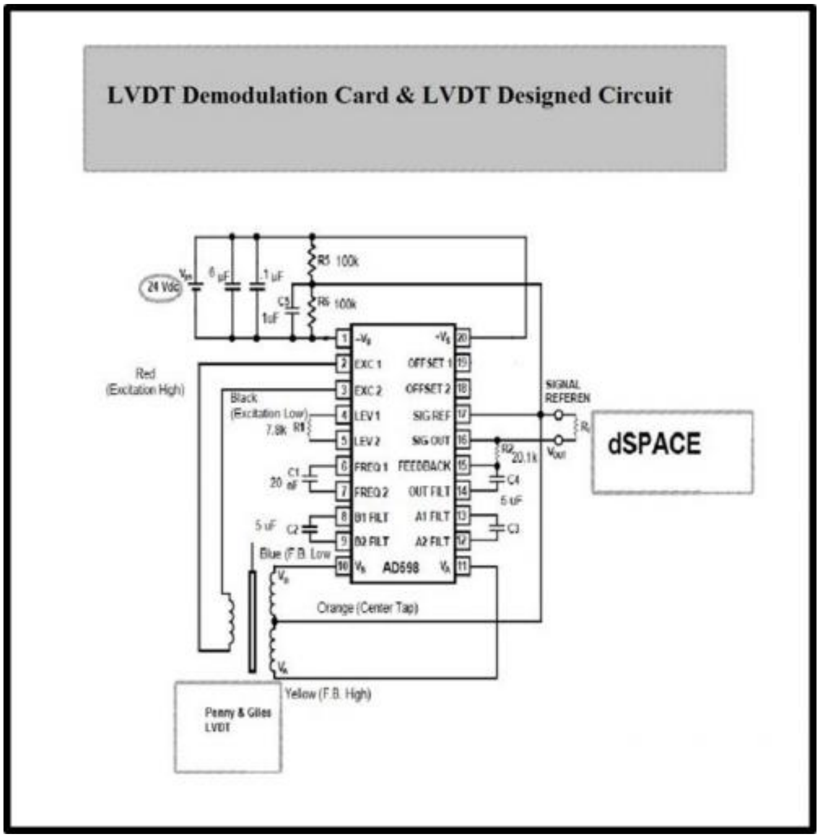

Figure (8) – LVDT Demodulation Circuit

Once the system is in place with the EMA attached, data points are taken from -2 to +2 inches. A straight-line curve is fit to acquire the equation to translate voltage out into inches moved.

DSPACE INTERFACE

In order to power and control the EMA a Moog T200 motor controller is implemented in this project. To interface with this controller a PC with dSPACE software is used. The dSPACE software includes SIMULINK plugins for MATLAB. Using these interface tools, a *.mdl file can be created for input and output of both digital and analog signals.

A cable needed to be constructed to interface the digital I/O signals from the 50-pin D-Sub port into the terminal blocks on the T200. Also, as an added level of protection, the cut-off switches are wired in line with the digital enable pin. Therefore, when a switch is triggered the enable pin is switched to ground and the EMA will be cut off. For the analog I/O, coax cables are used throughout this project.

The next step is to set the T200 into velocity mode. Once established, the controller can be fed an analog voltage representative of the EMA output velocity. The position is fed back from the LVDT and this is used as negative feedback. The error is fed into a PI control law and an output velocity command is created for the T200.

SAFETY CONSIDERATIONS

Safety for both the operator and test rig itself were a consideration in this project, and the following safety measures were taken to reduce the likelihood of harm coming to the test rig or it’s operator: safety cutoff switches to limit the range of EMA actuation, a safety cage designed to enclose the entire test rig, and a wire cover to enclose the controller connectors.

The safety cutoff switches were designed to limit the actuation of the EMA to prevent the springs in the passive loading system from reaching their solid length. If the springs were to reach their solid length, the brackets supporting them may fail under the combined spring load and EMA load, resulting in a catastrophic mechanical failure of the test platform. The cutoff switches, if engaged, will signal the controller to stop the EMA immediately.

The safety cage was designed to enclose the entire test rig as a barrier between any moving parts and the operator. In the event of a catastrophic mechanical failure of the test rig, the safety shield will provide protection from any shrapnel that may occur. The safety cage is constructed from 1 inch profile t-slotted aluminum extrusion and ¼ inch thick polycarbonate panels.

The controller wire cover encloses all connections to the controller. Some of these connections are high voltage, and the wire cover was installed to prevent anyone from accidentally electrocuting themselves. In order to access the connections, the operator would first have to shut off power from the wall using either the emergency stop or the throw switch mounted on the wall near the controller.

RESULTS AND DISCUSSION

Success for this project was defined as having a functioning test platform and control system at the end of week ten of MSD2. The success of the entire project therefore lies on the completion and success of several subsystems within the test platform and control system. The critical subsystems include the demodulation card, safety cutoff switches, controller installation, construction of safety shield, construction of the controller cable shield, dSPACE program development, and machining of all mechanical components including mounting hardware and test platform modifications.

The safety cutoff switches were installed to trigger at 2.125 inches of displacement from the neutral position in either direction. When triggered, the switches send a digital signal to the T200 controller stopping any further actuation of the EMA.

The safety shield was constructed from one inch t-slotted aluminum extrusion and 0.25 inch thick polycarbonate panels. The polycarbonate provides a transparent, but impact resistant barrier. Any failure of the test platform or EMA will be contained by the enclosure. The safety shield mounts directly to the table.

The dSPACE program was written to signal the controller how to move the EMA based off the real time displacement of the LVDT. The dSPACE program allows the user to control how far the EMA will actuate and at what rate and how many cycles. The program will also have safety measures to ensure that if an actuation distance of greater than two inches is input, the program will flag the user.

Figure (9) – Mounted T200 Controller

Figure (9) shows the mounted T200 controller with all cabling attached. The cables interfacing the T200 and the EMA were provided, however the power and dSPACE interface cables were fabricated. The controller cable shield shown in Figure (9) covers all connections to the controller and was manufactured out of 0.25 inch thick polycarbonate. The controller cover was designed such that the power would need to be disconnected in order to gain access to the connectors.

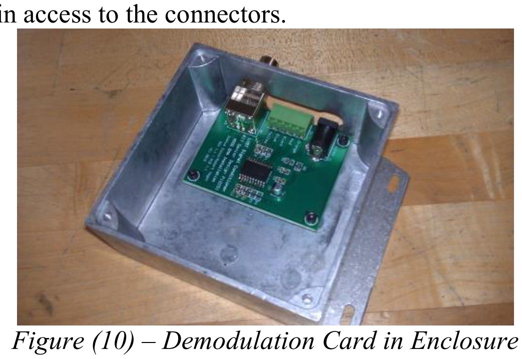

Figure (10) – Demodulation Card in Enclosure

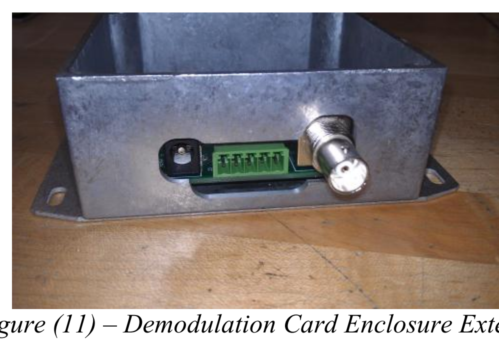

Figure (11) – Demodulation Card Enclosure Exterior

Figures (10) and (11) show the completed demodulation card and enclosure. Note that the enclosure has a top; however, it has been left off in these photographs to show how the PCB board is mounted. The demodulation card has three connections that can be seen in figure (11). From left to right are the power connector, lvdt connector, and BNC connector. The lvdt connector both provides power to the lvdt and reads the signal back from it. The BNC connector provides a useable voltage signal corresponding to location to the dSPACE control system. The BNC signal can range from -7V to +7V, corresponding to 0 inches to 8.5 inches of displacement.

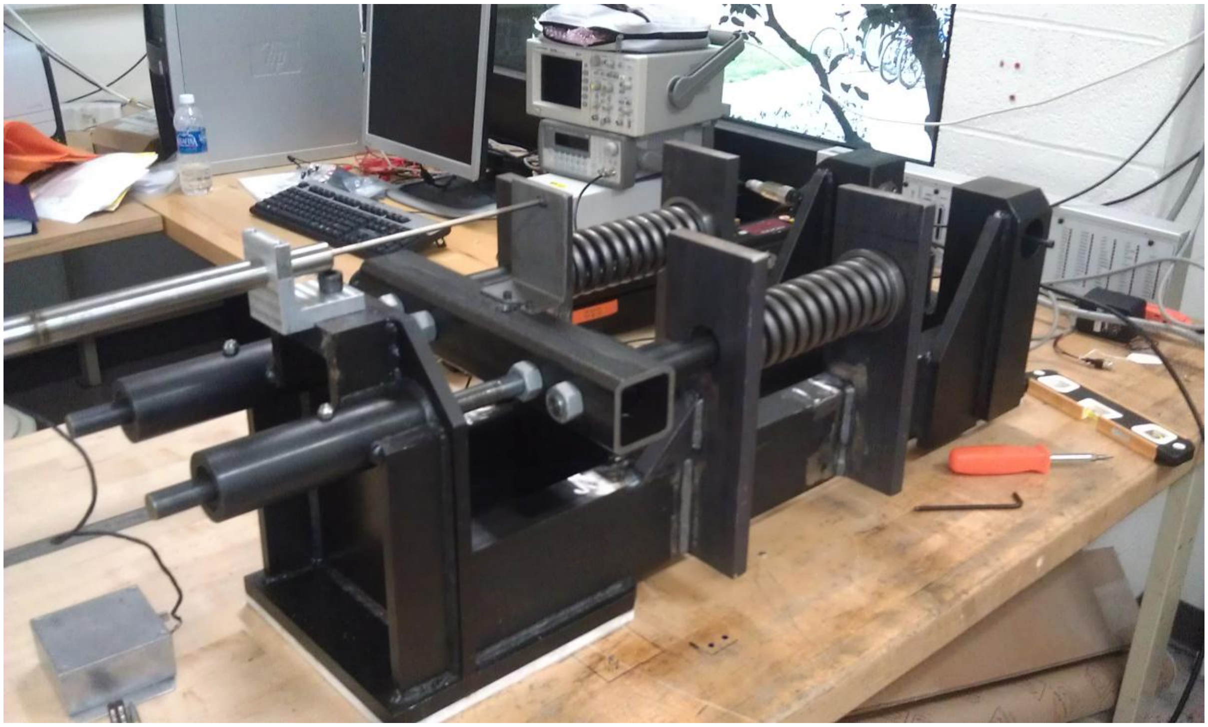

Figure (12) – Mechanical Modifications to the Test Platform

Figure (12) shows all of the completed machining for the modification of the donated test platform. The machined components include the spring assembly, trunnion mounting system, and lvdt brackets. The spring assembly brackets were welded to the existing test platform and all other components bolted together. Note that the EMA is not installed in the above photograph.

CONCLUSIONS AND RECOMMENDATIONS

While the group considers the project successful, there were few issues that cropped up over the past twenty weeks. Looking back, some of these issues may have been avoided with better planning. Some future work recommendations will also be discussed in this section.

Having a defined budget would have reduced the need for component redesigns in the detailed design process. For the duration of our project there was no set amount of funding, and designs were either accepted or rejected based on the customer's judgment of what a certain component should cost. Significant effort was spent trying to adapt the existing test platform for a larger EMA than it was originally designed for. If able to restart the project, the group would have suggested designing the test platform from scratch. It was also noticed once machining was completed and the system was ready to be tested, that additional software was needed to communicate with the T200 controller. To counteract this oversight, more care should have been taken in reading the T200 manual back in MSD1 to ensure appropriate time to acquire any needed software and troubleshoot it.

Future work for this project includes modifying the safety enclosure to increase rigidity, and modifying the spring assembly brackets to better support the spring shaft.

The initial design for the safety enclosure consisted of a top and bottom frame, connected by four legs, and for cost purposes, the bottom frame was removed. The enclosure then consisted of the top frame, and four legs, and five panels of polycarbonate. The lack of support on the bottom of the enclosure allows the polycarbonate to flex too much, and reduces the effectiveness of the device. In order to increase the rigidity, a bottom frame matching the top should be constructed and installed after removing 0.25 inches from the length of the legs. The leg material must be removed in order to seat the polycarbonate panels into the bottom frame similar to the top.

When the main block was designed, the spring shafts and bearing shafts were to thread in on each side of the square stock. During machining, it was realized that thread misalignment was a concern in that the tap was not long enough to remain engaged on the front side and begin threading the back side. As a result, the back side was opened up to be a clearance hole for the shafts, and a nut was fitted on the end. The resulting slop in the clearance hole allows the end of the spring shaft furthest from the main block to droop. To counteract this droop, a method of supporting the spring shaft so that it actuates in the horizontal plane only should be designed.

Overall, the group was pleased with the outcome of the project.

REFERENCES

[1] Moog, 2011, “Operation and Maintenance Manual, Flexible Electric Linear Servo Actuators,” Document Number CDS7287, Revision C.
[2] Moog, 2000, “T200 Programmable Servo Drive User Manual,” Document Number C27095-001.

ACKNOWLEDGMENTS – USE STYLE “ACKNOWLEDGMENTS CLAUSE TITLE”

P12251 would like to thank Dr. Kolodziej for his support and guidance throughout the MSD process.