Endurance Testing of Aircraft Electro-Hydraulic Actuator Using LabVIEW

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Abstract

In Aerospace Industry, Automated Test System at the qualification and certification laboratory improves characterization accuracy and plays a vital role to prove the airworthiness of the aircraft components. It is very helpful in achieving high quality standards of aircraft components by meeting the predefined qualification and certification test criteria. This paper outlines a comprehensive design and development of an Endurance Automated Test System for performing qualification and certification testing of Electro-Hydraulic (EH) Aircraft Actuator uses LabVIEW Graphical Test Software platform. This method is aimed at replacing the tedious and time consuming traditional method of performing the endurance testing for Aircraft Actuators.

Keywords: LabVIEW, Portable Test Controller (PTC), Automation, Electro-Hydraulic (EH), Actuator and Smart Controller Unit (SCU), Automated Test System.

1. INTRODUCTION

Being relatively new to the field, Electro-Hydraulic (EH) actuators are being used widely in the aerospace field. The quantum of knowledge as compared to ones accumulated for the other actuator types are much less and especially when it comes to Endurance Testing. Lack of health monitoring data from the test system installed in the field and prohibitive costs of carrying out real flight tests push for the need of building test system models and designing affordable but realistic experimental setups at qualification laboratories.

Electro-Hydraulic (EH) Actuators are presently used in numerous aerospace applications, from robotic applications to thrust vector control of rocket engines, where they accomplish a range of rotary and translational functions. [Pawel Rzucidlo, 2006].

Of the various kinds of actuators, Electro-Hydraulic (EH) Actuators were chosen for this study because of their growing role in the aerospace field. They are relatively compact and can offer high power-to-weight ratios and motion velocities. [Andrew Goldenberg & Saeid Habibi, 1999].

The electromagnetic actuator is preferably a linear motor with a piston rod arranged to reciprocate in response to an electric signal supplied to the electromagnetic actuator. A pump is preferably arranged between the electromagnetic actuator and the hydraulic actuator and causes movement of the hydraulic actuator as a result of the movement of the shaft of the linear motor. [J. Edge, 1978] [G. Daneker, 1973]

Endurance Testing is the ability of a test system to continue to load or a difficult situation, experience, or activity over a long period of time. Endurance testing is usually done to determine if the system or a subsystem can sustain the continuous expected load. During endurance tests, memory utilization of the test system is monitored to detect potential leaks. Also important, but often overlooked is performance degradation of the Unit Under Test (UUT). That is, to ensure that the throughput and/or response times after some long period of sustained activity are as good as or better than at the beginning of the test. The goal is to discover how the system behaves under sustained use. [H. Moon and W. Knowles, 1970] [G. McGrath, 1964].

The measurement and instrumentation requirements in the area of aerospace and automotive testing have increased many folds owing to the increasing and stringent demands imposed by several regulatory bodies such as the FAA, EASA, ADA, BIS, CMVR, EEC, etc. The type of tests to be carried out depends upon the purpose of evaluation such as for certification, design validation, etc. The parameters to be evaluated pertaining to the testing of vehicles are many. Presently, a number of dedicated instruments are being employed for the above purpose, each instrument meant to carry out evaluation of a specific parameter. However, one of the major disadvantages in such instruments is that their functionality is rigid and is difficult for reconfiguration. Also, it requires the adjustments of many hardware components to achieve the desired functional behavior. It was, therefore intended to have an instrumentation system, which could be completely customized to the user requirements and at the same time be flexible enough to cater for the changing requirements of the test methodologies pertaining to the variation in the test standards. [S V Londhe et al, 1999] In view of this Moog Inc. has developed test controller hardware for testing and validating the EH actuators.

A detailed description has been provided about the test system architecture of Endurance test systems and how various Endurance test Spectrum profiles are tested in the test environment and corresponding test data are collected to verify the physics and mechanics based models.

A design and development of endurance test system have been included to outline the details of the experimental data collection and calculate the test results depending upon the collected test and predetermined data. While performing endurance testing, the endurance test spectrum has been tested under load conditions. Finally, the roadmap leading from this experimental effort towards developing a successful endurance test system for aircraft electro-hydraulic actuators are discussed.

2. TEST SYSTEM OVERVIEW

The endurance test system uses PTC, a digital servo controller to command and control the load and position. It is a 1 to 4 channel digital servo controller with Liquid Crystal Display (LCD). This controller gives the flexibility to add additional hardware like the digital and analog inputs and outputs that includes vibration inputs, strain gauge amplifier inputs, remote control units etc.

The endurance test system monitors a LVDT transducer within UUT (Unit Under Test) i.e. EH Actuator, to measure the linear position and uses it for the position loop closure. UUT has a differential pressure sensor to measure the difference of the pressure on the load side and send a voltage signal back to the PTC, so that it can measure the actual force exerted by the load cylinder on the UUT. The endurance test setup is as shown in figure 1.

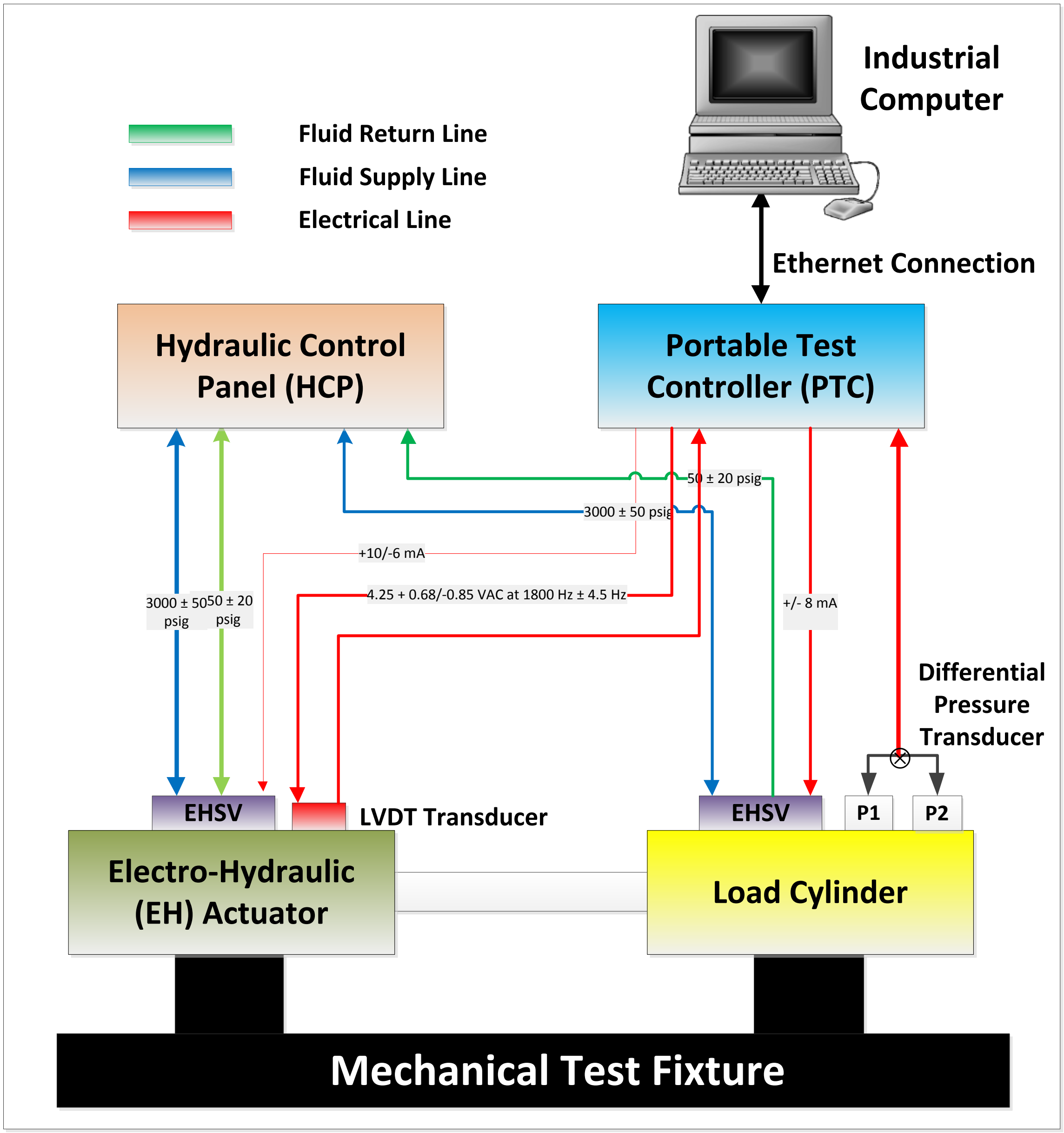

FIGURE 1: Endurance Test System Overview-System Level Block Diagram.

3. AUTOMATED TEST SOFTWARE IMPLEMENTATION

The Endurance Test Software implementation can be classified into three major parts.

i) LabVIEW Test Software Application

ii) Hardware Abstraction Layer (HAL)

iii) PTC Interface Level Drivers

Figure 2 shows the interface between the LabVIEW Test Software Application, which executes on Host Computer and PTC Interface Level Drivers through the HAL layer.

The PTC hardware is connected to the LabVIEW test software application through the Ethernet Communication using the IP address of the PTC. Therefore, the Host Computer and PTC both should be on the same Local Area Network (LAN).

A hardware abstraction layer is part of an application layer at the LabVIEW test software application which isolates physical test hardware and test software that executes on the host computer. PTC Test Hardware has three major functionalities.

a. Test Safety Module: It basically consists of, an Emergency Stop Chain Functionality and fail-safe conditions.

b. Position Control Loop: PTC generally uses Moog's customized closed loop control algorithm, to bind a position loop control and feedback with Smart Control Unit (SCU) at PTC. The customized closed loop is a unique control loop control algorithm designed and developed for dual mode controller, which allows switching between load and position close loop control modes. The SCU has all necessary inputs and output hardware to connect a typical electro hydraulic actuator. Usually this will be a hydraulic or servo-controlled actuator. Each SCU is connected to its own actuator. It is the functionality of the SCU to modify the test output (i.e. current mA) connected to the actuator in such a way that the feedback (i.e. load or position) is always as close as possible to the commanded set point.

c. Load Control Loop: The PTC uses the Moog's customized closed loop control algorithm, to control and monitor the load loop using SCU. It uses differential pressure Transducer to dynamically calculate the force\load feedback, to close the Load Control Loop.

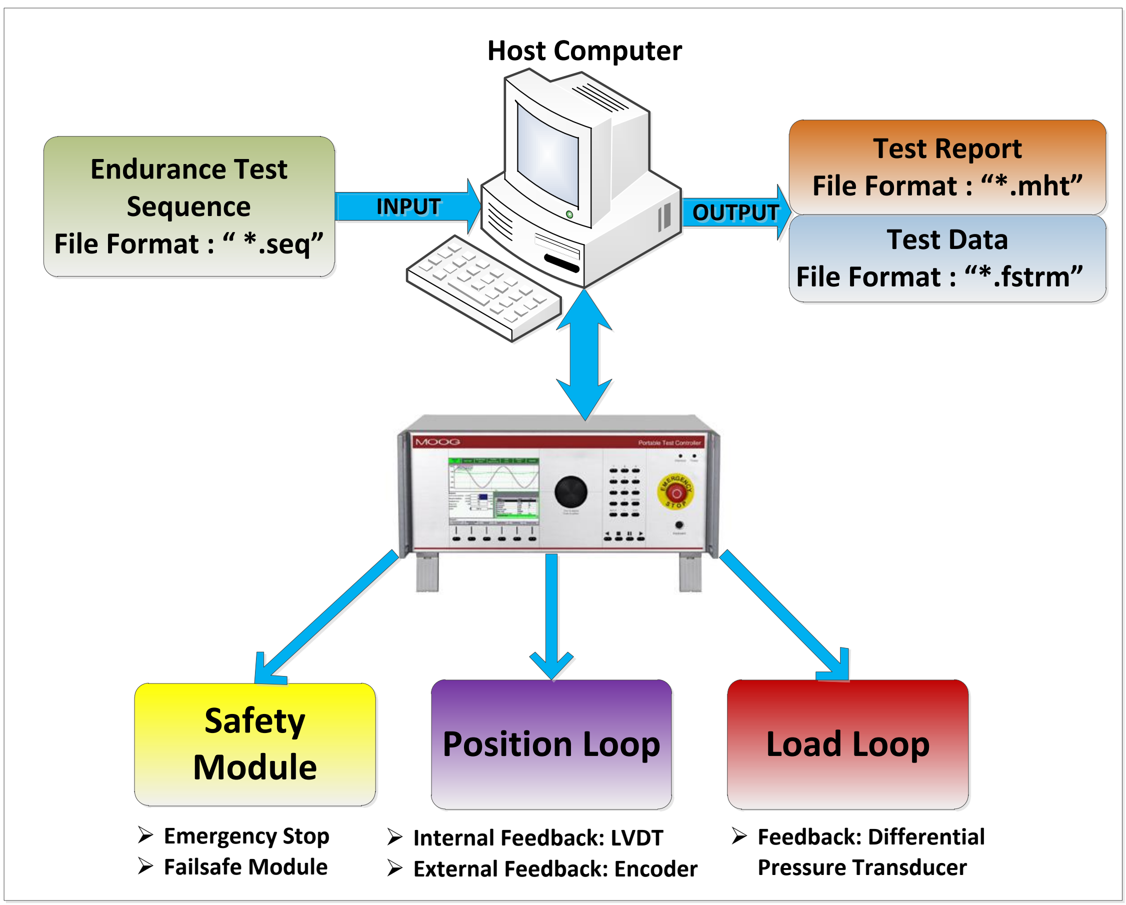

FIGURE 2: Endurance Automated Test Software Architecture Block Diagram.

Host Computer gives the input command to PTC interface level drivers which will interact with the test hardware system and gives the feedback command to the PTC.

LabVIEW Software Module: This Software interacts with the operators and engineers. The Test Software uses the stacked sequence with four states in it. The overall functionality logic of these states is shown in figure 3. LabVIEW Software Application has three different control logic loops, which are continuously executing and controlled with a control button and conditional terminal.

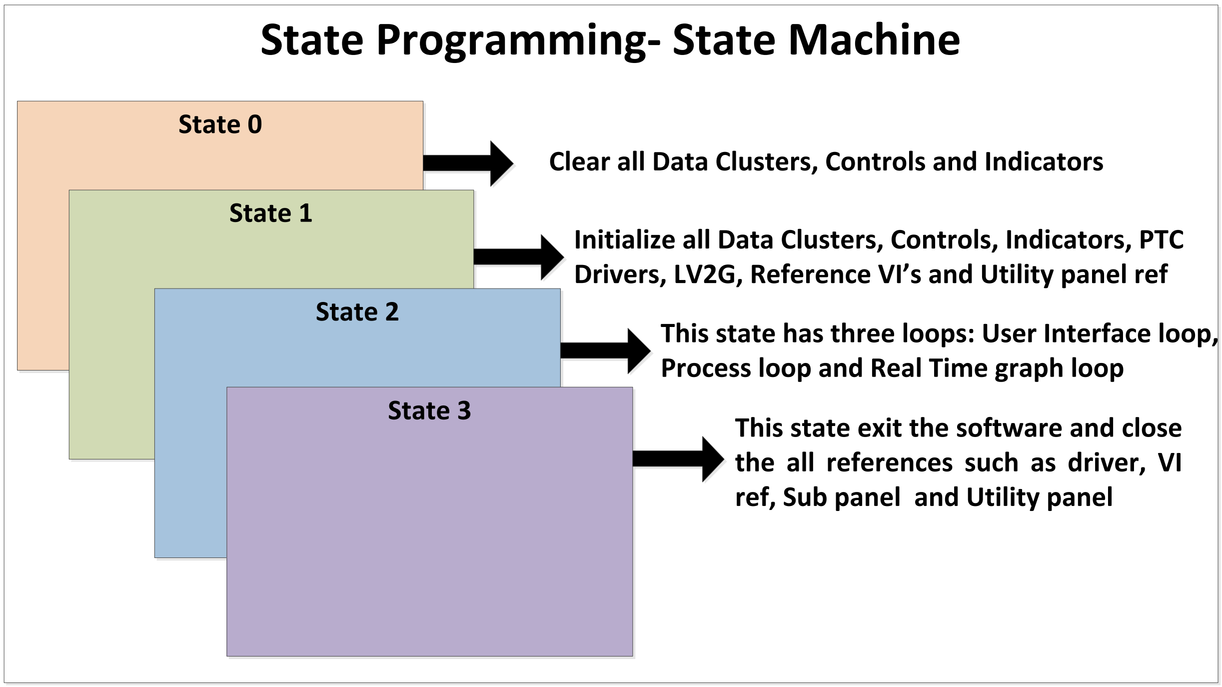

FIGURE 3: LabVIEW Test Automated Test Software –State Programming.

"While-Loop1" is a Graphical User Interface (GUI) loop which uses Event Driven Programming Structure, to capture the user events occurred at GUIs. This loop generates an event notification and communicates to the "While-Loop2" for further processing as shown in figure 4.

"While-Loop2" is a process loop which executes the corresponding design state depending upon the event notification generated by "While-Loop1" as shown in figure 5. A case structure inside "While Loop 2" executes the functional logic flow and contains the HAL and PTC interface level drivers to establish communication with the PTC hardware.

"While-Loop3" is used for plotting the Real-Time graphs on the GUI window by means of collecting the test data from the PTC hardware through UDP communication as shown in figure 6. Loop Synchronization Logic in the LabVIEW Software Application will be used for plotting the real-time graphs in the GUI.

4. HARDWARE- SOFTWARE INTEGRATION

To interface PTC with LabVIEW Software Application, the configuration settings of the PTC is required to be changed according to the project specific requirements.

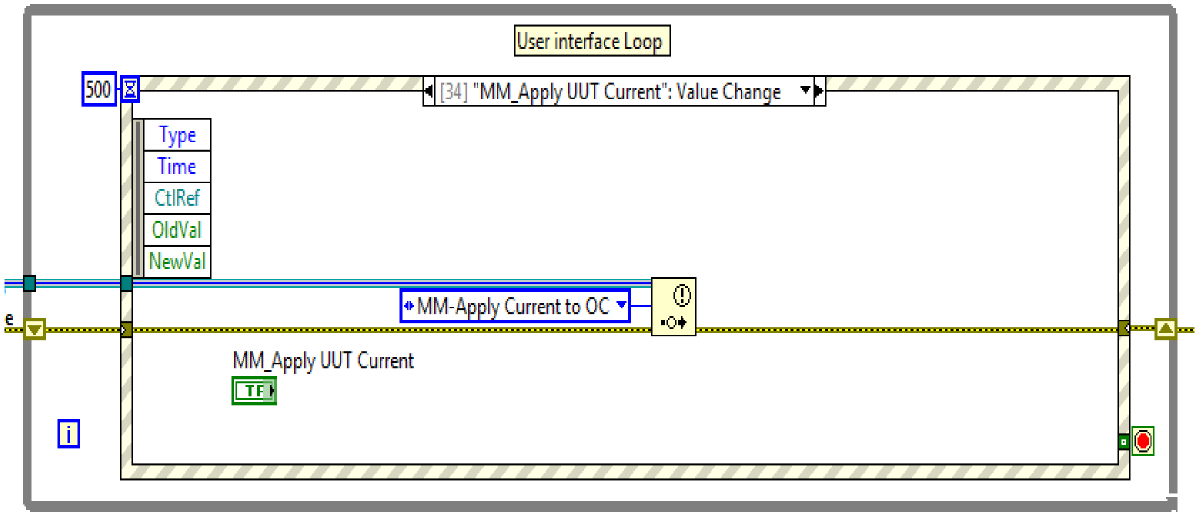

FIGURE 4: LabVIEW Software Application - User Interface Loop.

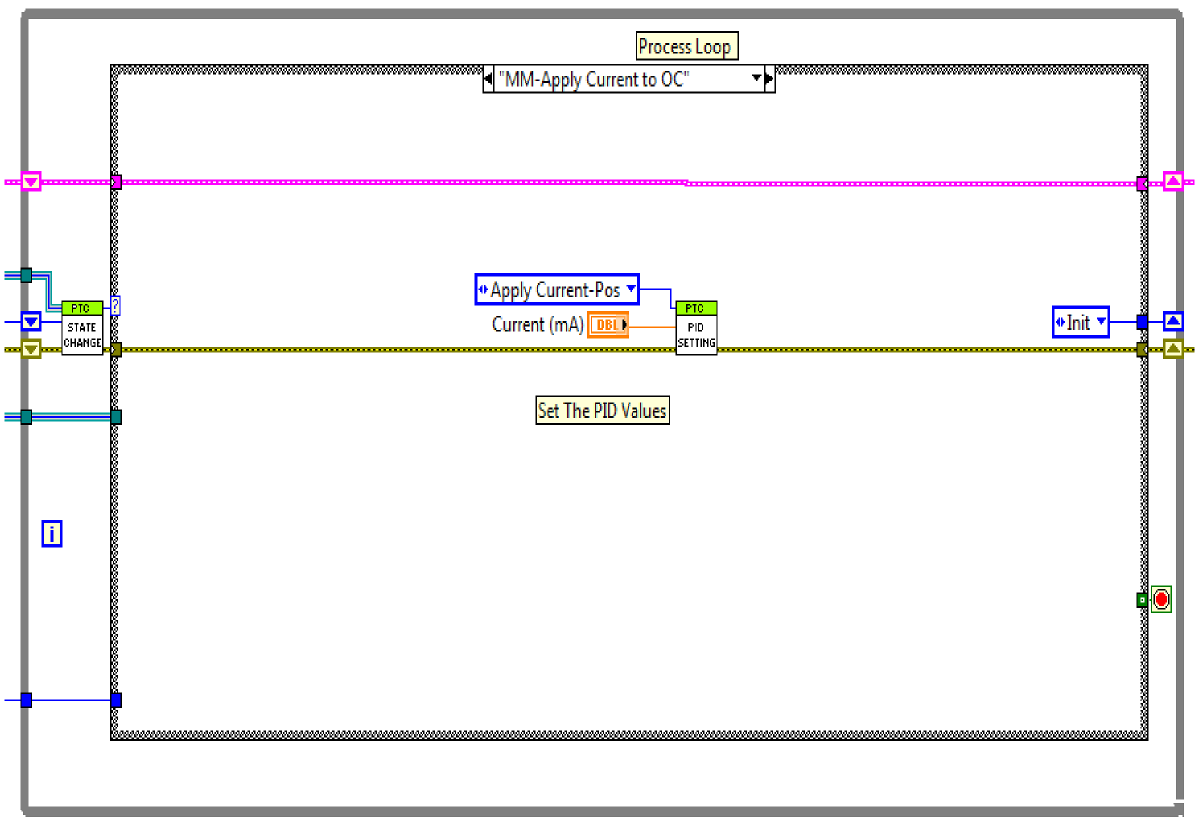

FIGURE 5: LabVIEW Software Application- Process Loop.

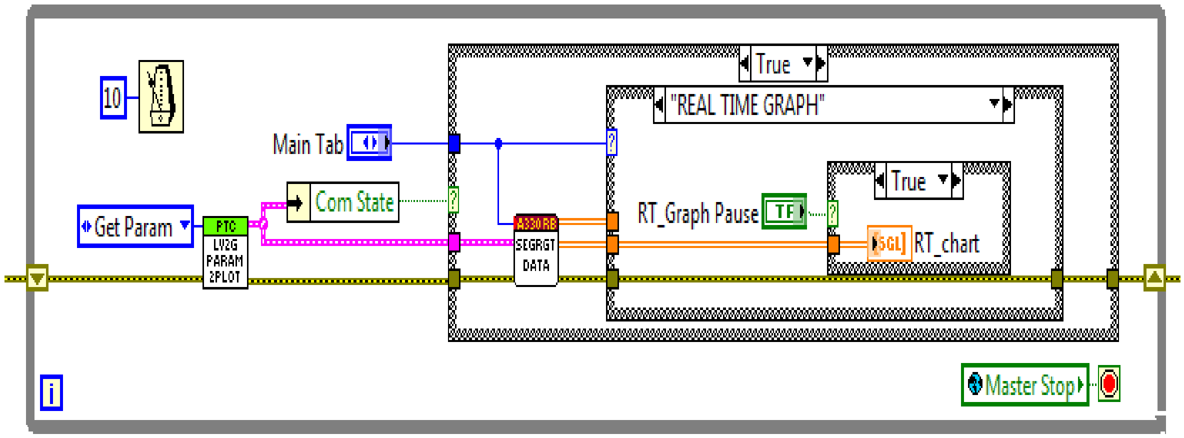

FIGURE 6: LabVIEW Software Application- Plotting Real Time Graph.

5. CONTROL LOOP CONFIGURATIONS

Two control loop channels are required to design the open/closed loops. Channel1 is for Position Control Loop, which is bound with “SCU-Channel1” and connected through Moog’s customized closed loop control.Channel2 is for Force\Load Control Loop, which is bound with “SCU-Channel2” and connected through Moog’s customized closed loop control.

Figure 7 shows the selected PTC channels on the complete list of available channels, as part of the Control Loop Configuration. Figure 8 shows the Physical Layer Channel Binding with the Moog’s customized closed loop with respective SCU’s.

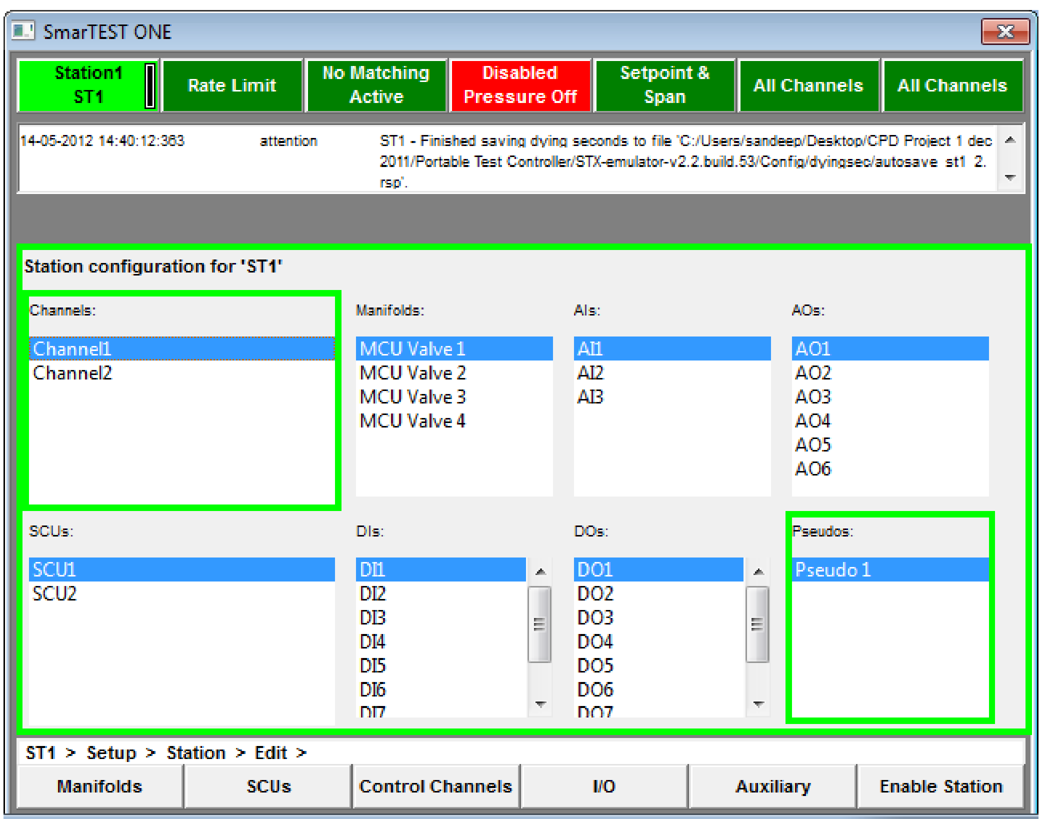

FIGURE 7: PTC Hardware Channel Configurations.

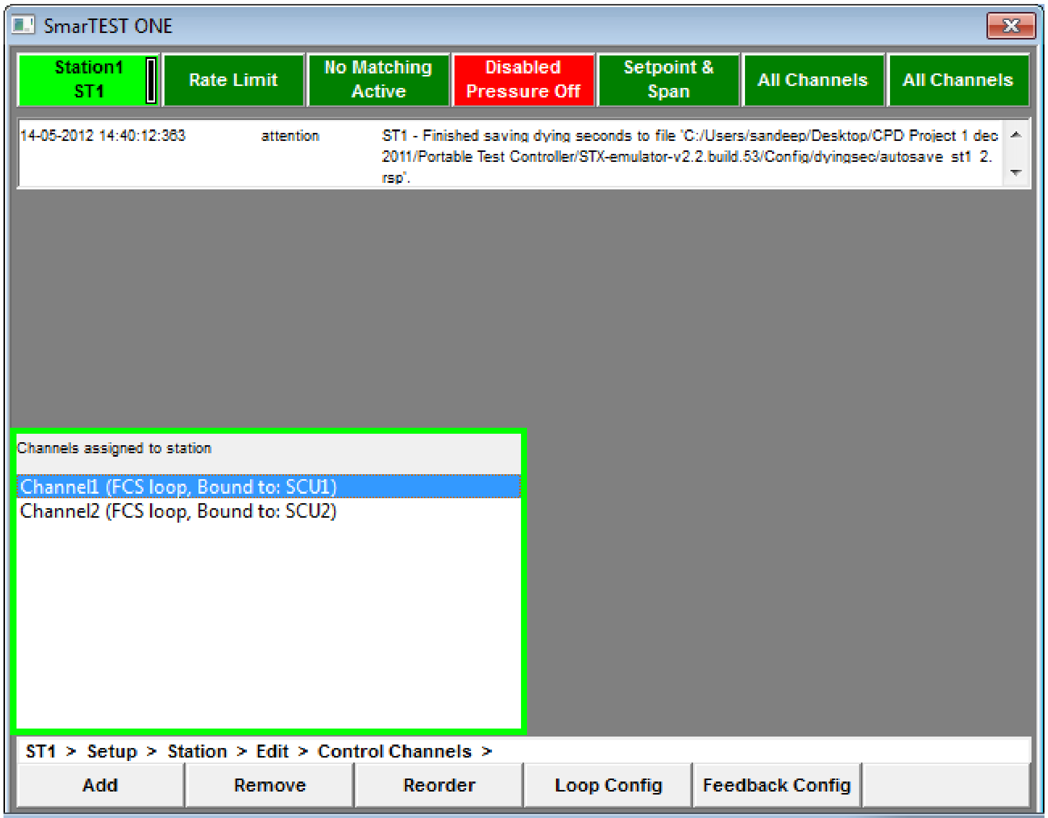

FIGURE 8: SCU Control Loop Channel Bindings.

6. END TO END CALIBRATION

LVDT Calibration is performed with the vendor calibration report and the PTC calibration utilities. The following figures show the calibration procedure of LVDT:

a) Select the LVDT sensor in figure 9 and Click On “Next” button.
b) Fill the given values with the help of vendor calibration report in figure 10.
c) Measure the LVDT value at specific points and enter these values in the measured box of figure 11.
d) Perform the “Five Point Calibration” using five set points from the vendor calibration report and save the calibration settings in the PTC.
e) Figure 12, 13 and 14 show the Load Calibration on UUT side.

<u>Pressure Transducer Calibration:</u>

- To measure force on UUT side, we are using Force A and Force B signals of SCU2 (because these signals are predefined in Moog Customized Control loop and it is easy to configure loop with these signals) and these data are coming from the P1 and P2 pressure ports of the Load Cylinder.

- Using the Pseudo Channel1, we can calculate the applied force on UUT with the help of following formula.

Pseudo Channel1 (force in lbf) = (Force A value (psi) - Force B value (psi))/ Annular area of the Load Cylinder (inch^2)

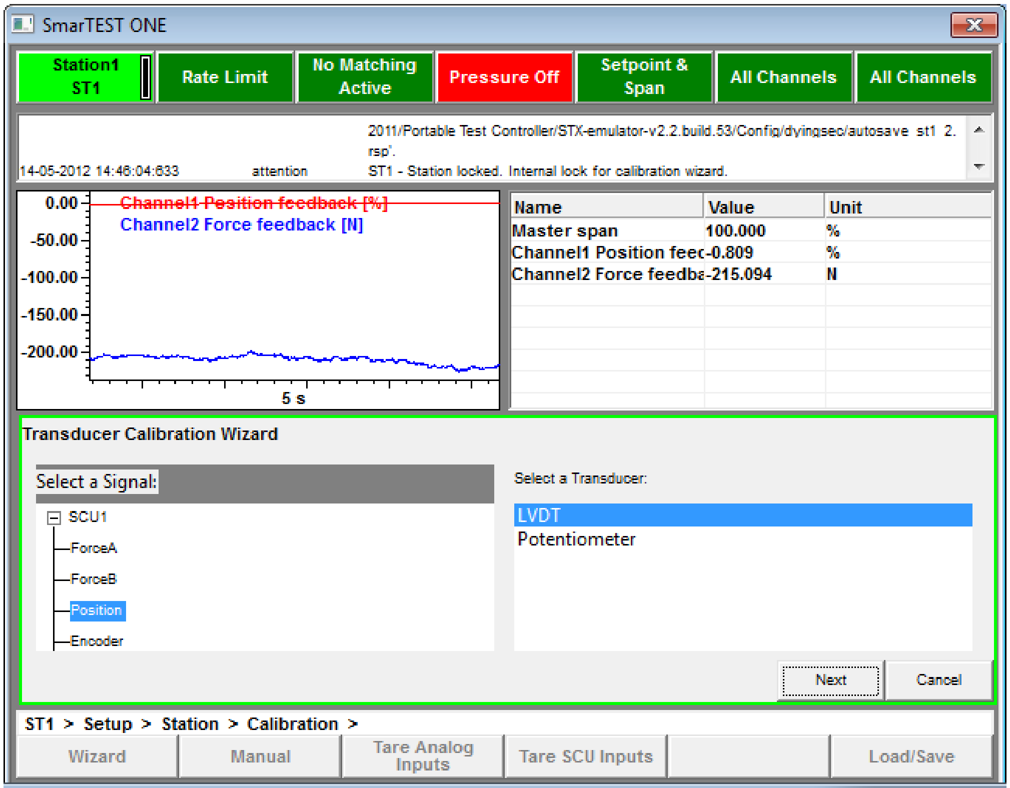

FIGURE 9: LVDT Transducer Calibration - Step 1.

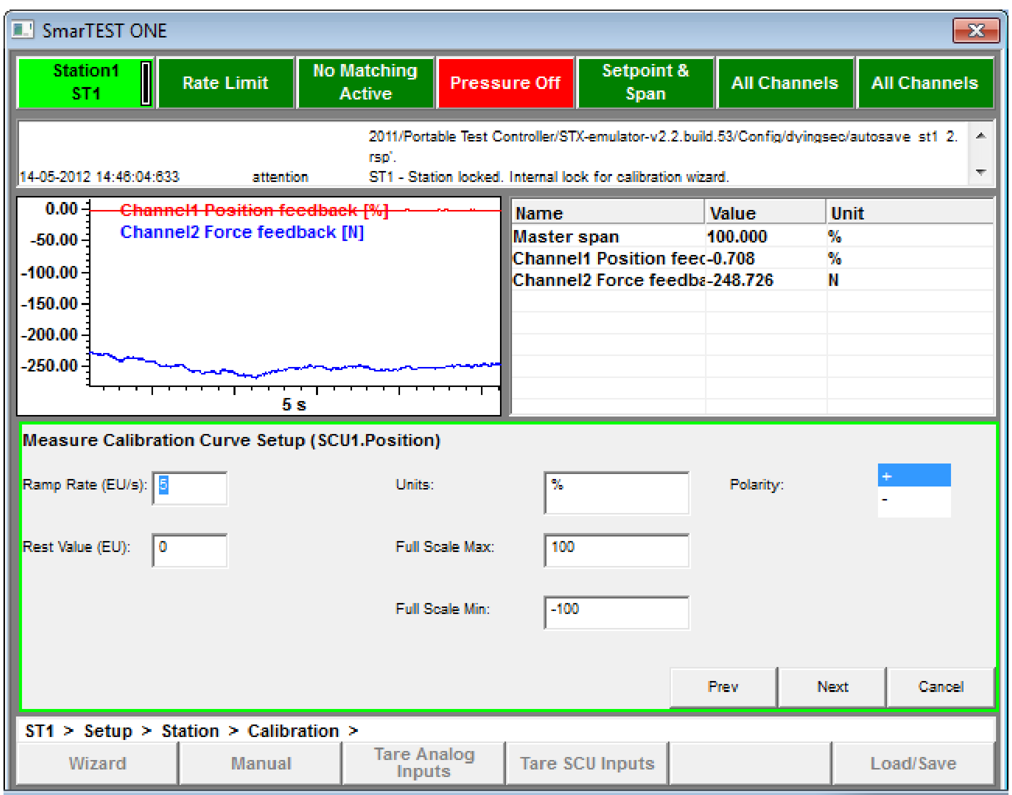

FIGURE 10: LVDT Transducer Calibration - Step 2.

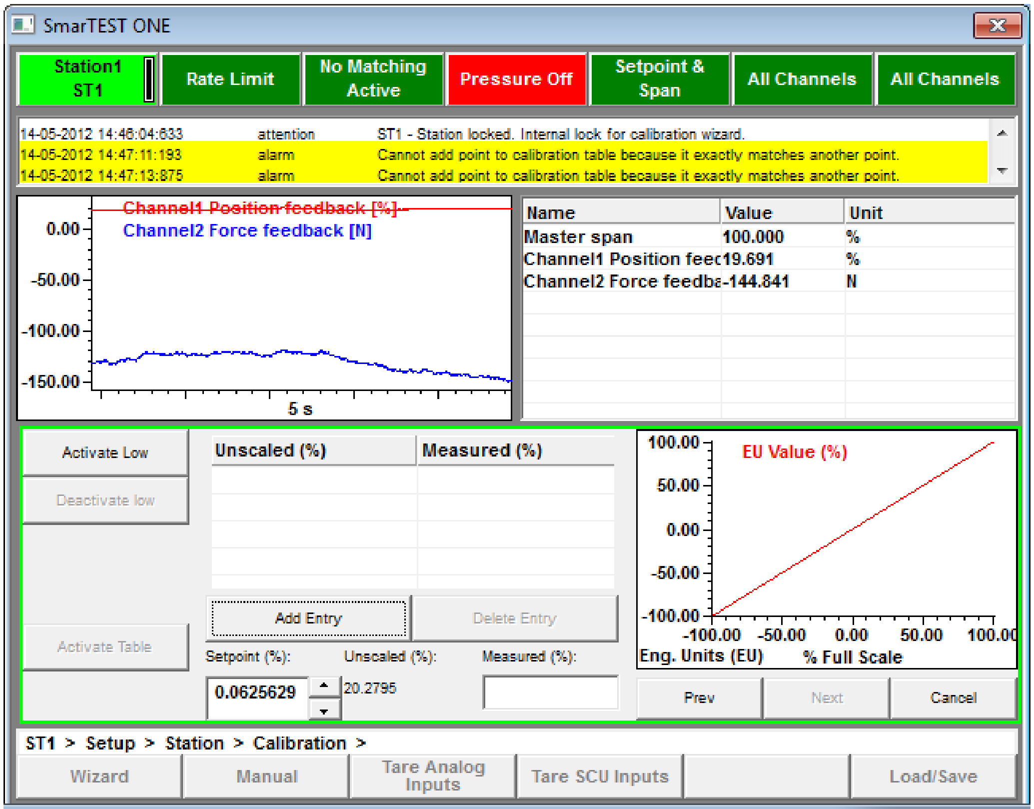

FIGURE 11: LVDT Transducer Calibration - Step 3.

7. POSITIONS LOOP TUNING

After binding the control loop and LVDT calibration, Tuning has to be performed for better output following with respect to input commands. A Proportional–Integral–Derivative controller (PID controller) is used to control the loop feedback mechanism. PID is the most commonly used feedback controller logic algorithm. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set-point. The controller attempts to minimize the error by adjusting the process control inputs. Figure 15 shows the Position loop tuning.

Position Loop Tuning Procedure:

a) Set all the PID values to zero, so that the closed loop becomes the open loop.
b) Apply the null bias servo value offset current to the UUT.
c) Slowly increase and decrease the offset current to move the UUT in Extend and Retract direction respectively.
d) Set the PID values in such a way that the system will not go in unstable mode. And set the optimum PID values so that output signal follows the input command exactly or nearly exact.

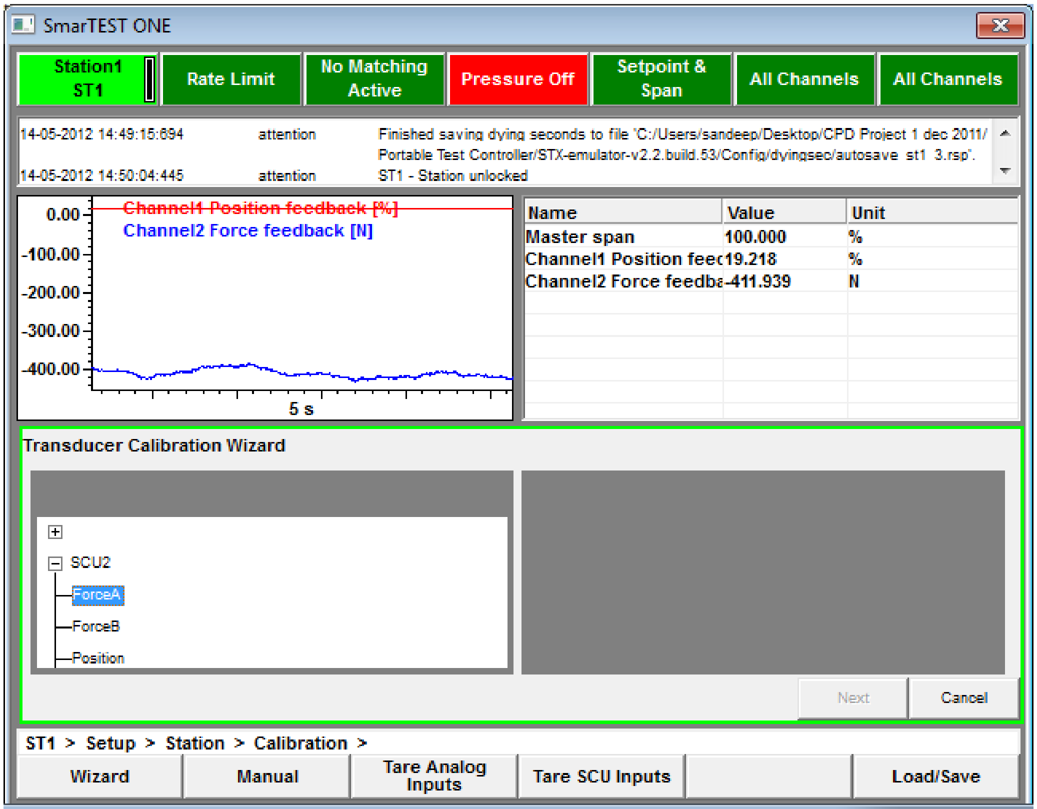

FIGURE 12: Load Pseudo Channel Calibration – Step 1.

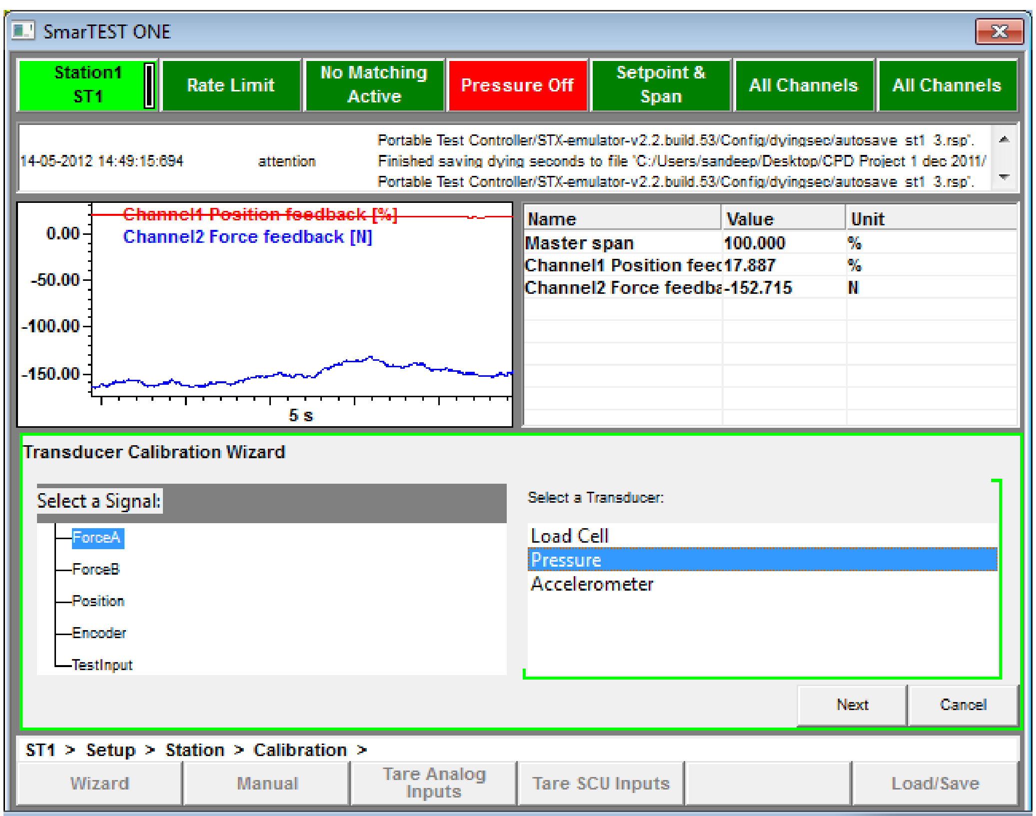

FIGURE 13: Load Pseudo Channel Calibration – Step 2.

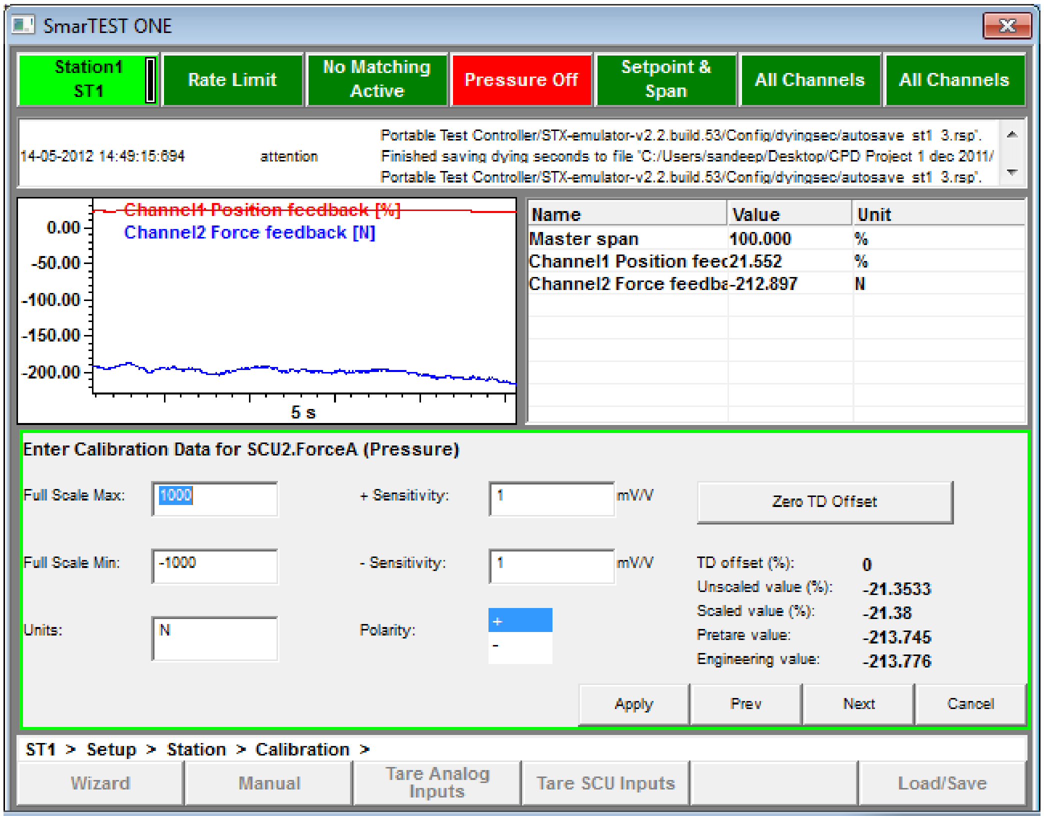

FIGURE 14: Load Pseudo Channel Calibration – Step 3.

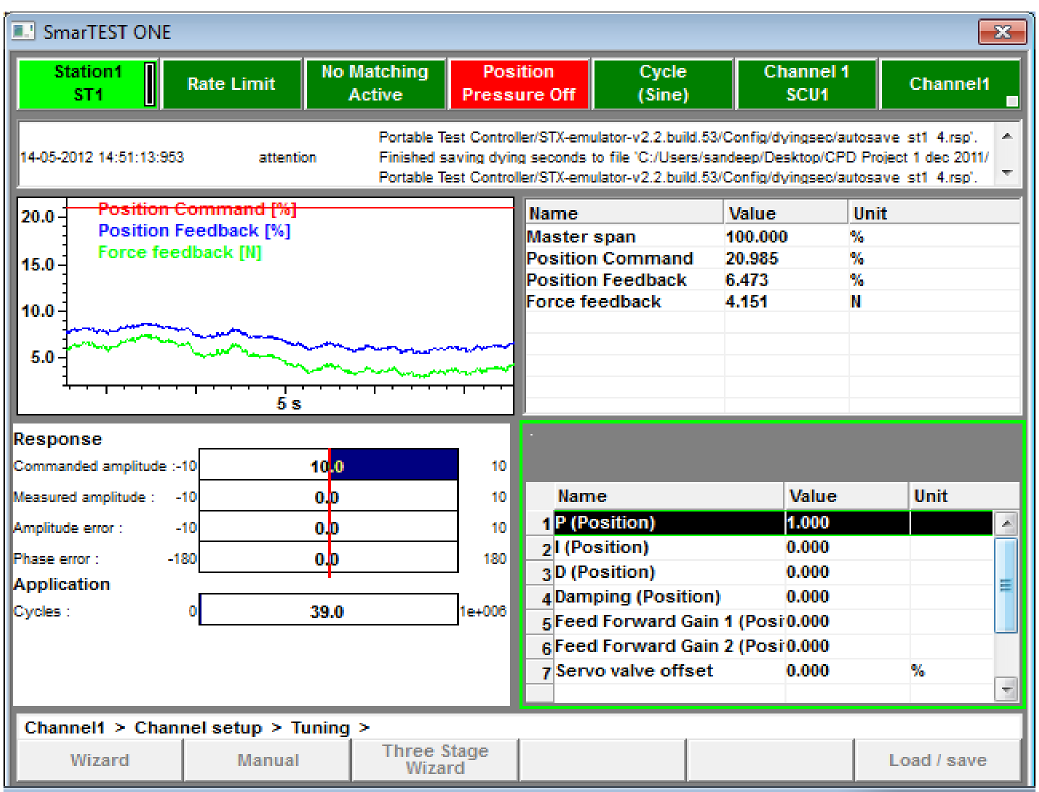

FIGURE 15: Position Control Loop Tuning

Load Loop Tuning Procedure:

Similar to Position Loop Tuning, after binding the SCU Channel Parameters to the Moog Customized loop and Load calibration, Tuning has to be done for the controller to minimize the error by adjusting the process control inputs. The procedure for Load Loop Tuning is given below and shown in figure 16.

a) Set all the PID values to zero, so the closed loop becomes the open loop.
b) Apply the null bias servo value offset current to the Load Cylinder Servo Valve.
c) Slowly increase and decrease the offset current to move the Load Cylinder and measure the tensile and compressive load on the load cell.
d) Set the PID values in such a way that the system will not go in unstable mode. And set the optimum PID values so that output signal follows the input command exactly or nearly exact.
e) After the configuration and control loop gain setting in the PTC hardware.

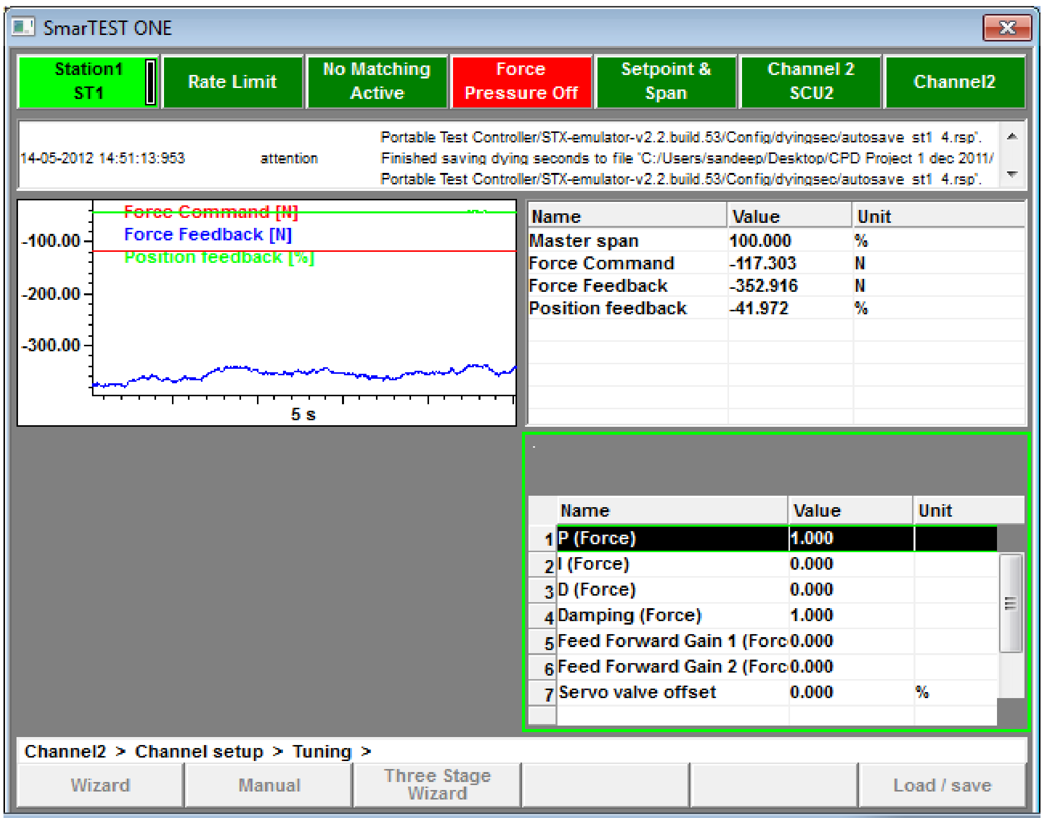

FIGURE 16: Load Control Loop Tuning.

8. ENDURANCE TEST RESULTS

Endurance Testing is used to test the life cycle of the actuator. In general, the endurance testing takes several months to completely execute the endurance spectrum and profile. There are different flight conditions for an electro-hydraulic actuator, as per the qualification test procedure. Flight condition test results have been shown below.

“Controls Check” Flight Condition and its test data analysis is shown below because all the test profile are similar to controls check (the differences are in stroke length, load and No of cycles).

“Controls Check” Flight Condition profile results for Position loop and Load loop is shown in figure 17 and figure 18 respectively.

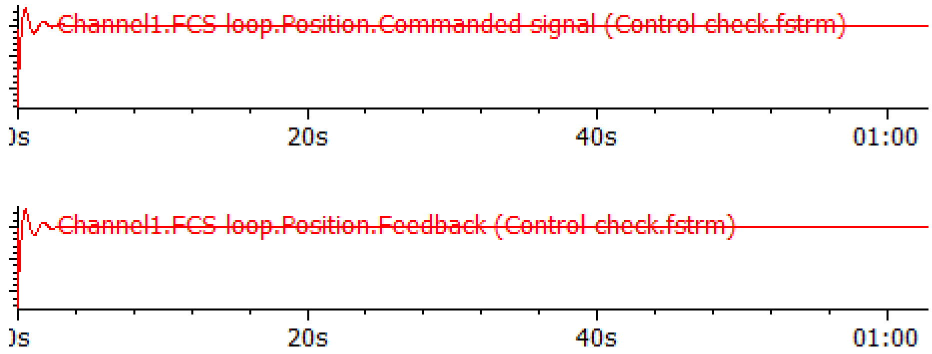

FIGURE 17: Control Check Position Loop Data.

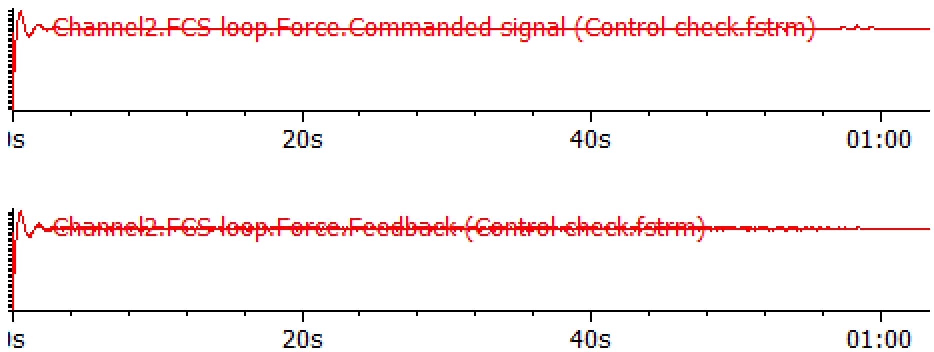

FIGURE 18: Control Check Load Loop Data.

<u>Endurance Test Data Analysis:</u>

a) In figure 17, the position feedback is exactly following the position command. It means the output is desired one.
b) This Position loop is stable and the response of the system is proper.
c) In figure 18, the load feedback is exactly following the load command. It means the output is desired one.
d) This Load loop is stable and the response of the test system is proper.

Similarly, “Landing” and “Descent-Roll Maneuver” flight condition test results are shown in figure 19, 20, 21 and figure 22 respectively.

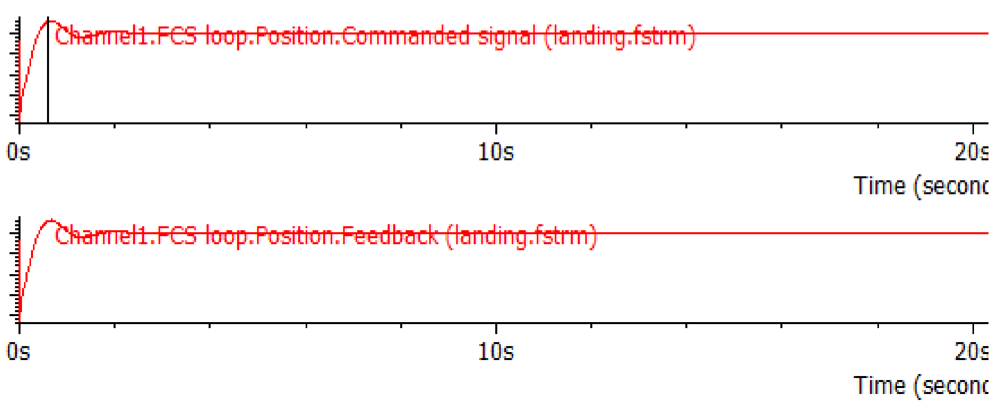

FIGURE 19: Endurance Spectrum (Landing) Position Loop Data.

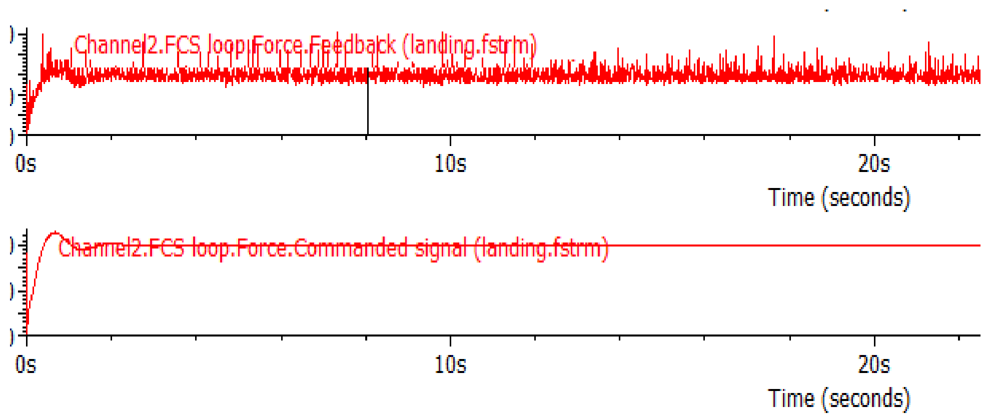

FIGURE 20: Endurance Spectrum (Landing) Load Loop Data.

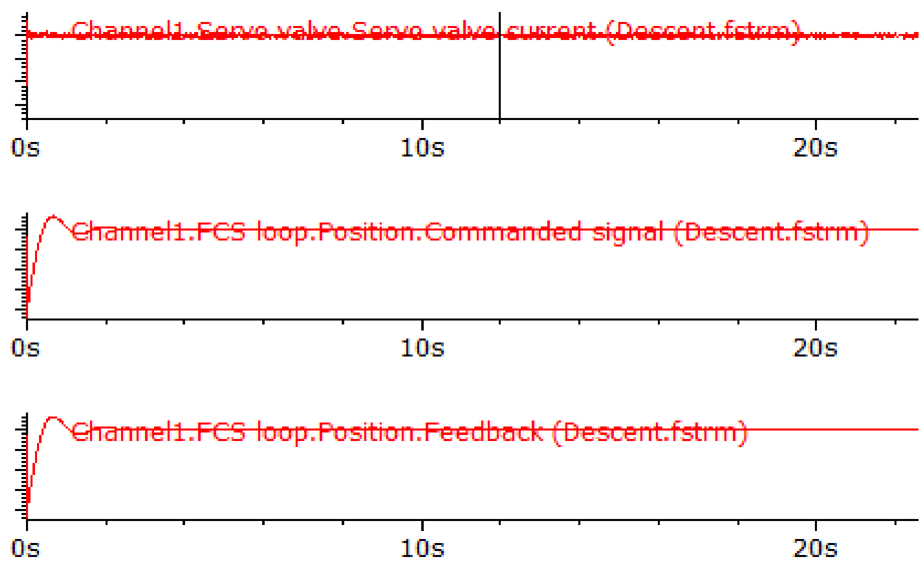

FIGURE 21: Endurance Spectrum (Descent Roll Maneuver) Position Loop Data.

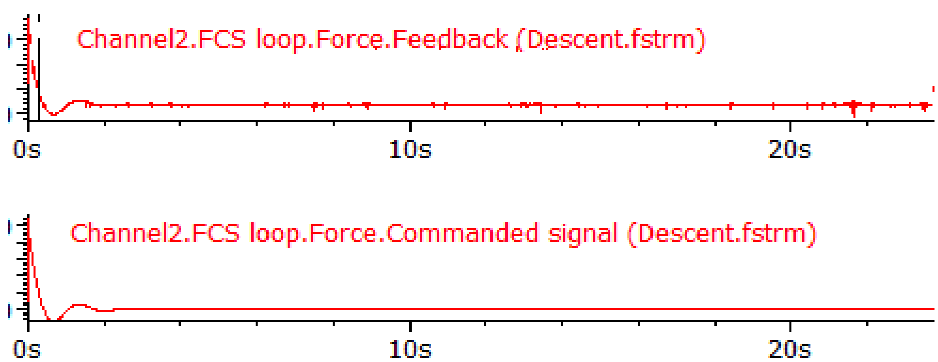

FIGURE 22: Endurance Spectrum (Descent Roll Maneuver) Load Loop Data.

9. CONCLUSION

As a consequence of the test results of the endurance testing conducted using Automated Test System at qualification laboratory, which mainly is constituted by the Moog PTC Hardware and

LabVIEW Graphical Programming platforms proves that Virtual Instrumentation Technology can be successfully used, to automate the endurance test execution of the Aircraft Electro-Hydraulic (EH) Actuator for High performance and productivity. The Automated Test System overcomes the defects of the traditional test system, simplifies the test hardware design architecture and improves the accuracy and consistency of Qualification Test System. The automatic test system reduces the artificial error and occurrence of system failures by ensuring the normal operation of the hydraulic system with all real-time diagnostic GUI features.

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