DEVELOPMENT OF ENDURANCE TEST SYSTEM FOR AIRCRAFT POWER DRIVE UNIT USED IN HIGH-LIFT SYSTEM

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ABSTRACT

Endurance testing of aerospace components tests aerospace components to examine its functioning over its entire lifecycle and hence check if it functions correctly over its entire useable lifecycle. Any aerospace component operates in a wide range of operating conditions. These include variations in conditions like temperature, pressure, humidity etc. Also, a standard flight cycle consists of various operating stages such as take-off, climb, cruise, descent, landing, ground maintenance etc. To satisfactorily guarantee the proper functioning of the components under all operating stages, under various conditions over its entire lifecycle is the purpose of endurance testing. In the course of endurance testing, the Unit Under Test (UUT) is subjected to the various operating conditions, at different temperature conditions and subjected to varying loads to simulate the actual operating conditions of the aircraft. These cycles are then repeated as many times as necessary to simulate the complete life cycle of the component. During the course of this entire testing, data is gathered from various temperature, pressure, position and speed sensors mounted on the UUT and test rig and examined to confirm that the UUT is performing under various operating regimes as expected. The test system consists of the mechanical fixtures to mount the UUT, Load systems to simulate external loads, Hydraulic setup to operate the UUT and Load systems, various sensors to gather the data, electronic hardware and test software to control the entire endurance test process. The UUT and Load control is achieved through a PID control system implemented using a Real Time Controller and LabVIEW software.

KEYWORDS: *Aircraft component; Endurance Testing; Unit Under Test(UUT); PID Control system; Real Time Controller; Automated Test System.*

I. INTRODUCTION

In Aerospace Industry, Automated Test System (ATS) at the assembly and manufacturing floor improves characterization accuracy and plays a crucial role to prove the airworthiness of the aircraft components. It is very helpful in achieving high quality standards of aircraft components by virtue of meeting predefined acceptance test criteria and quality test criteria.
Traditionally, a hydraulic test system comprises of several sensors, transducers, manually operated valves and analog meters. During the execution of the test, the technician needs to understand several engineering work instructions (records) and extract the test results by analysing the recorded test data. This approach is proved to be very tedious, time consuming task with lack of accuracy in test results, inefficient and involving artificial errors[2]. With advancements in information, Control and Instrumentation technology, an Automated Test System (ATS) has been envisioned, for ease of use and better productivity. ATS comprises of an industrial computer, automated test software and Test hardware module. An ATS consists of four basic elements as shown in Figure 1; Test Program, Test Controller, Instruments and User Interface. The Test software and Test Controller interface directly with the test procedure and the technician in test operation[1].

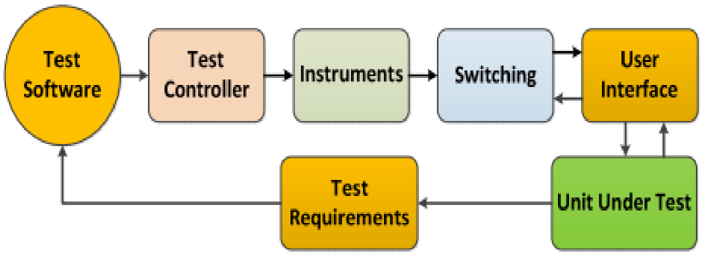

Figure 1 : High level testing process closed loop

This thesis outlines a comprehensive design and development of ATS for Quality Test of Power Drive unit (PDU) used in high Lift System of an aircraft. It uses LabVIEW and Moog Real Time Controller hardware platform to automate the test. PDU plays an important role in distributing the hydraulic power to the flight actuation system in an aircraft. Hence, before integrating with the actual flight actuation systems, it would be subjected to Acceptance Test Procedure (ATP) and Quality Test Procedure (QTP), as part of assembly and manufacturing level testing. QTP includes Endurance and Fatigue Test. 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. Also important, but often overlooked is performance degradation of the Unit Under Test (UUT). That is, to ensure that the thought 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. The experimental test results show that the automated Quality Test Procedure is effective and the parameters under test are in good co-relation to standard values. Using good programing practices and rugged automated test software architecture, an efficient ATS has been developed and deployed at Assembly and Manufacturing floor. This method is aimed at replacing the tedious and time consuming traditional method of testing the unit at Assembly and Manufacturing Floor[3].

A detailed description has been provided about the UUT used for endurance testing in II chapter. It is followed by the different profiles of the endurance testing mentioned in the III chapter. Overview of the test system is provided in the IV chapter. The two important control loops are discussed in the V chapter. VI chapter talks on automated test system implementation. It provides the description of all blocks in the ATS. This followed by the results and analysis, conclusion & future scope.

II. POWER DRIVE UNIT (PDU)

A Power Drive Unit is used to convert electrical or hydraulic power into mechanical motion (often rotary) and drive a mechanical actuation system.

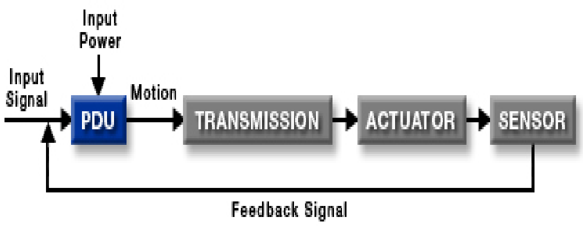

Figure 2 : Power Drive Unit

Unit Description: In our case, a common PDU is used for both the flap and slat high lift systems. Each PDU is fitted with dual hydraulic motors providing independent drive to the transmission system via a speed summing gearbox. Each motor is controlled by a different hydraulic supply via a dedicated valve block providing hydraulic isolation between the two systems. In normal operation, both motors drive simultaneously into the speed summing gearbox to achieve rated transmission shaft speed. Certain failures will result in the PDU operating with a single motor. In this mode, full load capability is still available from the PDU but system transmission shaft speed is halved. To hold system position against surface loads, and to provide a gearbox earthing point in the event of single motor operation, a spring energized pressure off brake (POB) is fitted at each motor input. The brakes are controlled (engaged or released) by signalling the solenoid valve fitted to each valve block. The solenoid also operates an isolation shut off valve to control the routing of supply pressure through to an EHSV. The EHSV controls the hydraulic motor direction and speed as part of the active position control loop provided by the Flap & Slat Electronic Control Unit (FSECU). Each motor speed is determined by the FSECU by assessing the rate of change of the PDU mounted resolvers which are geared directly to each motor shaft. The output of the differential speed summing gearbox drives through additional gearing in order to increase the torque to the level required to drive the transmission system against surface loading. At the output stage of the PDU is a System Torque Limiter (STL) and energy absorber mechanism. The STL prevents the full stall torque of the PDU from being delivered into the transmission components in one wing by sensing the torque across a set of differential ramp plates and clamping a set of brake plates if the torque exceeds a predefined value. The trip torque setting of the STL is slightly above the maximum normal operating torque for the system to avoid spurious torque limiter engagements. The system torque limiter is applied very rapidly and in order to prevent internal damage to the PDU, the rotating energy of the PDU gearbox components and hydraulic motors is absorbed by a compliant energy absorbing sliding ring pack.

III. ONE ENDURANCE LIFE

To execute the Quality Test, initially we shall define PDU life cycle. Quality Test Procedure (QTP) includes Endurance and Fatigue Testing. All Endurance and Fatigue testing to be done in room temperature as the magnitude of loading is adjusted to the room temperature values. One Endurance life consists of Flight cycles, Ground maintenance cycles, dynamic wing trip brake and Torque Limiter Trip Cycles. It should be noted that the loading shall be planned equally between left and right motors of PDU. Each step is explained along with the results in Result and Analysis section.

IV. TEST SYSTEM OVERVIEW

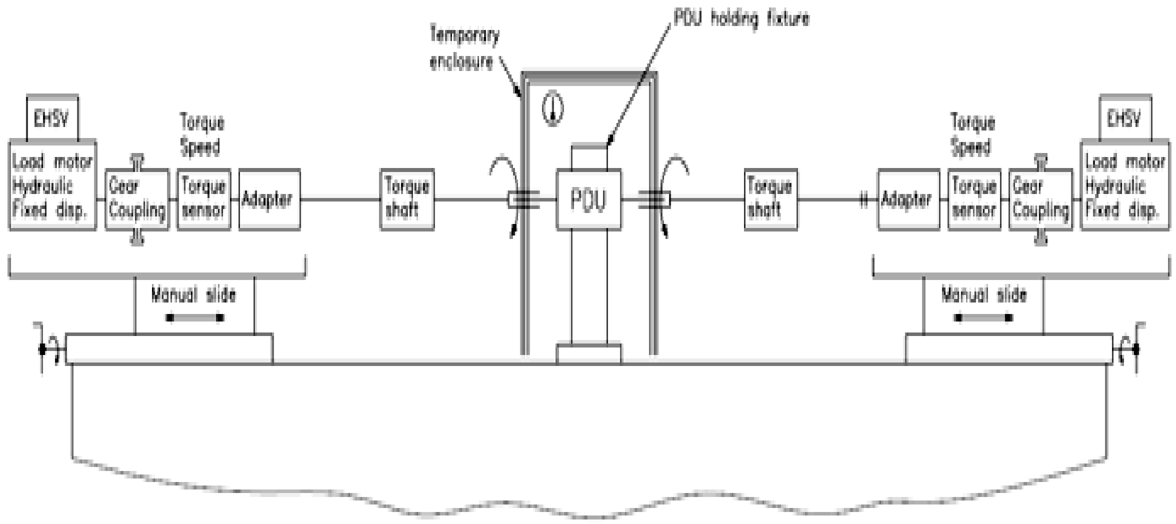

Figure 3 : Test Rig

Figure 3 shows the Test Rig Fixture. This consists of a UUT holding fixture. Since our UUT has two motors on either sides, the loading motors are provided on both sides of the fixture. This is coupled with the shaft. The sensors are mounted on the rig.

Our area of concern is to automate the QTP for the given UUT. Hence we shall look the Test System in a different view. This is showed in the below Figure 4. Our test system will have two control loops for achieving the Endurance test. First control loop is for automating the UUT to behave as in working conditions. This data is to be collected statistically and various calculations which is beyond the scope of this paper. Second control loop is to load the UUT. This loop simulates the entire load that UUT will absorb for the entire life time. Hence to meet our objective two controllers are used.

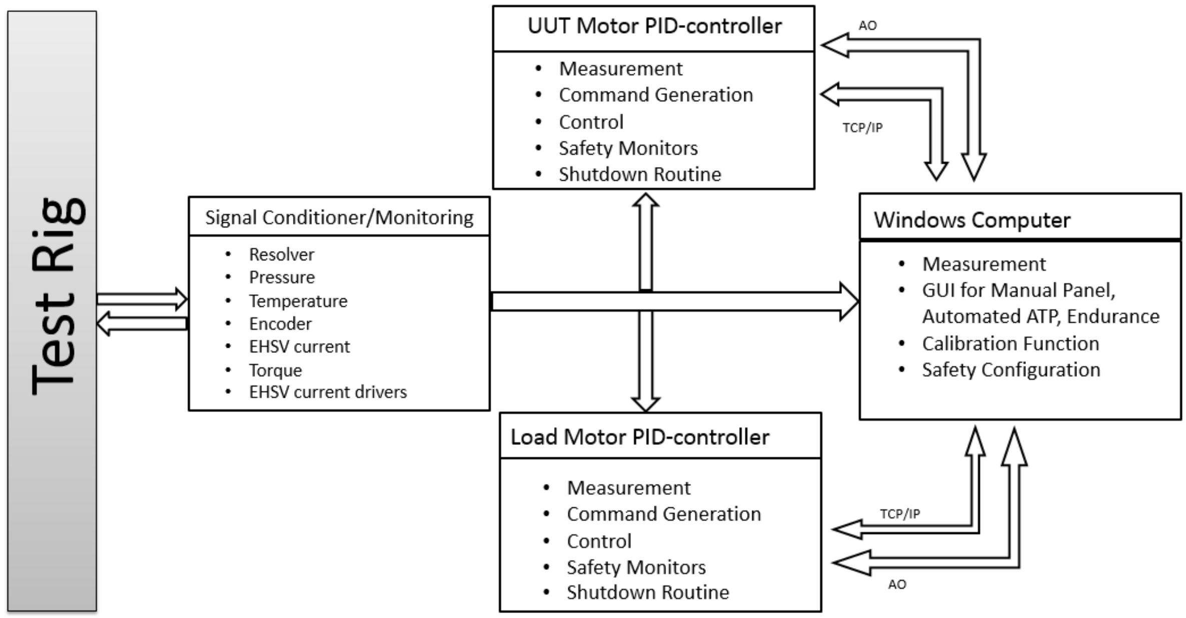

Figure 4 : Test System Block diagram

V. CONTROL LOOPS

Test system consists of two control loop, namely, UUT Control Loop and Load Control Loop. The two control Loop block diagram is shown in below figures.

5.1 UUT Control Loop

This control loop is to achieve the operation of PDU similar to its working conditions in the aircraft. This is similar to the cascade control system of Flaps and Slats in Aircraft system. This consists of speed controlling inner loop and a position controlling outer loop of a cascaded system. Smooth response and required speed profile is achieved by PID controller.

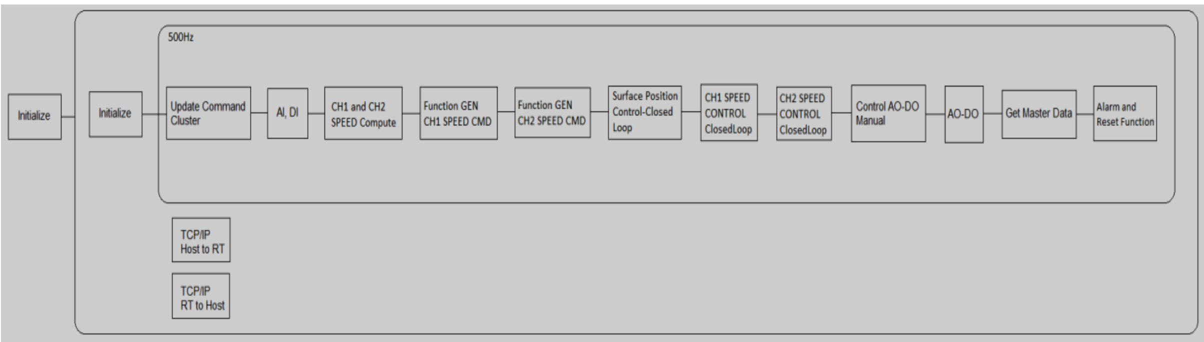

Figure 5 : UUT Control system block diagram

5.2 Load Control Loop

This control loop is to achieve the load torque. This includes the automating the test system to simulate the entire endurance of PDU.

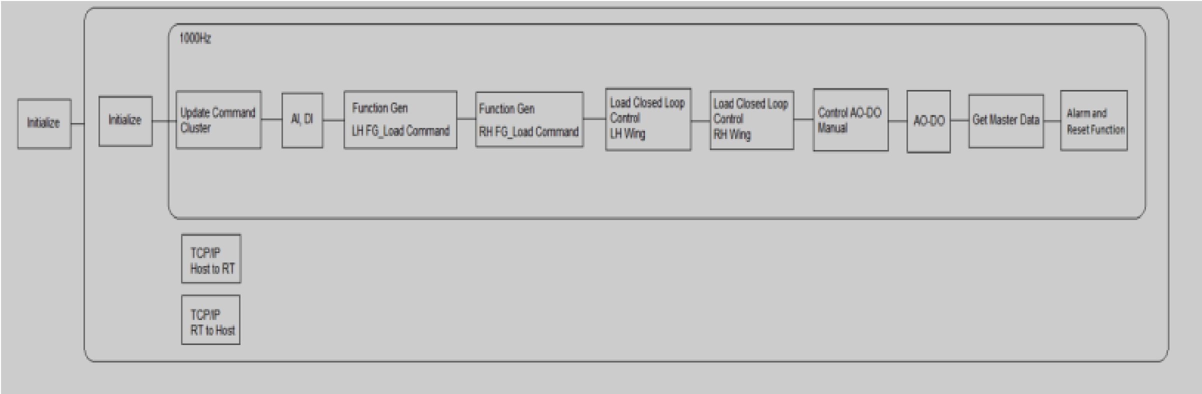

Figure 6 : Load Control system block diagram

VI. AUTOMATED TEST SOFTWARE IMPLEMENTATION

Figure 7 shows the implementation of the ATS using LabVIEW and Data Acquisition (DAQ) Driver through Moog microcontroller. The test system software is user friendly and powerful graphical user interface. There are four key features of ATS which has been listed below.

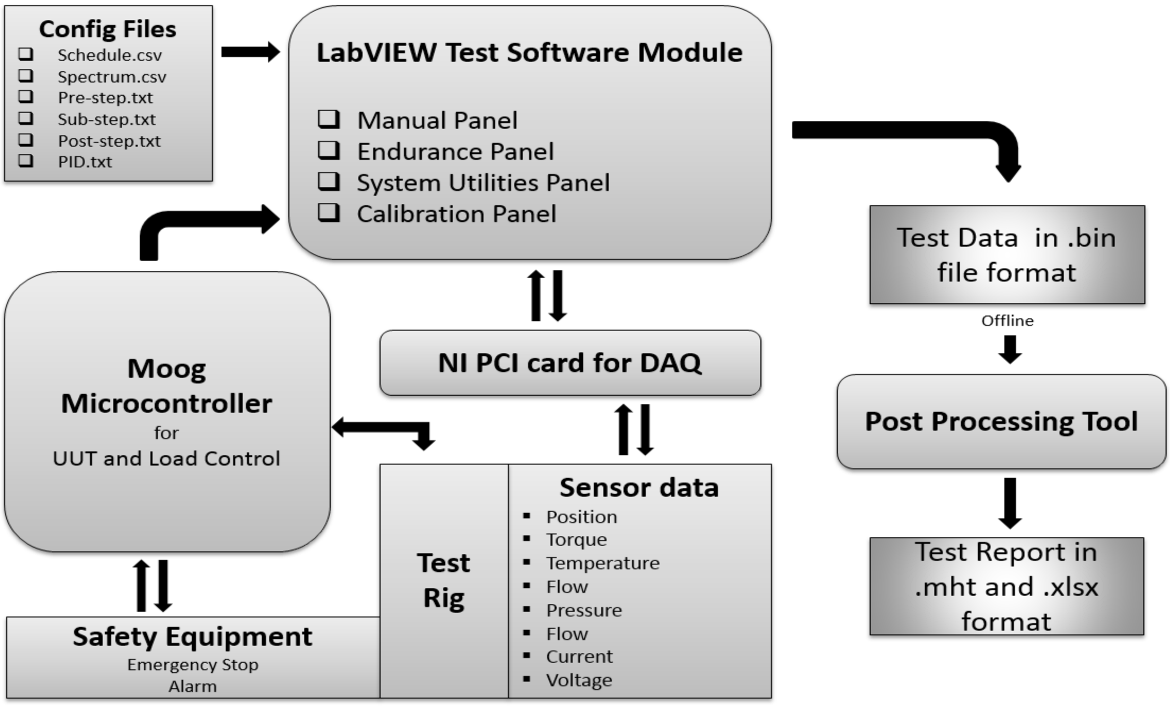

Figure 7 : ATS SW Implementation

6.1 LabVIEW source code

LabVIEW code provides the top level coding for ATS. This provides the interface between the technician and test rig. Implementation of ATS is developed by state machine architecture on LabVIEW. LabVIEW code when launched, provides the user login initially, when completely launched it navigates to the main panel of the ATS. This is shown in Figure 6 2. This provides the path to various functionalities. Endurance button navigates to the main endurance automated test panel. This is shown in Figure 8. This helps us to read the various physical parameters such as temperature, voltages, current, pressure, torque, position etc. and also the status of the QTP. This provides the recording the test data in bin file format, which can be used for analysis. Various test procedures can be adopted by making the software generic. This is achieved by using configuration files. It also provides the real time graph of which required parameters are viewed by selecting the required channel. It also provides the various alarm status of test conditions which are configured using config files.

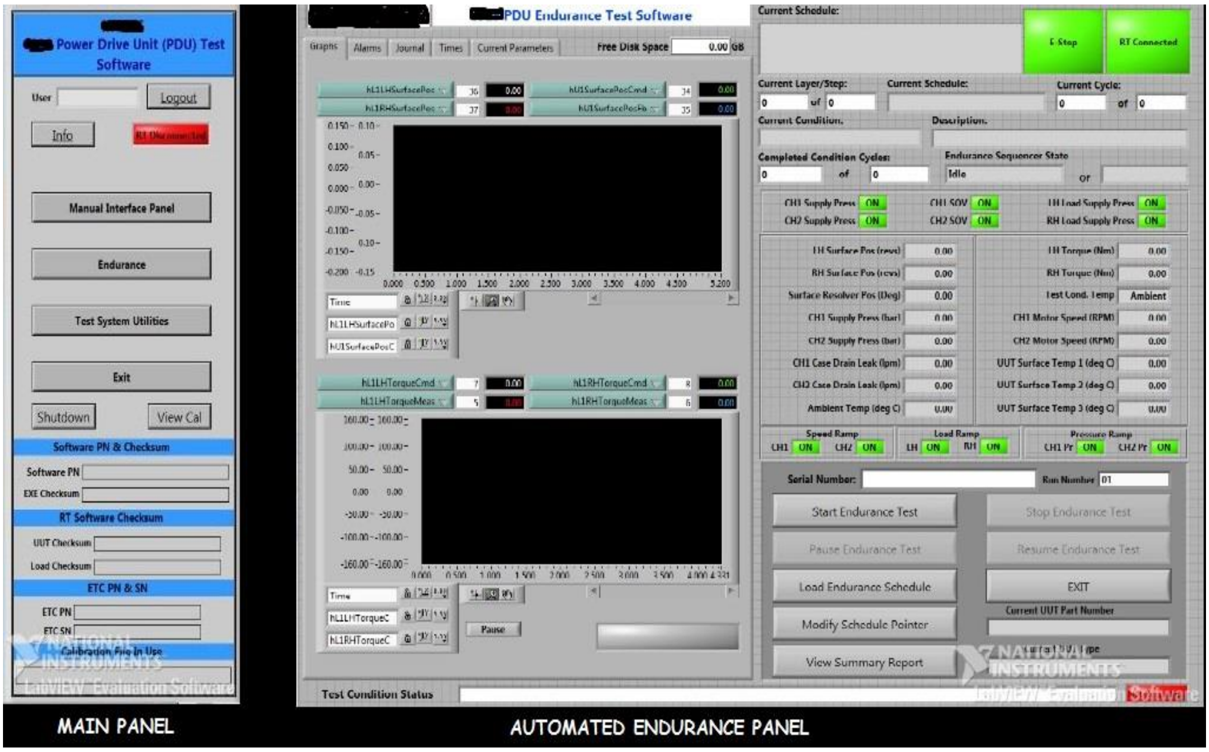

Figure 8 : LabVIEW front panel of ATS

6.2 Configuration files

Config files define the QTP. This behaves as the series of commands for ATS to execute the endurance test. This consists of mainly schedule file, spectrum file, pre-step file, post-step, sub-step and procedural specific step files. This also includes PID co-efficient files which are obtained on tuning.

Schedule file: This is a .csv file which gives the information of all Layers in the QTP. This also gives the information of the spectrum file, pre-step files and post-step files to be considered for a particular layer in endurance testing. Schedule file specifies the number of mission cycles to be executed for a layer and the temperature at which it has to execute.

Spectrum file: This is a .csv file which will be picked up by the schedule file. This contains the important information for different conditions that need to be executed in endurance testing. This file will have the information of position and load to be applied to the UUT, type of loading (weather Static loading or spring loading etc.), sub-step file, PID co-efficient file and alarm parameters with their limits.

Pre-step file: This file is picked up by the Schedule file. Pre-step files contain the information of all the initial conditions to be updated in between the layers or the starting of the test. This is a very prominent text file which contains the commands for achieving the initial conditions of the test setup.

Post-step file: This file is picked up by the Schedule file. Pre-step files contain the information of all the final conditions to be updated in between the layers or the starting of the test. This is one of the prominent text file which contains the commands for achieving the final conditions of the test setup.

Sub-step file: This a text file picked up by the spectrum file. This contains the command for the Remote Terminal (RT). It contains the amplitude, frequency, offset etc. for commanding the RT.

6.3 Moog microcontroller source code

Moog manufactured microcontroller is used for DAQ and commanding the test rig. This is coded in the Moog mass code platform which is similar to the assembly level programming. Here PID algorithms are implemented for controlling the system. And also data acquisition is done. This is placed in an Electronic Console.

6.4 Automated Calibration SW

The real time values have to be captured form the test system for which sensors are mounted on the test system. Therefore calibration of the sensor becomes a high priority task. The sensors used in the system are calibrated by their respective vendors. But it becomes necessary to calibrate the path to compensate cable and connector losses. Hence a calibration platform has been given by the LabVIEW code. Here we can choose the required channels and capture the data. According to the calibrated range and values provided by the vendor, voltage /current is fed to the particular path using the required source. By the data sheet provided by the vendor, expected value can be feed in and data is captured. This is performed for various values between the ranges of the sensor and captured by the software. When update is clicked, the application automatically does the curve fitting (y=mx+c) and calibrates the end to end path. The calibration window is show in Figure 9.

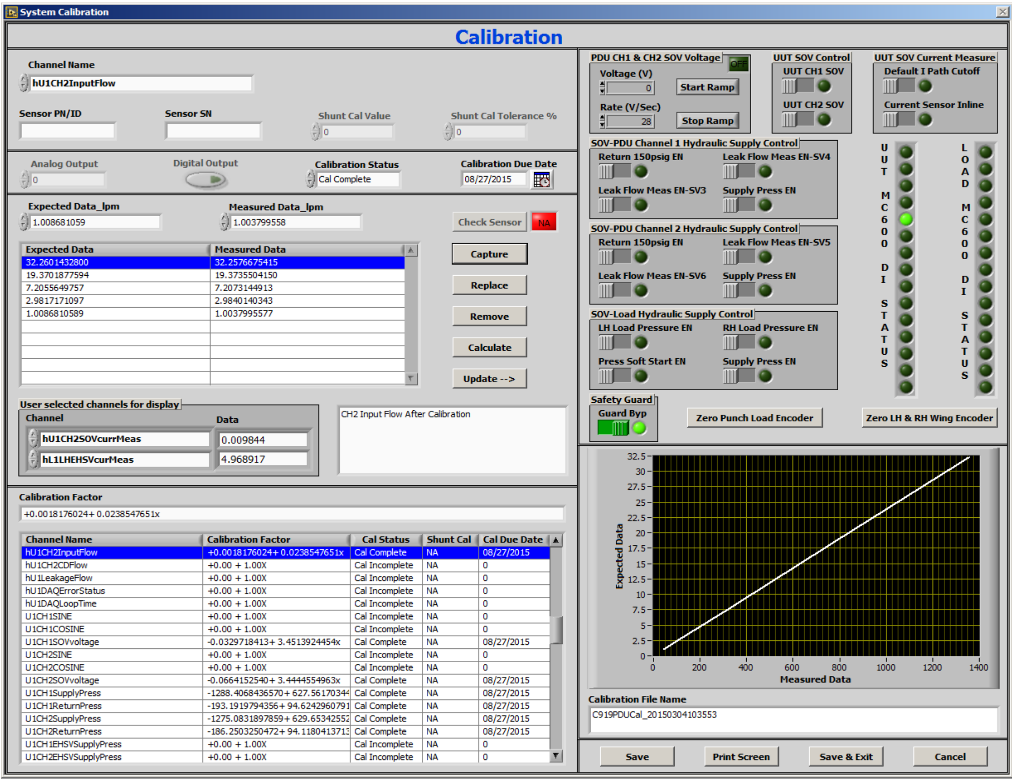

Figure 9 : Calibration window

6.5 Post Processing Tool

The data recorded is saved as a binary file. To analize the test data ATS provides the post processing tool which reads the bin files and process the data for our understanding. This reads the bin files and generates the graphs and automatically generates a excel report and a html report with the screen shots of the graphs. This tool provides us the analysis for our Endurance testing. The figures provided in Results and Analysis section is generated by the Post Processing tool. Figure 10 shows the post processing tool.

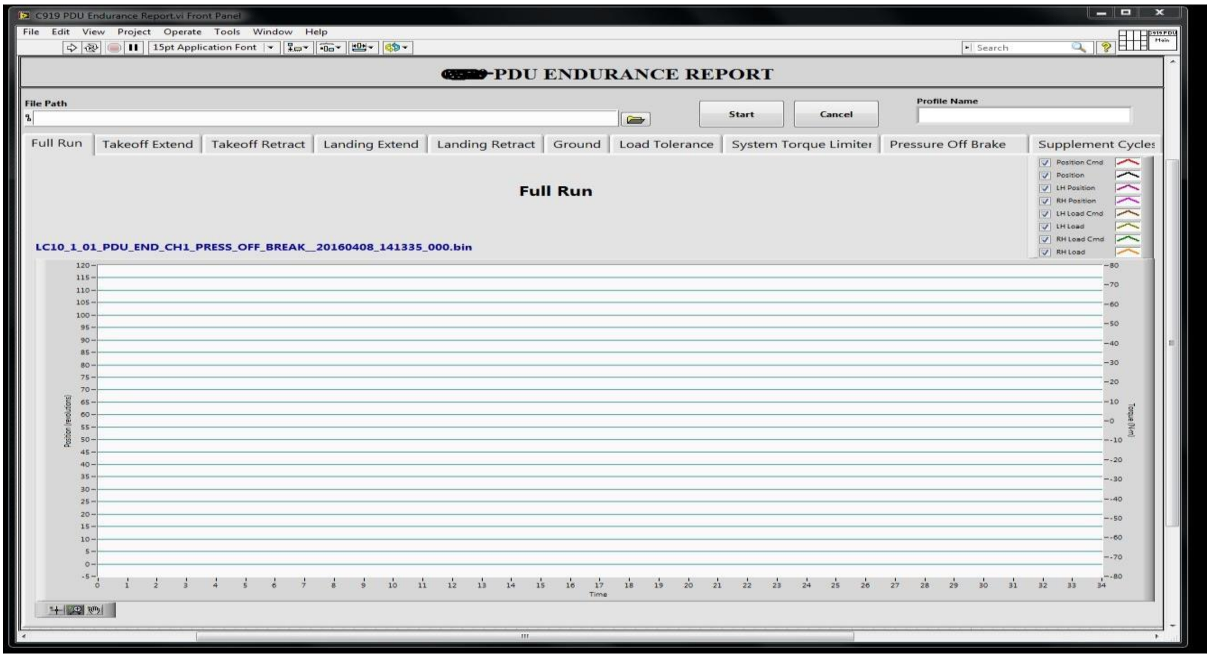

Figure 10 : Post Processing Tool

VII. RESULTS AND ANALYSIS

Testing of Endurance test on the PDU includes the following type of cycles which was mentioned in the previous section of the paper. The below plots shows the test data generated and analysed by Post Processing tool provides the analysis of Endurance test.

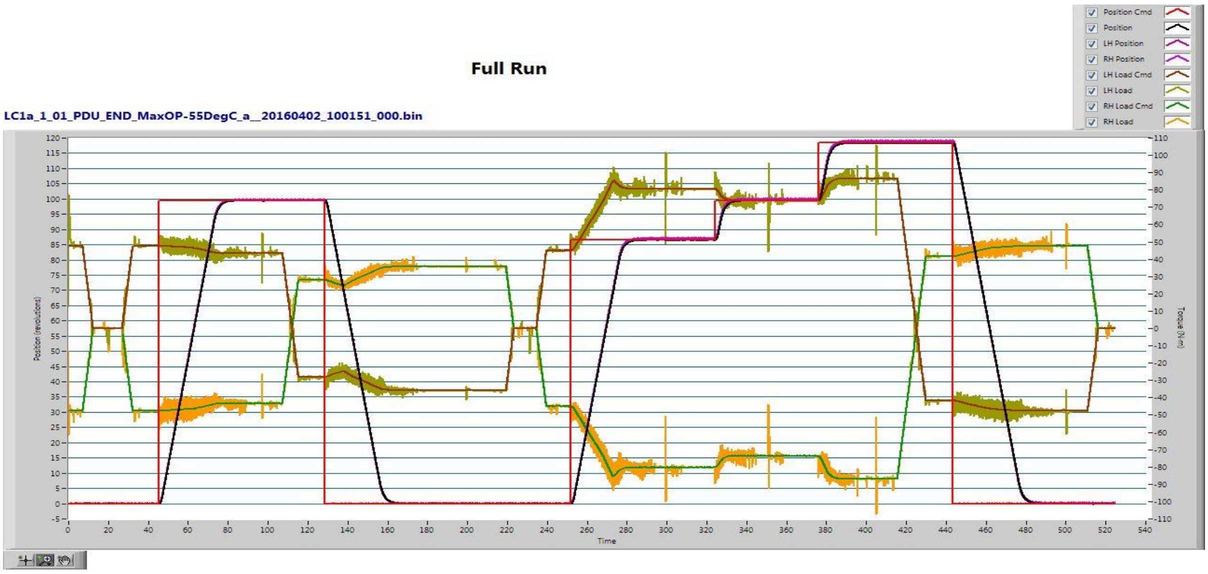

Figure 11 : Full run which includes Take-off and Landing (both extend & retract operation)

Normal extend and retract operations are performed in Flight cycles and Ground Maintenance. Supplement cycles include the extra extend and retract action of the UUT.

Flight Cycles: This includes Take-off and Landing.

Ground Maintenance Cycles: This includes the operation of Actuators during Maintenance.

Supplement Cycles: This application is performed by applying a constant load of 100Nm which is opposing the extend motion of the PDU and 60Nm for Retract operation.

Since all three are similar in operation we have shown Full run plot in Figure 11. This shows the plot of Endurance test run for Maximum operating conditions at 55deg temperature layer. It can be seen that position feedback follows the position command. The load applied to the UUT also follows the command. Though load feedback has too many spikes, Figure 12 shows that the loading is achieved with respect to our requirement and measured load is within the tolerance band.

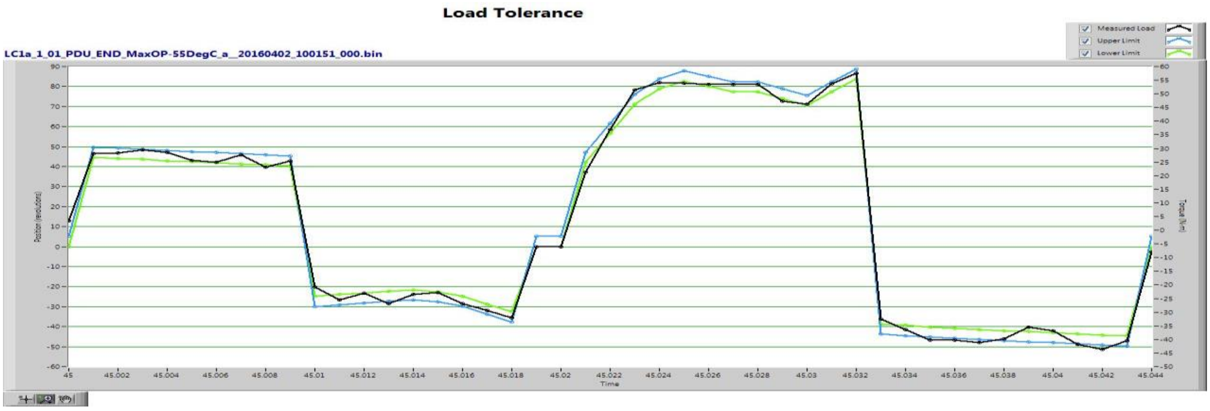

Figure 12 : Load Tolerance plot

Torque Limiter: Torque Limiter has two different mechanisms to test. They are,
<u>Extend Trip</u>- Signal the UUT from 0 Deg to 34 Deg. Gradually increase the Load Torque to Left PDU shaft of nominal rate of 2.5Nm/rev, Until the PDU Torque Limiter Trips. Same is repeated for Right PDU also.
<u>Retract Trip</u>- Signal the UUT from 34 Deg to 0 Deg. Gradually increase the Load Torque to Left PDU shaft of nominal rate of 2.5Nm/rev, Until the PDU Torque Limiter Trips. Same is repeated for Right PDU also.

Figure 13 shows the System Torque Limiter plot of Left motor, for both extend and retract operation. We can observe the LH-load suddenly reaching zero, which indicates that tripping has been successfully executed and tested.

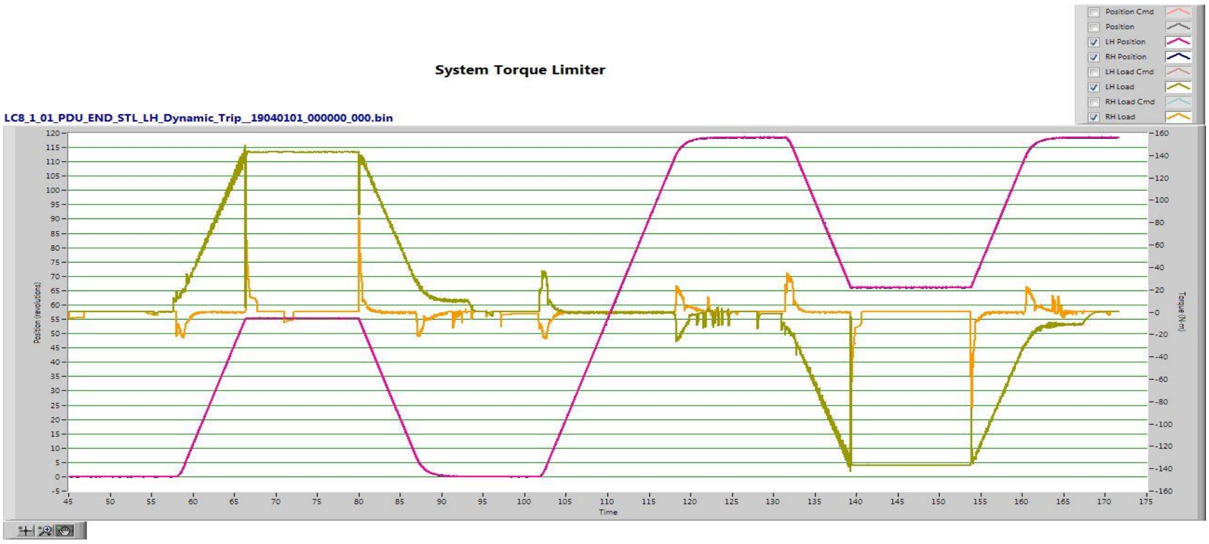

Figure 13 : System Torque Limiter

Dynamic Trip Break: Can also be called as Dynamic Pressure Off Break. This is performed both for Extend and Retract. Initially the PDU is signalled to extend to 10 Deg. With PDU running at 420rpm, Solenoid valve is de-energized, there by disconnecting the supply for the PDU. Time is measured for PDU to come to complete rest. This time constant T should be less than 90ms. Same can be tested with signalling the PDU from 10 Deg to 0 Deg in retract application. This operation is performed for both left and right side motors.

Figure 14 shows the Pressure of Brake operation for channel-1 SOV (Solenoid Operated Valve). It can be observed that when SOV Voltage is cut off, speed gradually come down to zero demonstrating the POB action.

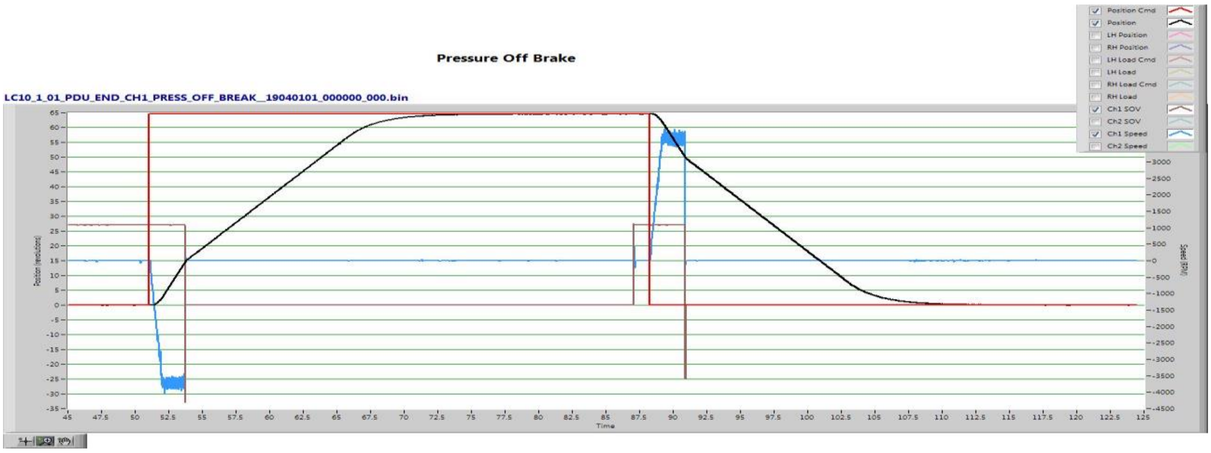

Figure 14 : Pressure of Brake

VIII. 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 Hardware and LabVIEW Graphical Programming platforms proves that Virtual Instrumentation Technology can be successfully used, to automate the endurance test execution of Power Drive Unit used in High lift system. 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.

IX. FUTURE WORK

Post processing module which is a part of ATS, is an off-line tool can be upgraded to online so a complete ready report is generated when a test is run. ATS can be improved so that it enhances the code repeatability.

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