DESIGN AND DEVELOPMENT OF AUTOMATED TEST SYSTEM FOR AIRCRAFT HYDRAULIC CONTROL MODULE AT ASSEMBLY AND MANUFACTURING FLOOR

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Abstract

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. This paper outlines a comprehensive design and development of ATS for Aircraft Hydraulic Control Module (HCM) at assembly and manufacturing floor. It uses LabVIEW Real-Time (RT) and PXI hardware platform to automate the Acceptance Test Procedure (ATP) for the Hydraulic Control Module (HCM) of aircraft actuator surface. HCM plays an important role in distributing the hydraulic power to the primary flight actuation system in an aircraft. Hence, before integrating with the actual primary flight actuation systems, it would be subjected to ATP, as part of assembly and manufacturing level testing. The experimental test results show that the automated Acceptance Test Procedure is effective and the parameters under test are in good co-relation to standard values. Using good programming practices and rugged automated test software architecture, an efficient ATS has been deployed at Assembly and Manufacturing floor. This method is aimed at replacing the tedious and time consuming traditional method of testing the Acceptance Test Procedure (ATP) at Assembly and Manufacturing Floor.

Keywords: Automated Test System, Actuator, Hydraulic Control Module, Data Acquisition.

1. Introduction

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.

With advancements in information, instrumentation and control 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 National InstrumentsTest hardware module. An ATS consists of four basic elements as shown in Figure 2: 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.

Figure 1Aircraft Hydraulic Control Module (HCM)

Similar to the importance of Electronic Stability System (ESP) in the Antilock Braking System (ABS), the Hydraulic Control Module (HCM) as shown in Figure 1 is an important component in the hydraulic circuit for the primary flight actuation of the Hydro-Mechanical Actuator in the aircraft. The function of the HCM is to control the desired hydraulic pressure and flow rate for the primary actuation system.

ATS is designed to stimulate and monitor Unit Under Test (UUT) occurrences at pre-defined UUT inputs, outputs and test points, to verify and validate the functionality of the UUT. This paper gives a detailed description about the design architecture of the ATS and various acceptance tests performed as part of Assembly and Production Testing.
2. System Overview

Stanley P. Case et al. (1995) stated that reaching the 21st century with superior test tools will require serious attention to areas in automatic test system (ATS) development the needs of users, powerful user interfaces, and data collection. Many of the Hydro Mechanical Devices include transducers and actuators, controlled by closed loop systems.

Pawel Rzucidlo et al. (2006) specified that an aircraft’s hydro-mechanical control modules and systems are controlled by Full Authority Flight Control Systems (FAFCS), however, during the development and system integration testing, FAFCS is often not available. Thus control algorithms and controls systems are specifically designed and built for each system.

Figure 4 depicts the functional block diagram of the ATS for the HCM, where the pressure supply is provided from the Hydraulic Control Panel (HCP), which is monitored by the pressure transducer on the both supply pressure and return pressure lines. The HCM has two output ports C1 and C2. First output port is dedicated for supply pressure, while the second for return pressure vice versa. The pressure and flow rate at the out port are continuously monitored by the pressure and flow transducers. The transducers are monitored using data acquisition card with high resolution and high sampling rate.

The test software processes the data signal, analyses and feeds the processed signal to the predefined channel of data acquisition card, which will generate the appropriate servo current (mA) to drive the Electro-Hydraulic Servo Valve (EHSV) of the HCM.

The pressure and flow transducer data collected is communicated to the LabVIEW Real-Time software module through Ethernet connection for post processing. With Real time, a deterministic response time required to acquire the pressure and flow transducer data and provide EHSV feedback control signals is achieved.

David Nosbusch et al. (2012) stated that as PXI test and measurement systems continue to grow it becomes increasingly important to understand the components of high throughput systems and the considerations that must be taken to ensure bottlenecks are not created. With the PXI Hardware Architecture, it has been feasible to acquire large data sets from various transducers. Through real-time operating system approximately 250,000 floating point calculations are handled per 60 msec, which identifies for loading or unloading faults in the Aircraft Hydraulic Control Module as part of component level testing at assembly and production floor.

The test data is analyzed using the post-processing modules in real-time and the test results are displayed in Graphical Use Interface (GUI) using Data Visualization components like graphs, charts and XY Graphs.

The complete control algorithm ran on Real Time Controller in 390 micro second per cycle. However, adding the input and output increased cycle time to 1.5 milli seconds. Communication between Real Time Controller and Host System is through 1 KB of Shared Memory. By using part of the shared memory as a circular buffer, the Real Time Controller could read and write data for every cycle, which host system, could read and write variable size batches of data on demand. Writing the batches of data to a graph provides an excellent real-time display that the user would use for signal monitoring and analysis at any time to give information on test performance.

The operator GUI reduced to the necessary display elements enables fast and easy control of measurement, but is still open for access to all the system parameters by interactive menu driven dialogs.

3. Test Software Implementation

Figure 3 explains the interface between the LabVIEW Software Module and the Data Acquisition (DAQ) Driver through Hardware Abstraction Layer (HAL). The test system software has a powerful GUI for the following test operations:

- Operator Test Sequence Execution at Assembly and Production floor
- Diagnosing Software for Test System Troubleshooting
- Creating test sequences with a sequencing editor
- Testing via a manual panel utility
- Analysis of the test data patterns for the offline data logged while the test is executing.
- Configuring and Performing End to End Calibration for the channels.
- Grouping the test sequences and editing using the Test Sequence Editor

There are five key Test Software Elements in an Automated Test System (ATS) are as mentioned below:

1. **Test Software Source Code**: It is a procedure which the ATS will use to test the UUT. It is written in a source language such as LabVIEW and is referred to as source code.
2. **Test Program Object Code:** Source Code is translated to a machine readable form known as object code by a compiler. The compiler may execute on the ATE computer or on an offline computer.

3. **Test Executive:** It is a test program executed on the ATE computer and works within the ATE computer environment under the control of the operating system. Test Executive automates the execution of code modules to increase test throughput at manufacturing floor.

4. **Automated Calibration Software:** As the accuracy of sensors drifts over time, Automated Calibration Software is used to perform the End-To-End Calibration of the Sensors and transducers in the ATS. Automated Calibration Software tracks the performance of the sensors and minimizes the time and costs associated with unscheduled downtime and quality issues.

5. **Post Processors:** Test software application produces binary data files to speed up file input and output operations and save hard disk space. Post processor is used to analyze the test data based on the pass / fail criteria and determine if particular acceptance test has passed or failed.

Manufacturing Level Automated Test System (ATS) includes features mentioned below:

- Perform online and post processing on the acquired Test data as part of test execution.
- Determine the Pass-Fail Criteria online, based on the post processing analysis
- Provide facility to monitor and control the manufacturing tests remotely.
- Provide Test Software Architecture that can support easy configuration, part management, test software integrity, reconfiguration and future expansion.
- Efficient timing and synchronization for better integration between various control loops and high speed data acquisition.
- Rugged ATS Architecture to withstand Assembly and Manufacturing Environment (No Instrumentation Failures).
- Accuracy and reliability of the test data with efficient test data storage for future reference.

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**Figure 3 Automated Test Software - High Level Design Block Diagram**
Figure 4 Test System Interface Block Diagram for Automated Test System

Figure 5 explains the detailed design architecture of the software including the state transition as per the user events in the GUI. Using below mentioned state machine architecture, complex decision-making algorithms which performs a specific action for particular state transition in the diagram has been implemented. Each state can transition to one or multiple states, and can end the software process flow. Different user actions transform the GUI into different processing segments and each of these decision algorithm segments will acts as a states in the state machine as part of software architecture.

Figure 6 shows the GUI for one of the test step for the Acceptance Test Procedure, performed at Assembly and Production Facility for Aircraft Hydraulic Control Module (HCM). Air Purge Cycling Test Step is used to remove the trapped air in the Oil, which can vary the dynamic and static stiffness parameters of Hydraulic Control Module (HCM).
Figure 5: Software Detail Level Design Architecture including State Transition
4. Test Results

The Automated Test System (ATS) has successfully performed the Acceptance Testing of the Hydraulic Control Module (HCM) at Assembly and Production Floor. The test results for each ATP test step were statistically analysed using the Reputability and Reproducibility (R&R) Analysis method. The derived test results are used to determine the uncertainty of ATS, before comparing, controlling or optimizing the manufacturing processes at Assembly and Production floor.

The measurements derived from the ATS provide valuable information for characterizing and improving the quality of the Aircraft Hydraulic Control Modules. As the actual analysis results meet the recommended analysis acceptance criteria shown in Table 1, the ATS has been accepted and deployed at Assembly and Production Floor.

<table>
<thead>
<tr>
<th>SI NO</th>
<th>Gauge R &amp;R Analysis Parameter</th>
<th>Recommended Gauge R &amp;R Analysis Acceptance Criteria</th>
<th>Actual Gauge R &amp;R Analysis Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coefficient of Determination</td>
<td>R &gt; 95% Accept&lt;br&gt;87% &lt; R &lt; 95% Marginal Accept</td>
<td>96%</td>
</tr>
<tr>
<td>2</td>
<td>Linearity to Gold System</td>
<td>Pass the hypothesis test that slope between the Gold and Production system is equal to one (unity)</td>
<td>0.973</td>
</tr>
<tr>
<td>3</td>
<td>Precision (Repeatability only)</td>
<td>&lt;10% Accept&lt;br&gt;10% &lt; P/T &lt; 30% Marginal Accept</td>
<td>9.3%</td>
</tr>
</tbody>
</table>
5. Conclusion

The test results of the acceptance tests conducted using Automated Test System (ATS) at Assembly and Production floor, which mainly is constituted by Test Hardware and Software platforms supports the use of Virtual Instrumentation Technology to automate the acceptance test execution of the Aircraft Hydraulic Control Module for High performance and productivity. The ATS overcomes the limitations of the traditional test system, simplifies the test hardware design architecture and improves the accuracy and consistency of Assembly and Production Testing.

The upgraded test capability improves manufacturing throughput and detects product design issues during acceptance testing at Assembly and Production floor. 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.

References