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Design and Implementation of a Data Acquisition System for Testing of Gas Turbine Engines

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***Abstract*— In this study it is intended to design and implement a data acquisition system for the testing of a gas turbine engine. This is achieved by selecting the necessary and appropriate hardware as well as the software for the data acquisition and installing to the test facility with required elements. The selection of hardware comprises the computer type, data acquisition system, instrumentation (transducers, thermocouples etc.) and other peripherals. The designed system is implemented for the testing of a turbofan engine. By using commercial data acquisition hardware and software, an application is made to collect test data of the turbofan engine. The required parameters such as pressures, temperatures, velocities, etc. are measured and the corrected parameters are calculated with the help of correction factors. Data are also checked for the range of acceptable limits to trigger necessary alarm messages or sounds where applicable. Test data are stored and archived for future analysis.**

***Keywords*— gas turbine, engine testing, data acquisition, instrumentation**

I. INTRODUCTION

The aim of the project is to design and implement a data acquisition system for the testing of a gas turbine engine. The project is realized in the turbofan engine test cell at Tusas Engine Industries Inc. (TEI). Although TEI has a modern test cell facility with full automatic engine control and computerized data acquisition system, it was decided to design and implement a separate but much simpler and versatile PC driven data acquisition system for testing a gas turbine engine to work as a parallel system to existing one for technology demonstration purposes. A new PC based data acquisition system and a special software were implemented [1].

A. *The Need for Testing*

Engine designers have had to make predictions as to the expected performance since the introduction of gas turbines and engine testing is the only way to demonstrate to both the manufacturer and to the client that his product can meet specified performance objectives [2].

B. *Types of Engine Tests*

The primary objective of engine testing is to obtain information about the engine or its components, accessories or systems at defined operating conditions. At its simplest, this may be to demonstrate that an overhauled engine destined to re-enter service is airworthy and meets the minimum guaranteed performance. At the other extreme, a high performance military engine demonstrator, containing advanced technology components, may be comprehensively instrumented to test its performance and perhaps failures. In between these extremes exists a whole range of test categories. Table I gives the general information about the types of engine tests performed and the objectives sought from these tests [3].

Engine tests generate a lot of data when hundreds or thousands of data channels are considered. Data amount becomes much bigger when engine transients are being investigated. Therefore, dependable and fast computer-based data acquisition systems are needed. These systems provide us with fast and data collection and processing capability.

The type of test influences the accuracy of measurement required and the rate at which data are gathered. For example, performance pass-off tests require high accuracy but only relatively slow response measurements whereas the evaluation of how a demonstrator engine fitted with a digital control system accelerates will demand a fast response measuring system.

C. *Quantities to be Measured and Related Instrumentation of Engine Tests*

There are many different physical quantities in an engine test which need to be measured. The measuring device, or the transducer is designed for the particular quantity to be measured and gives output signals which are characteristic to its design and construction. Some of the most common measurement signals are discussed in the following section and a summary is given in the Table II [3].

TABLE I. TYPES OF ENGINE TESTS [3]

Type of Test	Objectives
Pass-off	Demonstrate performance guaranties and airworthiness after overhaul.
Endurance	Demonstrate capability of mechanical integrity and reliability over an extended period e.g. 150 hour type test or accelerated mission test.
Fault Diagnosis	Identify reason for performance shortfall or component failure.
Ingestion	Demonstrate capability to withstand ingestion of foreign objects, sand or birds.
Systems Development	Evaluate the new technology systems or accessories, often on a well established engine, e.g. digital control system.
Engine Development	Evaluate the new technology engine components on an established engine, identifying performance benefits and any handling problems.
Demonstrator	Assess the overall performance and handling qualities of a completely new engine containing many advanced technology features.

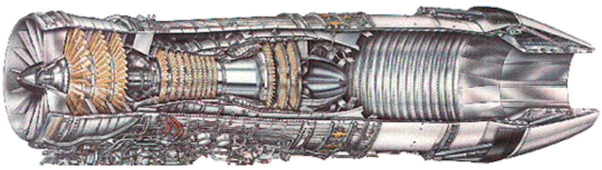

Fig. 1. *Cutaway view of F110 turbofan engine [5]*

TABLE II. COMMON MEASUREMENT SIGNALS [3]

Quantity	Transducer Type
Pressure	1. Silicon bonded strain gauge 2. Vibrating cylinder
Temperature	1. Thermocouple 2. Resistance Bulb
Fuel Flow	1. Turbine Flowmeter 2. Bulkmeter
Thrust	Strain gauged beam or diaphragm
Rotation	1. Toothed wheel 2. Tacho generator
Vibration	1. Piezo-electric 2. Strain gauge

II. MATERIAL AND METHODS

Although the test cell facility in TEI is a very sophisticated and advanced one, the main purpose of the present study was to demonstrate that the task of automatic data collection from this test cell facility could be achieved with in-house efforts. In a way it was decided to show and prove in a smaller scale that the same tasks could be performed with much simpler equipment and that the know-how of setting up such a sophisticated test cell and their related instrumentation could be achieved by putting together the simpler building blocks as demonstrated in this study. One of the building blocks of such a system is definitely the computerized data acquisition system and the related software which makes measurements, calculations and recording. Without touching the instrumentation already mounted on the turbofan engine, a simple data collection system is connected in parallel to the existing measurement system and with a simple software, data are collected at the same time with the original system. This section makes a brief introduction about the operation principles of the turbofan engine and describes how the new data acquisition system is implemented, giving details of the data acquisition and processing program, samples of test results of measurements.

A. *Basic Engine Description*

The F110 turbofan engine is mixed-flow, augmented, dual-rotor machine consisting of a high pressure system, a mechanically independent low-pressure system and a variable-area exhaust nozzle [4]. A cutaway view of the engine is given in Fig. 1.

B. Data Acquisition System Setup

A commercial data acquisition system is adopted to the turbofan engine test cell at TEI. The new data acquisition system is set to work in parallel to the existing system and to measure and record partial testing data of the turbofan engine. There are about 200 parameters which need to be scanned automatically through the data acquisition system in the test cell of such a complicated jet engine. However due to the limited number of channels of the new data acquisition system it was concentrated only on 15 most important parameters of the turbofan engine. The selected parameters are measured and recorded continuously. These parameters are given in Table III. For the partial data acquisition of turbofan engine the following hardware is used (see Fig. 2):

1. Personal Computer
2. Data Acquisition System comprising of ;
   - Multimeter installed internally
   - Multiplexer
3. Different types of cables, thermocouples and connectors.

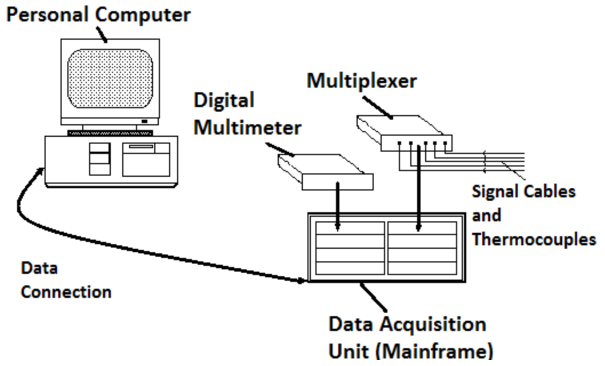

Fig. 2. *Simple sketch of data acquisition system*

Same signals which are coming from the test engine to the existing data acquisition system are used for the new data acquisition system. Some signals are taken directly coming from the engine monitoring system processor (EMSP) which is a part of the control system of the engine. The engine has some sensors of his own in order to control itself and the signals that are measured are directly coming from these sensors through the EMSP.

All channels of the data acquisition system were grounded appropriately and the overall calibration or check is done to maintain the confidence in its accuracy and to avoid the collection of faulty data. Calibration is, in a way, checking and controlling of the route from measuring device or transducer to computer through the data acquisition system by applying prescribed inputs to the measuring system to see the expected value in the range of acceptable limits.

TABLE III. MEASURED PARAMETERS OF TURBOFAN ENGINE

Parameter Name	**Description**
A8	Exhaust nozzle area (%)
AUG	Augmenter fuel valve ratio
APLA	Aircraft power lever angle (deg)
CDP-CBP	Compressor discharge and bleed pressure difference (kPa)
DPP	Fan duct pressure ratio
EPLA	Engine power lever angle (deg)
IGV	Fan inlet guide vanes (deg)
NF	Fan speed (% rpm)
NG	Core (or compressor) speed (% rpm)
Mach	Simulated flight Mach number
T2	Fan inlet temperature (K)
T56	Exhaust gas temperature (K)
Thrust	Observed thrust (kN)
VIBC	Vibration of compressor at turbine frame (mils)
VIBF	Vibration of fan at turbine frame (mils)

C. Description of the Data Acquisition Program

The data acquisition program of turbofan engine is written using a commercial data acquisition and control software which is an iconic programming language optimized for instrument control. In order to create an application icons are connected to each other accordingly with a mouse. The program resembles a data flow diagram. There are icons for instruments, data analysis, file input/output, data displays in the form of alphanumeric, dial gage meters, fill bars, X-Y graphs and strip charts. Software supports the hardware used in the measurements which means that it has drivers of instruments and commands for configuring and measuring available in the program making easy to learn and to use. Another advantage of software is the capability of building good and useful user interface on the screen using different types of display icons which is very difficult to obtain with a textual programming language like C or Visual Basic. After connecting the icons it has been actually created an executable program [6].

The simplified flow chart is given in Fig. 3, for the data acquisition and processing program which takes measurements, converts the voltage readings into engineering units, performs the necessary calculations and displays the results, writes them in appropriate data files and/or sends to a printer. The data acquisition program has two views that can be seen on the computer screen. “detail view” is used when writing the test program which includes all of the icons whereas “panel view” comprises only display parts of detail view such as strip charts, X-Y graphs, input objects, alphanumeric displays etc. In other words some of icons, especially displays and input objects are taken to “panel view” in order to create a user interface which is to be observed during the run.

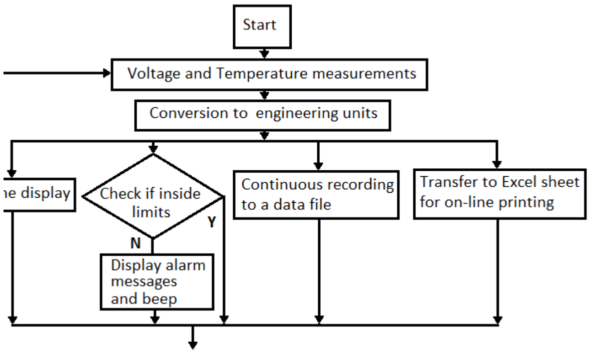

Fig. 3. *Simplified flow chart of application*

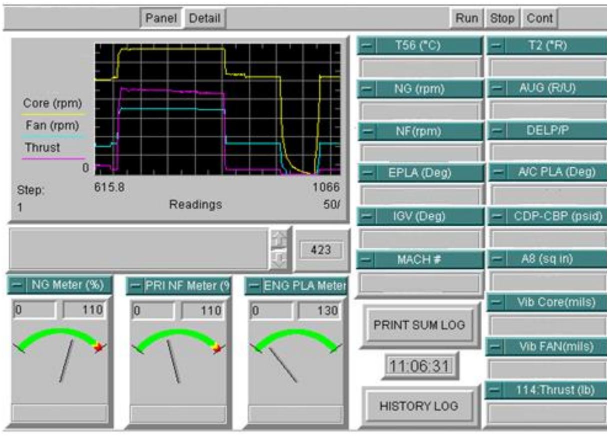

Fig. 4. *Panel view of application on the computer screen*

Fig. 4 shows the panel view of the data acquisition and processing program which is seen on the computer screen. On the right hand side there are alphanumeric displays of the 15 measured parameters. On the left hand side there is a strip chart of thrust, core and fan speeds vs. time and below it, three dial gage displays. These displays show fan and core speed percentages and the engine power lever angle. Between the strip chart and the dial gage displays there is a reserved area on which alarm messages appear. The “PRINT SUM LOG” button is clicked when a summary report of all current values is desired to be sent to the printer. The program starts recording every data when “HISTORY LOG” button is pressed. Similar displays or charts with different sizes can be added to the next test pages according to the need.

D. Sample Measurements

Different engines were tested and the parameters in Table III were recorded vs. time. In Fig. 5-9, engine power lever angle, thrust, fan speed, compressor speed and exhaust gas temperature are plotted vs. time reflecting the related steps indicated on the technical test procedure from minimum to maximum power.

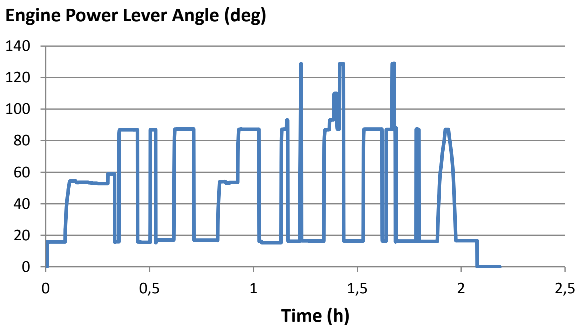

Fig. 5. *Engine power lever angle measurement*

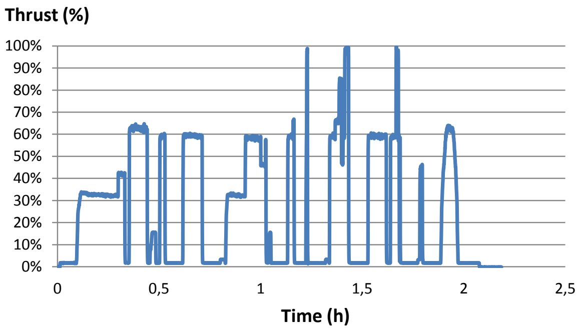

Fig. 6. *Thrust measurement*

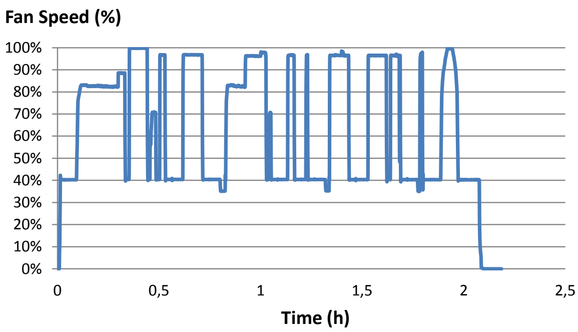

Fig. 7. *Fan speed measurement*

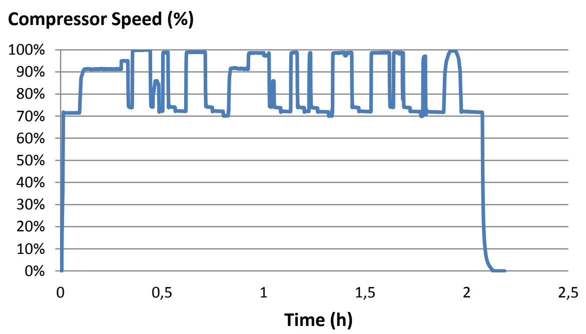

Fig. 8. *Compressor speed measurement*

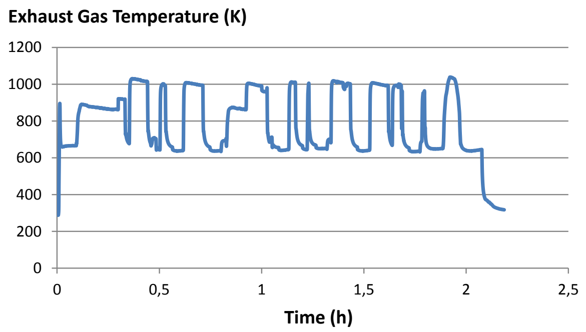

Fig. 9. *Exhaust gas temperature measurement*

III. Discussion

A commercial data acquisition system is implemented for the testing of a turbofan engine. Measurement results are satisfactory in terms of the precision, however the overall speed of the system decreases with the increasing number of measurement channels and with increasing length of the test program. In other words, the system is good and suitable for testing of small engines with maximum number of measurement parameters around 20, but it is found to be inadequate for testing of large engines, such as F110, in terms of speed response times for online analysis.

The data acquisition system is composed of a portable mainframe with a multimeter installed internally and a 16-channel multiplexer driven by a personal computer. Although maximum sampling rate of the data acquisition system is 13 kHz, for the above configuration sampling rate is reduced in multichannel readings.

The amount of time taken for the calculations, continuous recording to disks or memory and displaying should be added to the total measurement time calculated above in order to find the total execution time of the test program. It takes longer for a personal computer to execute the test program as it gets more complicated. Therefore the execution time of the test program plays an important role as well as the sampling rate of the data acquisition system. The execution time is between 2 to 3 seconds for acquisition, calculations and recording of 15 test parameters for every loop or cycle of program.

Possible Improvements:

1. Instead of a personal computer, a workstation and/or a larger capacity host computer system capable of performing multi-tasking should be used to obtain higher sampling rates with the existing data acquisition system. A workstation can do multitasking which means that it can perform two or more program loops at the same time. In a normal configuration, data acquisition is done in one loop with high speed and the averaged data is transferred to the calculations loop in every second or less as required.

2. Data acquisition system should be improved. New data acquisition cards should be selected which have their own microprocessors on them and with higher sampling rates of at least 100 kHz. In this configuration, data acquisition and averaging are done by the microprocessors on the cards, decreasing the amount of work for the main CPU of the host computer and therefore increasing the overall performance of the system.

3. A part of the degradation of the system performance comes from the commercial software because making measurements using the instrument drivers that are available makes the programming easy to learn and use, but slows down the execution speed of the program. A better solution is to use the commercial software and C++ together [7].

IV. Conclusion

The new data acquisition system is implemented to the turbofan test cell to work parallel with the existing data acquisition system. The system is demonstrated to make measurements and process the data in a certified test cell. The measurements of both new and existing data acquisition systems have good correlation.

The results obtained here showed that the new data acquisition system is capable of performing data acquisition and processing. Demonstrated system can be used for testing of a small engine, where the number of channels less than 20. For the tests of larger engines with measurement channels more than 100 or where faster response times are needed, a more advanced hardware and software configuration should be used.

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