An Electronic Pressure Profile Display System for Aeronautic Test Facilities

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ABSTRACT

The NASA Lewis Research Center has installed an Electronic Pressure Profile Display System. This new system provides for the real-time display of pressure readings on high resolution graphics monitors. The Electronic Pressure Profile Display system will replace manometer banks currently used in aeronautical test facilities.

The Electronic Pressure Profile Display System consists of an industrial type digital pressure transmitter (DPT) unit which interfaces with a host computer. The host computer collects the pressure data from the DPT unit, converts it into engineering units, and displays the readings on a high resolution graphics monitor in bar graph format. Software was developed to accomplish the above tasks and also draw facility diagrams as background information on the displays. Data transfer between host computer and DPT unit is done with serial communications. Up to 64 channels are displayed with 1 sec update time.

This paper describes the system configuration, its features, and its advantages over existing systems.

INTRODUCTION

The Electronic Pressure Profile Display System was developed to replace existing mercury manometer banks that were used in Lewis Research Center’s 8- by 6-Foot Supersonic and 9- by 15-Foot Subsonic Wind Tunnel Complex. The manometer banks were used to obtain pressure profiles of the tunnel compressor and the supersonic tunnel test section. The compressor profile is used to monitor the performance of the compressor and to watch for a dangerous unloading of the compressor stages. The test section profile is used to monitor the position of the shock in the test section. This allows the tunnel operator to keep the shock downstream of the model.

The Electronic Display System was installed during a rehabilitation of the wind tunnel’s control room. Reasons to replace the manometers were twofold. The first reason was to eliminate the obvious health hazards involved with a possible mercury spill in the control room. The second reason was that the new control room was designed to be divided to allow secure (classified) tunnel testing in either the 8 by 6 or the 9 by 15 test section. With the old system a duplicate manometer bank for each half of the control room would have been required. The Electronic Display System only requires a second color graphics monitor for display. The system also allows the displays to be custom made for operator requirements. It also allows for the displays to be located closer to the tunnel operators allowing for a more efficient work area.

The Electronic Pressure Profile Display System is a low cost stand alone system, which provides a more convenient method of viewing pressure profiles, while eliminating the hazards of using mercury manometer banks.

GENERAL SYSTEM OVERVIEW

The Electronic Pressure Profile Display System configuration is shown in Fig. 1. The system consists of an industrial type 64 channel digital pressure transmitter (DPT) unit which interfaces with a host computer. It measures pressures by multiplexing between 64 individual pressure transducers. The DPT unit transmits the pressure data to the host computer.

The host computer collects the pressure data from the DPT unit, converts it to engineering units, and displays the data in bar graph format on high resolution graphics monitors. The host computer is also responsible for initiating an on-line calibration of the DPT unit. It accomplishes this by measuring the values of the calibration pressures and transmitting them to the DPT unit along with a calibration command. The calibration pressures are measured using high accuracy analog pressure transducers PT1 and PT2. The DPT unit applies the pressures to its transducers, calculates conversion coefficients, and then transmits the coefficients to the host computer. The host computer uses these coefficients to convert the pressure data into engineering units. Calibration of the DPT unit is done when the system is first initialized. Calibration can also be activated by an operator push-button.
The host computer accomplishes the above tasks by running a custom application program. This program was written in compiled BASIC and consists of an initialization routine, a calibration routine, a data collection routine, and two display routines.

HARDWARE

The DPT unit used for the system is a commercially available Industrial type unit manufactured by Pressure Systems Incorporated (model DPT 6400). The DPT unit consists of a 19 in. (48.3 cm) rack mainframe which houses eight transducer modules, each containing eight solid state silicon pressure transducers. For this application 15 psi (103 kPa) differential range modules were used. Each module has an electronic signal multiplexer and a two position pneumatic calibration valve for its transducers. The mainframe also contains the microprocessor control unit, calibration pneumatics, and serial interface unit. Pressure inputs are connected to the rear of the mainframe. Connections for calibration valve shuttle pressure, reference pressure, and calibration pressures are also on the rear of the mainframe. The DPT unit requires 100 psi (690 kPa) gage for the shuttle pressure. Pressures of 4 psi (27.6 kPa) absolute and 27 psi (186 kPa) absolute are used for calibration. Atmosphere is used for the reference pressure. The DPT unit's block diagram is shown in Fig. 2.

On-line calibration is performed by utilizing the integral calibration valve in each transducer module. This valve is moved between a RUN and a CALIBRATE position by applying the shuttle pressure to a cylinder and piston. In the RUN position the calibration valve connects the transducers to the measurement pressures. In the CALIBRATE position the calibration valve manifold the transducers to a common calibration pressure. When a calibration is activated, the calibration valve is moved to the CALIBRATE position and two accurately measured pressures are sequentially applied to the transducers for a two point calibration. The 8-bit A/D card records the voltage reading for each transducer and calculates the conversion coefficients for each transducer. It then transmits the coefficients to the host computer which uses the coefficients to convert the pressure data into engineering units. Communications between the host computer and the DPT unit are by serial communications at 9600 BAUD.

The host computer runs the software which drives the electronic display system. The microcomputer used for this system is an IBM AT compatible rack mountable personal computer. Communications to the DPT unit are through the computer's RS232C serial communications port. An analog to digital conversion card is used to measure the calibration pressures which are monitored by 0 to 5 V high accuracy pressure transducers. The A/D card uses 12 bit resolution for the A/D conversion. The A/D card also has digital inputs and outputs which are used for operator interface via remote push-buttons. The remote push-buttons allow the operator to either initiate a DPT unit calibration or to obtain a screen copy of the pressure profiles. The screen copy is produced on a dot matrix printer. The pressure profiles are displayed in bar graph format on high resolution color graphic monitors. The monitors use a 640 pixel wide by 350 pixel high format. A total of 64 colors are available to be used for displaying the profiles. The monitors are driven by a Enhanced Graphics Adaptor card, located in the computer. The Pressure Profile Display System has two monitors being run in parallel from the same graphics card. Each monitor is located remotely at a tunnel operator's station.

Physically, the Electronic Display System is located in the wind tunnel control room. The DPT unit, host computer, and system pneumatics are located in one 19 in. (48.3 cm.) rack (Fig. 3). The display monitors and operator push-buttons are located at the tunnel operator stations (Fig. 4). Overall, the system is compact and uses less space than the old manometer banks.

SOFTWARE

The software that runs the Electronic Pressure Profile Display System is written in compiled BASIC. The program consists of five parts. They are as follows: DPT initialization, DPT calibration, background diagram display, data collection, and data display. The program flow chart is shown in Fig. 5.

The Initialization routine sets up communications with the DPT unit. The initialization routine also sets up the following parameters used by the DPT unit:

- RS232C communication parameters - Allows user to set up communication parameters, such as handshaking characters and protocol to be used for data transfer. For this application the format of eight data bits, one stop bit, and no parity is used.
- Output options - Allows user to specify where DPT unit output is to be sent and what order the DPT channels are to be scanned. For this application the DPT output is sent to the serial port and the transducers are scanned sequentially 1 to 64.
- Number of averages to be used - Allows user to specify how many averages are to be taken for each transducer reading. Options of 1, 2, 4, 8, and 16 averages are available per reading. This application uses eight averages per reading.
- Other options and parameters are also sent to the DPT unit during this portion of the program. This part of the program is executed during initial system start up.

The calibration routine initiates a two point calibration of the DPT unit. Calibration pressures are measured using the 0 to 5 V analog pressure transducers. The values of the calibration pressures are read into the computer by accessing the...
of the compressor stages. The second diagram is
matic of the seven stage compressor. This diagram
mands on the high resolution color monitors. The first
data for 64 channels is 0.7 sec. Time re-

The main part of the electronic display program
is the data collection routine. The host com-
puter sends a scan command to the DPT unit. The
DPT unit executes a scan of the 64 pressure trans-
ducers and transmits the pressure data back to the
host computer. The data received by the computer
is in counts. Each pressure reading consists of
four ASCII characters. The ASCII high byte is
stripped from each character and the program uses
the following conversion to convert the readings
into actual pressure (psia):

\[ \text{PSIA} = \left( \left( B_1 \times 4096 + B_2 \times 256 + B_3 \times 16 + B_4 \right) \right. \text{cts} \times \left( 10 \text{v/cts} \times (C_1 \times \text{PSIA/v}) \right) + \text{CO} \]

where

- \( B_n \) byte
- \( C_1 \) span coefficient
- \( \text{CO} \) zero coefficient

This conversion is executed for all 64 channels.
Engineering units are stored in an array that is
used for graphical display. The output option of
counts is used so data transmission would only
require four characters per reading. Other scan
commands were available that transmit the data in
actual engineering units. This requires transmis-
sion of nine characters per reading, thus doubling
data transmission time. It was found that by us-
ning the output in counts and making the engineer-
ing unit conversion in the computer, faster scan
time could be obtained. Time to scan and trans-
mits data for 64 channels is 0.7 sec. Time re-
quired to convert 64 readings into engineering
units is 0.1 sec. Total data collection time for
64 readings is 0.8 sec.

The display routines of the program use graphics
commands to display the data in bar graph format
on the high resolution color monitors. The first
display routine draws background diagrams
(Fig. 6). Diagnoses are drawn using graphics com-
mands in BASIC. The diagrams are drawn to relate
the pressure bars to the pressure sampling port
locations. In this configuration there are two
background diagrams. The first diagram is a sche-
matic of the seven stage compressor. This diagram
allows the operator to view the pressure profile
of the compressor stages. The second diagram is
a schematic of the wind tunnel's test section.

A/D Input port. The values of the span and zero
pressures along with a calibration command are
then transmitted to the DPT unit. The DPT unit
applies the calibration pressures, records the
voltage readings, and calculates the conversion
coefficients. The coefficients are sent back to
the host computer and stored in an array designated
for each transducer. A calibration sequence
requires 0.2 sec to read calibration pressures,
17.6 sec for DPT unit to calibrate and calculate
coefficients and 14.2 sec for the coefficients
to be transferred to the host computer for a total
time of 32 sec. The calibration routine is exec-
cuted on initial boot up of the system or by
operator request using a push-button. The cal-
bration push-button input Is looked for every data
scan. When the DPT unit Is calibrating, data Is
not taken or displayed.

The user interface with the program is minimal. The
Display System was designed as a stand alone sys-
tem. The operator is able to initiate two func-
tions through push-button inputs. The first
function allows the operator to initiate a DPT
calibration. The second function allows the oper-
ator to obtain a screen copy and data print-out
of the pressure profiles. Both of these functions
are accomplished in the program by scanning the
respective push-button inputs and executing the
required routine when a push-button Is detected.

The display system has a display rate of 64 read-
ings per sec, with the following breakdown of time
required for each task:

<table>
<thead>
<tr>
<th>Action</th>
<th>Time Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scanning/collecting data</td>
<td>0.7 sec</td>
</tr>
<tr>
<td>Converting readings to</td>
<td>0.1 sec</td>
</tr>
<tr>
<td>engineering units</td>
<td></td>
</tr>
<tr>
<td>Displaying pressure readings</td>
<td>0.25 sec</td>
</tr>
<tr>
<td>Total time required for</td>
<td>1.05 sec</td>
</tr>
<tr>
<td>displaying 64 channels</td>
<td></td>
</tr>
</tbody>
</table>

The DPT unit specifies a nominal throughput rate
of 60 readings per sec. Thus, the display system
update time is limited by the throughput rate of
the DPT unit. The update time of once a second
was adequate for the application of displaying
pressure profiles. System update rate could be
improved by using an IEEE 488 parallel commu-
ications Interface for obtaining data from the DPT
unit. The DPT unit has a data throughput rate of
500 readings per sec when the parallel interface
option is used. This would increase the display
rate of the display system. The IEEE 488 parallel
interface option is available for the DPT unit.
However, the data collection and transmission rou-
tines used in the program would have to be
modified.

System accuracy

Based on the vendor's equipment specifications,
the Electronic Pressure Profile Display System ac-
curacy is as follows:
DPT unit: 0.25% x 15 psi (103.4 kPa) = 0.038 psi (0.26 kPa)

Transducers used for calibration pressure measurement: 0.05% x 50 psi (344.8 kPa) = 0.025 psi (0.17 kPa)

\[ \text{\texttt{=}0.063 psi (0.43 kPa)} \]

This yields a worst case error of 0.063 psi (0.43 kPa) in measuring the pressures. However, the drawing resolution is 10 pixels/psi and pressure bars are displayed to the nearest 0.1 psi (0.69 kPa). The error in measuring the pressures is within this drawing resolution. Thus, the electronic display system accuracy is limited by the drawing resolution to 0.1 psi (0.69 kPa). In this application this was satisfactory since the desired output was a pressure profile and not actual pressure readings. In applications where pressure readings would be required an accuracy of 0.063 psi (0.43 kPa) could be obtained.

COST

The cost of the Electronic Pressure Profile Display System is as follows:

- DPT unit with 64 channel capability: 13 K
- Personal computer: 2 K
- Display monitors (1.5 K each): 3 K
- Transducers for calibration pressures (1 K each): 2 K
- A/D card: 0.5 K
- System pneumatics (regulators, vacuum pump, etc.): 0.5 K

**TOTAL SYSTEM COST:** 21 K

This translates into $330 per pressure reading. This is a relatively low cost when compared to the potential costs associated with mercury clean up if a manometer bank were to overflow.

Another benefit of the electronic display system is the low manpower time required for maintenance. There is minimal set up time involved with the system. Once the system is brought on-line it is left running continuously. The only operator requirement is to calibrate the system periodically. This is accomplished as a daily run checklist item and is initiated by pressing the calibration push-button. The only other periodic maintenance required is the recallibration of the pressure transducers used in measuring the calibration pressures. This is done every 6 months as part of a periodic maintenance checklist. Thus, the Electronic Display System requires less set up and maintenance time as compared to other pressure display systems.

SUMMARY

The Electronic Pressure Profile Display System provides a modern state of the art replacement of manometer bank used for displaying pressure profiles in aeronautic test facilities. The system eliminates the hazards of mercury while adding a more flexible display system. Displaying the pressure profiles on the graphics monitors presents a more visible display and enhances the operation of the facility. The Electronic Pressure Profile display system is currently being used in the 8-by-6- and 9-by-15-Foot Wind Tunnels, and is planned on being used in the 10-by-10-Foot Supersonic Wind Tunnel.

In conclusion, the Electronic Pressure Profile Display System is a major improvement over existing mercury manometer banks being used in aeronautic test facilities.

REFERENCES

FIGURE 1. - ELECTRONIC PRESSURE PROFILE DISPLAY SYSTEM.
FIGURE 2. - DPT UNIT BLOCK DIAGRAM.
FIGURE 3. - DPT UNIT, COMPUTER, AND SYSTEM PNEUMATICS.
FIGURE 4. DISPLAY MONITOR AND OPERATOR PUSHBUTTON STATION. (LOCATED TOP CENTER OF PHOTOGRAPH).
Figure 5. - Program Flow Chart.
FIGURE 6. - PRESSURE PROFILE DISPLAY BACKGROUND DIAGRAMS.
FIGURE 7. - PRESSURE PROFILE DISPLAY FOREGROUND PRESSURE BARS.
### Abstract

The NASA Lewis Research Center has installed an Electronic Pressure Profile Display system. This new system provides for the real-time display of pressure readings on high resolution graphics monitors. The Electronic Pressure Profile Display system will replace manometer banks currently used in aeronautical test facilities. The Electronic Pressure Profile Display system consists of an industrial type Digital Pressure Transmitter (DPT) unit which interfaces with a host computer. The host computer collects the pressure data from the DPT unit, converts it into engineering units, and displays the readings on a high resolution graphics monitor in bar graph format. Software was developed to accomplish the above tasks and also draw facility diagrams as background information on the displays. Data transfer between host computer and DPT unit is done with serial communications. Up to 64 channels are displayed with one second update time. This paper describes the system configuration, its features, and its advantages over existing systems.