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COMPUTERIZED DATA ACQUISITION SYSTEM FOR PRODUCTION, INJECTION, AND INTERFERENCE TESTS

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ABSTRACT

A computer-based system for collecting, processing, and analyzing pressure transient data has been developed. Primary components include downhole pressure sensors, line-drivers, a micro-computer, data storage disk, scanner, frequency counter, digital voltmeter, power supply, graphics plotter, and printer. In-field data processing and analysis greatly aid in handling the large volume of data that are collected during pressure transients tests, particularly the multi-well interference tests that are so important for characterizing and assessing geothermal reservoirs. In-field data processing provides the field engineer, on a real-time basis, with the information needed to make decisions regarding test parameters and duration. The system has been used on numerous occasions and has proved itself to be reliable under the harsh operating conditions that are usually encountered in the field. This paper describes the advantages of using this type of system for collecting data, the components and configuration of the system, and the software programs used to collect and process the data. Finally, two field applications are presented.

INTRODUCTION

Production, injection, and interference tests require collecting and processing large volumes of data. Typically, little, if any, of the test data are processed during the test. Only after returning from the field, and after considerable preparation, is it possible to begin assessment and analysis of the data. The lack of real-time access to the bulk of the data makes it impossible to judge the quality of the data and make informed decisions regarding the test parameters and test duration while there is still an opportunity to make changes in the instrumentation or test design. In-field data processing, display, and analysis greatly enhance the control the field engineer has over the quality of the test. Costly mistakes, resulting from poor quality data or inappropriate test design, are minimized if all of the test data are accessible while the test is underway.

During a well test several types of data from various physical locations must be collected. At a minimum these include: wellbore-pressures; flow rates (perhaps both steam and water); temperatures; and barometric pressure. In addition, pressures, temperatures, and flow rates, at various points in the piping system, as well as in-line monitoring of fluid properties or composition, may be required. Collecting data from all of these sources is time-consuming and subject to human error when each type of data is collected and recorded individually. Not only are the data collected by several people, but it also must be transferred (usually manually) to a central data base. This procedure is labor-intensive and leaves room for a large degree of human error.

For pressure transient analysis, the most detrimental errors result from collecting data with more than one time reference (clock). Since pressure transient analysis is very sensitive to time-measurement errors, especially during the time-periods near flow rate changes, errors as small as several minutes may result in a large degree of uncertainty in the data interpretation. This uncertainty can be eliminated by collecting all of the data with a single time reference. Computerized data acquisition makes it possible to collect all data at a single location, using a single time reference. This cuts down on both the labor requirements and measurement errors associated with well testing.

Additional benefits from using a computer-based data acquisition system include: increased measurement rates; improved measurement accuracy and resolution; real-time barometric and earth-tide corrections for pressure measurements; minimized time and effort for data handling; and enhanced capabilities for applying some of the more novel well testing techniques, such as pulse testing.

This paper describes the hardware and software for a 20-well data acquisition system. The system can be used to measure: (1) downhole pressures at temperatures up to 125 °C; (2) pressure differential across an orifice plate (for measuring flow rates); (3) surface pressure of a gas-filled capillary tube (for making downhole pressure measurements in high temperature geothermal wells); and (4) barometric pressure. Two field applications are also described.

CONFIGURATION

The computerized data acquisition system described in this paper can be used to collect a variety of types of well test data, including: interference tests; production tests; and injection tests. The basic system consists of pressure sensors, line drivers, and a recording station. A brief description of the equipment configuration for the different tests is given below.

Interference Tests. Interference tests require measuring pressure drawdown at one or more observation wells while another well is produced. Simultaneously, the flow rate is measured at the producing well (see discussion below). A schematic of a typical test set-up at the observation well is shown in Figure 1. Pressure sensors are placed at the well-head (for artesian wells) or downhole in each of the observation wells. Since the observation and production wells are usually spaced over an area of several square miles the data

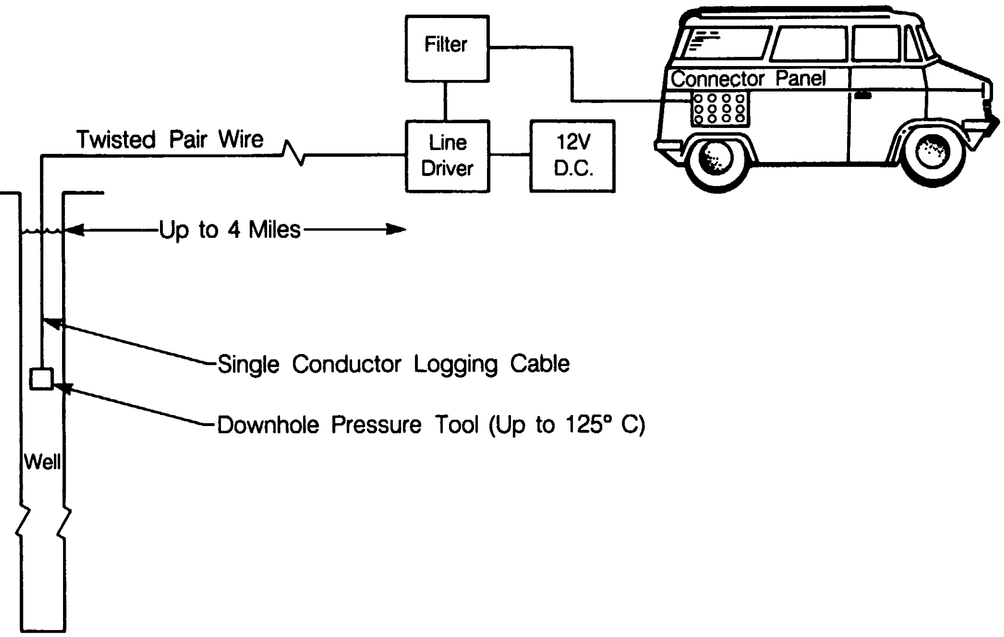

Figure 1. Schematic of a typical interference test set-up. XBL 865-10796

must be transmitted to the central recording station. This is accomplished with the aid of a line-driver and inexpensive twisted-pair military communication wire. At the recording station (van), the signal from the pressure transducer is filtered, measured, processed, and recorded.

Production and Injection Tests. Pressure transient production and injection tests require simultaneous measurement of downhole pressures and production rates. Downhole pressures can be measured either by lowering a pressure transducer into the well (if the temperature is below 125 °C) or by measuring the pressure at the top of a gas-filled capillary tube whose bottom is positioned adjacent to the producing formation (Miller and Haney, 1978). The system described here can be used for either of these applications. In addition, differential pressure transducers, located across orifice plates in the steam and/or water flow-lines, can be used to measure production/injection rates. The configuration of the system for single-well tests is similar to that for interference tests (see Figure 1) except that all of the measurement stations are in close proximity to one another. Therefore, line drivers, signal amplifiers, and noise filters may not be required.

HARDWARE

The entire data acquisition system is housed in a large delivery-type van equipped with a generator, air-conditioning, back-up battery bank, and instrument racks. A schematic of the system, with all of the principal components, is shown in Figure 2. A micro-computer performs the central role of interacting with the operator, preparing the instruments for measurement, controlling the flow of data, interfacing the various components of the system, and tracking the test status. The system is currently configured for purely digital data acquisition because the pressure sensors are piezoelectric transducers with a digital output. However, devices with analog output signals are easily incorporated into the system with the addition of a digital voltmeter. A detailed description of the primary components of the system is provided below. Reference to specific components or brand names does not imply that we endorse the use of these particular products.

Computer. A Hewlett-Packard 9000 Series 200 Modular Computer (model 220) with 1.2 Mbytes of RAM serves as the "brain" of the system. The computer, designed primarily for scientific and engineering applications, is based on the Motorola MC68000 family of micro-processors with 16/32 bit architecture. Both Basic 3.0 and Pascal 3.0 operating systems are available. The operating system and hardware come "factory ready" for interfacing the computer with a variety of instruments. For this application, two Hewlett-Packard Interface Buses (HPIB), one for servicing the scanner and frequency counter, and another for sending data to the hard disk and printer are connected to the system.

Display and Keyboard. A Hewlett-Packard model 35721A Monochromatic Monitor provides both numeric and graphic display. The keyboard (standard with the model 220 computer), in addition to the standard ASCII characters, is equipped with a mouse and a set of user-defined keys, allowing the operator to interrupt the normal operation of a program and enter one of 20 preprogrammed subroutines.

Data Storage. A Hewlett-Packard model 9133D 14.8 Mbyte Winchester/3.5 in Microfloppy Combination is used for mass-storage. The Winchester Disc is the primary storage medium for the operating system, data logging and processing programs, and data files. The 3.5 in microfloppy disk drive, which can store up to 710 kbytes on a double-sided disk, is used to back-up the data and programs stored on the hard disk.

Printing and Plotting. In-field hard copies of data plots are prepared on either the Hewlett-Packard Think Jet Printer or a dual pen (felt tip) plotter (HP model 7470A). The Think Jet Printer, which prints up to 150 characters per second, is also the primary system printer.

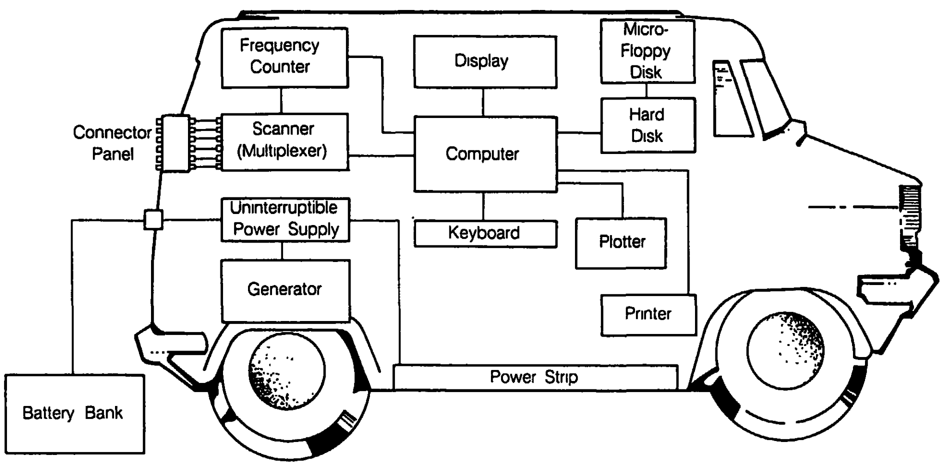

Figure 2. Schematic of the data acquisition van showing the principle components of the data acquisition system.

Frequency Counter. Precise, high resolution frequency measurements are the key to high quality, high speed digital pressure measurements. To obtain the necessary resolution at the desired measurement rate, we selected the Hewlett-Packard Model 5334A 100 MHz Universal Counter with a high stability time base option. The counter has a 9 digit per second resolution capability. In the normal operating mode, up to ten readings per second can be sent to the computer. In a high speed mode, a maximum of 150 readings per second is possible but the computer must then perform the bulk of the data processing. Additional features include: a gate time (averaging period) which is adjustable in 1 ms increments between 1 ms and 99.999 s; a fully programmable front panel; HPIB compatibility; external arming for synchronizing the counter with real time events; and numerous signal conditioning options.

Scanner (Multiplexer). As used in this system, the scanner (HP Model 3497A Data Acquisition and Control Unit) has several essential roles, including: providing the capability of multiplexing the input signals from a variety of devices to the frequency counter; providing a real-time non-volatile clock; and synchronizing (arming) the counter measurements with the rest of the system. At the present time the system is configured for up to 20 channels. However, the multiplexing capability is expandable in 20-channel increments up to 100 channels. The time base for the system is a quartz-referenced real-time clock (with a battery backup) with a maximum time period of one year and a resolution of 1 s. In addition, the internal timer, with a maximum 1 s period and 100 μs resolution, can be used to output a chain of pulses to arm the counter.

Power Supplies. A gasoline powered 6.5 kW generator in a side-panel of the recording van provides 110 V ac for operating the data acquisition system. An uninterruptible power supply (UPS) with 110 V ac supplied by the generator and backed-up with a battery bank, prevents data loss due to power failures and protects the instruments from power surges. The dc power required by the line drivers and pressure transducers is provided by rechargeable 12 V batteries.

Pressure Sensors. High resolution, thermal stability, temporal stability, and reliability are essential attributes of pressure transducers for well testing applications. Experience has shown that Paroscientific Digiquartz pressure transducers have all the necessary attributes and are very effective for measuring downhole, surface, differential, and barometric pressures (Bodvarsson and Benson, 1982). They are available in a variety of ranges (from 15 to 10,000 psia), making it possible to choose the transducer with the most suitable range for the application. The transducers are rated for use at temperatures up to 125 °C. As such, they can be used to make downhole pressure measurements for interference tests as well as for production and injection tests where the downhole temperature does not exceed 125 °C. The downhole packaging for the pressure sensors is illustrated in Figure 3 and described in more detail by Solbau et al., 1981.

The pressure transducers are piezoelectric devices that that provide a digital output with a nominal frequency of 40 kHz at zero load and 36 kHz at maximum load (Paros, 1976). With the HP 5334A Universal Counter, pressure resolution of 0.0005% full scale (FS) is obtained when the readings are averaged over a 20 ms period. Higher resolution is possible with longer averaging, but for well testing applications, 0.0005% FS is more than adequate if the pressure range of the transducer is chosen judiciously. The digital signal is converted to a pressure reading using a second order polynomial.

Signal Processing. When the measurement stations are spaced over a large area it is necessary to amplify and filter the frequency signal before it is measured. Two components are used for this purpose; a line driver amplifies the signal and rejects high frequency noise, and an isolation transformer eliminates noise due to ground-loops and stray ac current. A detailed description of the line-driver is available in Solbau et al., 1981.

SOFTWARE

The computer programs for operating the data acquisition system were all developed in-house and written in HP's Basic 3.0. The code, which is approximately 1200 lines, took

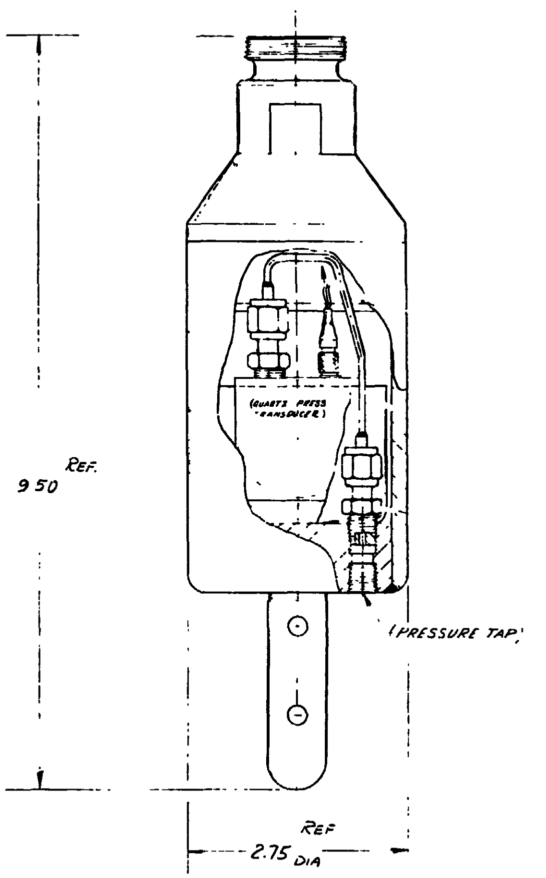

Figure 3. Downhole packaging for the Paroscientific Digiquartz transducer.

2 months to develop and debug. A schematic of the program's structure and capabilities is shown in Figure 4. The code is written so that data acquisition (measurement, display, storage, and printing) is the primary task of the computer. However, at the touch of a button, the program changes context and can perform the following tasks: graphing previously stored data; copying data from the hard-disk to a 3.5 in microfloppy; printing previously stored data; printing test specifications (well names, instruments, calibration information, data files, etc.); re-initializing test specifications (adding instruments and wells, changing data files, etc.); and halting operation of the logging program. Additional detail on the primary functions of the logging program is provided below.

Initialization. At start-up, the computer initializes all of the instruments and devices on the HPIB interface. This involves setting up the gate time (20 ms averaging period) and specifying values for the various measurement options on the frequency counter, as well as initializing the multiplexing parameters on the scanner. At this time, the internal timer in the computer is synchronized with the real-time clock in the scanner. Formatting information for the printer is also specified.

Initialization also requires setting up the test parameters. This includes specifying the pressure sensors to be used, providing calibration data for the pressure transducers, identifying data files, and specifying the desired printout and data storage intervals. Once initialization is complete, the program begins to collect data.

Data Acquisition. The primary tasks of acquiring data include measuring the frequency signal from each of the transducers, converting the frequencys to pressures, displaying the time and pressure data on the monitor, storing the data on disk, and printing the data (see Figure 4). In the current configuration, up to ten channels are logged at a rate of one data point per second (10 channels, each at a rate one data

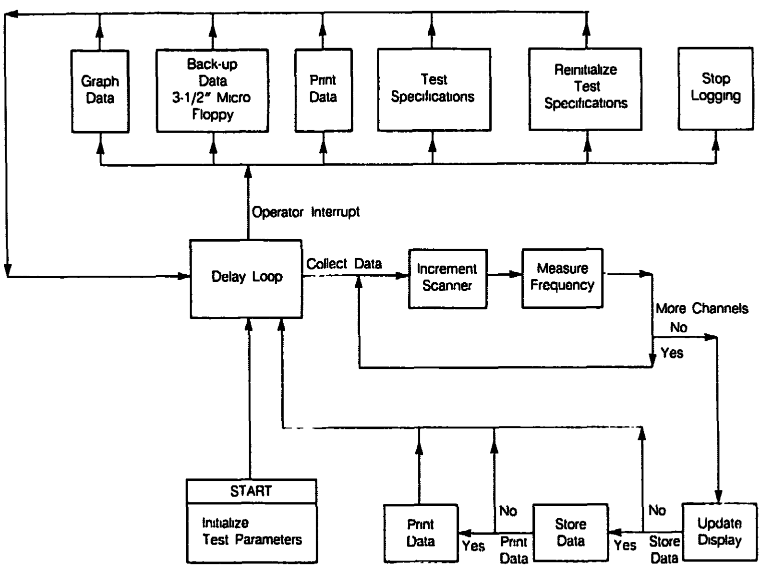

Figure 4. Flowchart for the data acquisition software.

point per second). However, during a typical test, only the display is up-dated that frequently. Storage and printout intervals are programmable at 1, 5, 10, 30, 60, 300, and 600 s intervals. Close to a flow rate change, 1 s storage and printout intervals are used, but for most of the test, 5 or 10 minute (300 or 600 s) time intervals are sufficient. If the program finishes a measurement cycle before it is time to begin the next one, the program waits in a delay loop until either a new measurement cycle begins or the operator interrupts the program.

Interrupt Options. When the operator interrupts the logger, the context switches from the main logging loop to one of 6 subroutines that allow the operator to graph or print the test data, backup the data on a microfloppy disk, change the test specifications, or stop the logging program (see Figure 4). Examples of the graphic output and printout are shown in Figures 5 and 6. With the exception of the "stop logging" option, the program automatically returns to the logger when the task assigned to the subroutine is complete.

APPLICATIONS

Barometric Corrections. Atmospheric pressure changes strongly influence water level and reservoir pressure measurements (Todd, 1980). In areas where frequent and large atmospheric pressure changes occur, measured water levels and/or reservoir pressures must be corrected to remove this influence from the data before it is used to calculate the reservoir properties. The data shown in Figure 7, collected during an interference test in a deep sandstone aquifer in southern Sweden, provides an excellent example of the need to make atmospheric corrections on a real-time basis. The top curve in the figure is the atmospheric pressure, the middle curve shows the raw data from the well, and the bottom curve is the corrected data. Pressure fluctuations corresponding to 20 cm of water level change (0.002 MPa) are measured in the observation well, whereas the corrected data show fluctuations of the scale of 1 to 2 cm. The 1 to 2 cm fluctuations are the result of earth-tide effects and are within the tolerable noise-range for the interference test. On the other hand, the large fluctuations in the uncorrected data mask the fact that the well did not respond to pumping during the interference test.

Interference Test. Interference tests are one of the most powerful techniques for evaluating the hydrologic properties of heterogeneous aquifers. The wells shown in Figure 8 were drilled specifically for the purpose of measuring the average horizontal permeability, vertical permeability, and anisotropy of the sands, silts, and clays of a near-surface aquifer in the

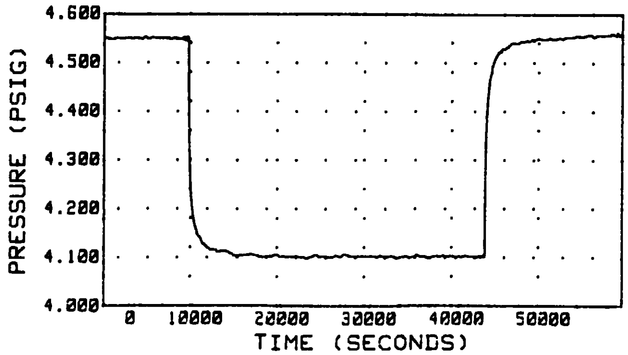

Figure 5. Example of the graphic output.

24 Feb 1986	18:20:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	18:25:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	18:30:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	18:35:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	18:40:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	18:45:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	18:50:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	18:55:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	19:00:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	19:05:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	19:10:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	19:15:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	19:20:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	19:25:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	19:30:00	30.0300	19.3250	18.4180	19.5940	19.1320
24 Feb 1986	19:35:00	30.0300	19.3250	18.4180	19.5940	19.1320

Figure 6. Example of the pressure data printout for a 4-well interference test.

Central Valley of California. Each of the wells I-1 to I-9 was instrumented (see Figure 9) with a Paroscientific Digiquartz pressure transducer (some wells with 45 psia range transducers and some with 400 psia units). Inflatable packers were placed above the transducers in order to minimize wellbore-storage effects in the observation wells and isolate the effects of barometric pressure fluctuations on the aquifer pressure.

The interference test was conducted over a 16-hour period; it included collecting 2 hours of background data, 10 hours of drawdown data, and 4 hours of recovery data. A total of 5000 data points were collected during this period. Without the aid of computer graphics, data processing, and storage; handling this volume of data would require weeks of hand plotting, key-punching etc. With the aid of the computer, all data were processed and plotted during the test itself. In fact, 10 similar tests, during which over 50,000 data points were obtained, were conducted during a one-month period.

Graphs of the pressure data (with barometric corrections) from two of the observation wells are shown in Figure 10. Notice that well I-7, at a distance of approximately 300 ft from the pumped well, has a maximum drawdown of approximately 2.7 in (0.1 psi). This small drawdown would be very difficult to measure with conventional instrumentation. However, the drawdown is far greater than the 0.00025 psi resolution of the 45 psia pressure transducer; therefore, it is easily measured with the system described here.

SUMMARY

A computer-based data acquisition system for conducting pressure transient tests has been developed. Advantages of using such a system include:

(1) Improving data quality by using a single time reference for all measurements;

(2) Improving test design and control by providing the field engineer with real-time access to the test data;

(3) Facilitating manipulation and processing of the large volume of data typically obtained during interference tests;

(4) Enhancing data quality by allowing high-speed, high resolution pressure measurements;

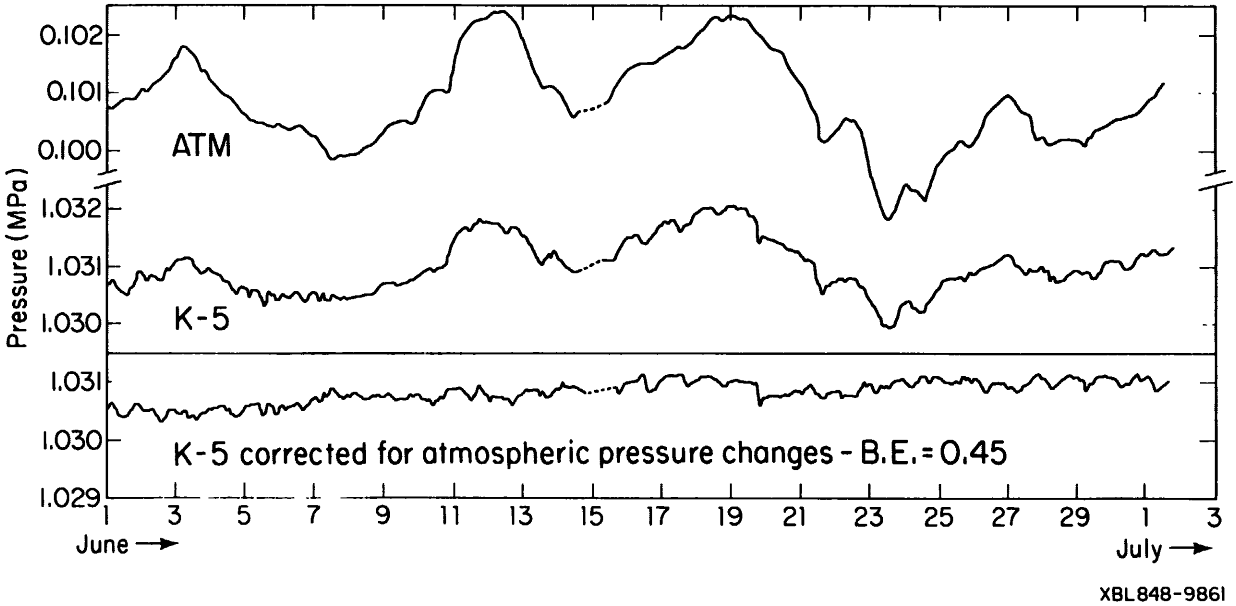

Figure 7. Atmospheric pressure, well data, and corrected pressure data from an interference test well in southern Sweden.

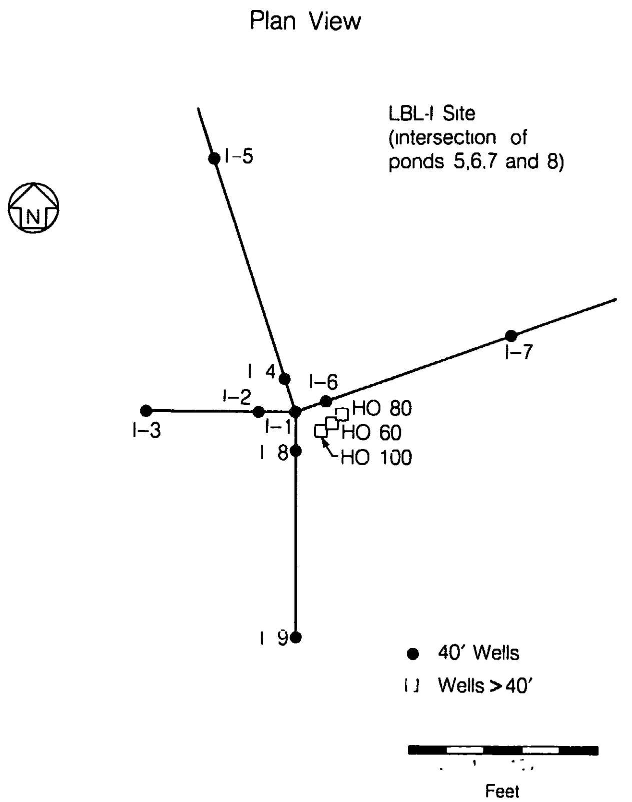

Figure 8. Array of wells for an interference test in the Central Valley, California.

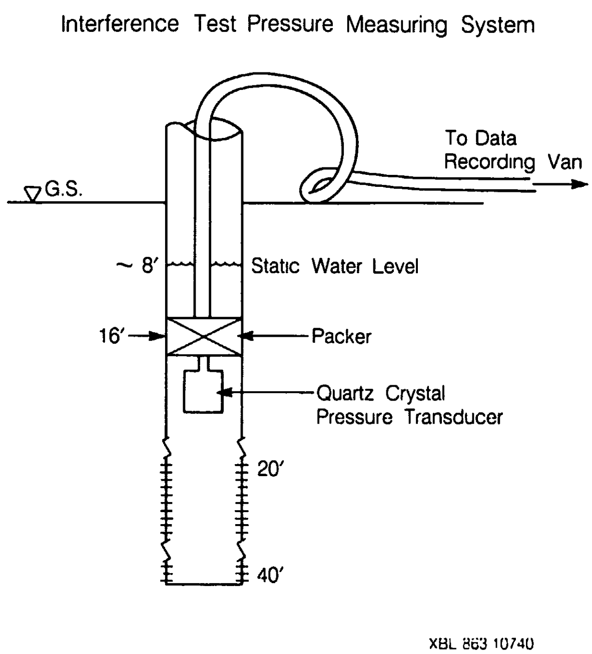

Figure 9. Interference test pressure measuring system showing the location of the pressure transducer, inflatable packer and slotted interval of the well.

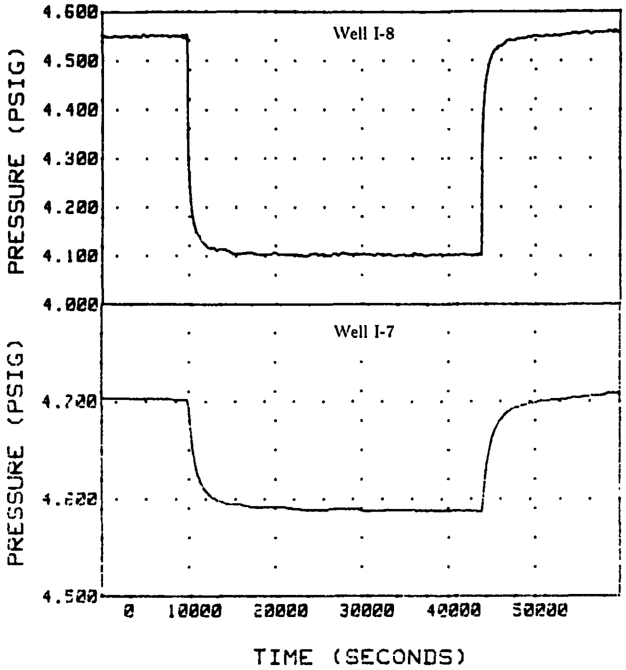

Figure 10. Pressure data with barometric corrections from observation wells LBL-I7 and I8.

(5) Facilitating application of advanced well-testing techniques that require high-speed, high resolution pressure measurements.

This paper provides a detailed description of a computer-based data acquisition system that was developed at Lawrence Berkeley Laboratory. Reference to specific components or brand-names is intended to be informative, rather than taken as an endorsement for a particular product or product line.

ACKNOWLEDGEMENTS

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REFERENCES

Bodvarsson, M. G. and Benson, S. M., 1982. Well Test Data from Geothermal Reservoirs, Lawrence Berkeley Laboratory report LBL-13795, Berkeley, CA.

Miller, C. W. and Haney, J., 1978. Response of Pressure Changes in a Fluid Filled Capillary Tube, in the proceeding of the *Second Invitational Well Testing Symposium,* p. 112-118, Lawrence Berkeley Laboratory report LBL-8883, Berkeley, CA.

Paros, J. M., 1976. Digital Pressure Transducers in *Measurement and Data,* Issue 56, Vol. 10, No. 2, March-April 1976.

Solbau, R. D., Goranson, C. B., and Benson, S. M., 1981. Recently Developed Instrumentation for Low-to-Moderate Temperature Hydrothermal Reservoirs, Lawrence Berkeley Laboratory report, LBL-13260, Berkeley, CA.

Todd, D. K., 1980. *Groundwater Hydrology,* John Wiley & Sons, New York, New York.