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DECEMBER 1988

A HIGH PERFORMANCE, INTRINSICALLY SAFE DATA ACQUISITION SYSTEM FOR UNDERGROUND USE

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Serata Geomechanics, Inc.

BUREAU OF MINES
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Up to one megabyte of measurement data can be recorded by the system's Data Logger, which uses internal solid-state memory. Stored data can be transferred directly via modem to a host computer or copied into another unit for transportation to the surface. A user-friendly menu system displayed on a hand-held terminal allows simple control of recording and data transfer functions. All system units are designed to meet drop-test, watertightness, and other environmental criteria to enhance reliability in field use.

The report includes photographs of the equipment and plots of data taken in laboratory and field tests. It also discusses system design considerations, the electronic design of each system unit, and system firmware and documentation.

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FOREWARD

This report was prepared by Serata Geomechanics, Incorporated under USBM contract number H0245009. It was administered under the technical direction of the Bureau of Mines Pittsburgh Research Center, with Mr. Richard Allwes acting as Technical Project Officer. Mr. David Askin was the Contracting Officer for the Bureau of Mines. This report is a summary of the work completed under this contract during the period October 1984 to December 1988. This report was submitted by the author in December 1988.

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UNITS OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere
AC	alternating current
DC	direct current
ft	foot
Hz	hertz
in	inch
KB	kilobyte (1024 bytes)
lb	pound
lbf	pound (force)
MB	megabyte (1,048,576 bytes)
psi	pound (force) per square inch
S	strain
V	volt

A HIGH-PERFORMANCE, INTRINSICALLY SAFE DATA ACQUISITION SYSTEM FOR UNDERGROUND USE

By Robert J. Van Scoy[1]

ABSTRACT

This report describes a portable, intrinsically safe data acquisition system designed specifically for use in underground coal mines. The system is designed for high resolution and stability, and can accept a wide variety of transducer types without modification or accessories. Input units may be easily added to the system to expand it to a maximum of 240 input channels.

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The report includes photographs of the equipment and plots of data taken in laboratory and field tests. It also discusses system design considerations, the electronic design of each system unit, and system firmware and documentation.

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1.0 INTRODUCTION

This report describes the design, construction and testing of a high-performance, intrinsically safe data acquisition system. This system was developed by Serata Geomechanics, Inc. under USBM contract #H0245009.

The objective of this project was to bring the measuring capabilities of laboratory-grade data acquisition systems to the underground coal mine environment. This required a custom design because of the shortcomings of commercially available portable data acquisition equipment.

Although a number of small data loggers are commercially available, they often are limited in memory capacity and measurement resolution. Most small loggers also require external signal conditioners or other "add on" hardware in order to be useful with differing transducer types. There is usually no way to include detailed setup information in the stored data, so separate records must be kept in a logbook and later entered manually into a data analysis computer.

Even if these limitations can be accepted, most commercial data loggers have not been designed for intrinsic safety and therefore cannot be used in gassy mine environments. Investigators have adapted some of these units to allow MSHA approval, but often the full capabilities of the unit are only available in fresh air. Further, the unusual severity of the coal mine environment frequently causes reliability problems in general-purpose loggers not specifically designed for it.

Data acquisition systems for fixed locations are considerably more advanced. Good systems have been available for laboratory and industrial use for many years, and typically offer great flexibility in transducer choice and large data storage capacities. They can be programmed easily for many different applications via "user friendly" menu systems.

However, it is hard to adapt these systems for coal mine use even when portability is not required. Because they require AC line power, these systems must be located in fresh air. In order to use them for measurements in locations where a methane hazard may exist, long cables must be run to the hazardous area and connections made through cumbersome protective barriers. The high cost of these installations can rarely be justified for research purposes.

Efforts to build semicustom portable systems from commercially available data acquisition modules and computer boards have also run into practical problems. Although this "building block" approach saves considerable hardware development costs, the power levels consumed by commercial boards or modules are prohibitive for a battery operated system. Even in the unlikely event that such a system could be made intrinsically safe, powering it for several days in the field might require a rechargeable battery pack weighing several hundred pounds. The physical packages of the individual modules are also often too heavy, bulky, and fragile to be suitable as components of a portable system.

The project discussed here was directed at overcoming the drawbacks of these various approaches by developing a custom system "from the ground up."

1.1 Objectives for the data acquisition system

The system described in this report was designed to meet a number of ambitious objectives. These included:

<u>Input performance and flexibility</u>

-- high resolution (e.g. 1 microstrain for strain gages)
-- automatic range switching
-- fully programmable transducer excitation
-- low level and high level voltage and current inputs
-- flexibility to use many common transducers without additional hardware
-- ability to expand number of transducer channels in system
-- ability to read vibrating-wire transducers (with separate input unit)
-- moderate speed (10 Hz sampling rate for each channel)
-- high stability with temperature change and aging

<u>Ease of use and portability</u>

-- small, lightweight units
-- battery operation from a lightweight portable pack
-- user-friendly menu system with alphanumeric display

<u>Large data capacity and easy transfer</u>

-- large (1-2 megabyte) nonvolatile electronic memory
-- simple transfer of stored measurements between units and to a host computer
-- data transfer speeds up to 38,400 baud
-- full alphanumeric labelling of all channel and measurement setups

<u>Intrinsic safety and environmental suitability</u>

-- full intrinsic safety for all operations
-- environmental packaging to meet requirements of USBM contract report # J0100040 to secure reliability in underground environment.

Several sets of these requirements were very difficult to reconcile. In particular, developing very low power analog electronics with the required performance required much "fine tuning" of the design. Also, the development of lightweight packaging for the units which could withstand the relatively severe "drop test" specified by the USBM requirements took considerable effort and testing.

2.0 SYSTEM DESIGN CONSIDERATIONS

Because the system was to be used for a variety of measurement applications, it was clear that the design should be modular to allow varying the number and type of transducer channels in the field. This would allow the weight and power consumption of the system to be optimized for each particular measurement setup (i.e. the system would be lighter and run longer on a battery charge if fewer channels were in use because fewer input modules would be required).

From field experience, it was also known that physically grouping all the channel input connectors on one unit was a bad idea. Often it is desired to monitor several groups of sensors which may be separated by up to several hundred feet. If all the input connections are in one place, some of the transducer cables must be very long. Since input signals are typically very low-level, long transducer cables often degrade measurement accuracy.

Therefore it was decided to divide the input channels among a number of self-contained, "intelligent" (microprocessor-controlled) input units. Each input unit is attached with an electrical cable to the system Power Supply, which provides operating power. The Data Logger is also plugged into the same Power Supply unit. In addition to the power lines, each of the connecting cables contain communications wires which let the Data Logger send commands to the input units and receive data in return. Because data is transmitted digitally over these cables rather than as a low-level analog signal, increasing the cable length does not affect measurement accuracy (and the critical transducer cables can be kept short.) Figure 1 shows the basic configuration of the data acquisition system when it is set up for data collection in the field.

A major focus of the system design effort was obtaining good performance from intrinsically safe circuitry. Intrinsically safe equipment must be designed so that malfunctions such as short circuits cannot produce a spark with enough energy to ignite a flammable gas mixture (in this case methane-air). This condition must hold even in the presence of two additional "faults," such as component failures. The idea is that there must be a vanishingly small probability a spark of sufficient energy being produced.

In practice, intrinsic safety requirements impose even more constraints on circuit design (1-2). Prescribed safety factors must be incorporated in the design, and there are other concerns besides spark ignition which must be considered. For example, component failures must not cause either the defective part or other components to overheat enough to thermally ignite coal dust or methane.

All these requirements lead to equipment designs which must operate at much lower power levels than are customary for high-quality data acquisition systems used in non-explosive environments.

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[2]Underlined numbers in parentheses refer to items in the list of references in section 8.0.

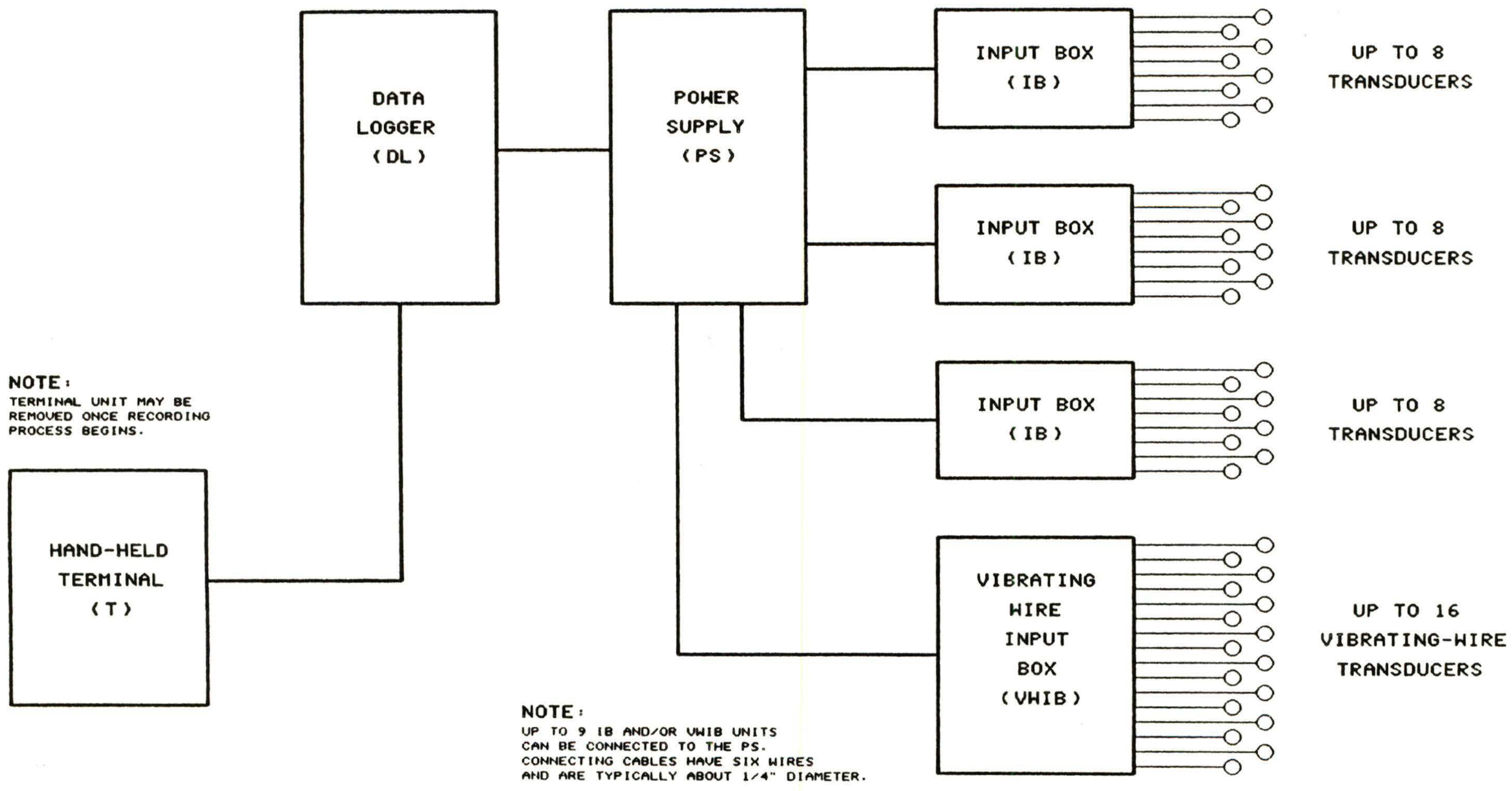

FIGURE 1 - SYSTEM CONFIGURATION FOR DATA RECORDING

The intrinsic safety requirements, as well as the need for battery operation, limited the choices of components for the system. In order to obtain up to 96 hours of operation from a small battery pack, efficient digital electronics were clearly necessary. When the project was initiated, a low-power CMOS microcomputer board based on the RCA 1802 microprocessor chip (3) was already well along in development at Serata Geomechanics. This design, which was intended for a similar portable application, was modified and used as the CPU board for most of the system units. This minimized additional development costs for this portion of the system hardware. Although later-generation CMOS processors were becoming available at the time and were considered as well, designs based on them did not offer significant advantages over the 1802 board in terms of "performance per watt" of power consumed. In addition, the 1802 had a proven track record of reliability in severe-environment systems.

Components for the analog electronics were chosen from state-of-the-art low power devices, with a few higher-power parts being used for critical input stages where performance was paramount. Attempts were made to use parts with industry-standard pinouts, both to simplify service and allow upgrading performance in the future as improved parts became available.

Another constaint on the system design was the need to meet a rather rigorous set of environmental requirements. A contractor for the Bureau of Mines, Dayton T. Brown, Inc., had previously developed a series of environmental tests for mine instrumentation. Several of these tests were specified for the data acquisition system. The most difficult specification was that the units in the system must survive a series of 26 three-foot drops (once on each face, edge and corner) without damage. In order to meet this requirement, a suspension system for the internal components of the units had to be designed which would provide sufficient shock isolation without adding unacceptable bulk or weight. Other requirements for temperature range and water and dust tightness were met by standard design approaches, but again with the additional requirement of efficient use of weight and space.

Finally, several tradeoffs were considered in determining the energy capacity (and thus the size and weight) of the power supply unit. A higher pack voltage allows longer connecting cables between units, and a larger ampere-hour capacity allows longer operation. The final compromise was to choose a pack size which allows 96 hours of data recording with a single Input Box or Vibrating Wire Input Box at moderate sampling rates.

3.0 SYSTEM OVERVIEW

As shown in figures 1 through 3, the data acquisition system consists of a Data Logger, Terminal, Intelligent Memory Box, Power Supply, and one or more Input Boxes or Vibrating Wire Input Boxes. Figures 4 through 9 are photographs of these units.

Figure 1 is a block diagram of how the system is set up for field data acquisition. The Data Logger controls the data gathering process. It communicates with the user through the hand-held Terminal unit, which is connected with a short cable. When the Terminal is plugged in, the Data Logger runs a menu system which allows the operator to record and inspect data, set up and calibrate transducers, transfer data to external units, et cetera. The Terminal unit is seperate from the Data Logger to allow convenient use of the system in cramped areas. When the system is gathering data unattended, the Terminal can be removed to discourage tampering.

Another cable attaches the data logger to the Power Supply, which is basically a battery box that serves as a "hub" for the system and a source of operating power to all units. Plugged into the Power Supply are one or more input units. There are two types of input units: Input Boxes, which handle 8 DC transducers (such as strain gages, thermocouples or potentiometers) each, and Vibrating Wire Input Boxes, which handle 16 vibrating wire transducers each. Up to 9 Input Boxes and/or Vibrating Wire Input Boxes can be plugged into the Power Supply unit. Under this contract, six Input Boxes and one Vibrating Wire Input Box are being delivered. This configuration can accomodate 16 vibrating-wire transducers and 48 other transducers simultaneously.

Each transducer in the system is attached to one channel of an input box. The Input Box provides any needed excitation power for the transducer and converts its analog output into corresponding digital data. Each Input Box is connected to the Power Supply with a six-conductor cable, which provides a path for high-speed data transfers as well as for power. The data lines from all of the Input Boxes are connected in the Power Supply unit, and a single cable transmits this data to the Data Logger and supplies it with power. This arrangement of routing all cables through the Power Supply is necessitated by intrinsic safety considerations, which limit the allowable supply current on any one cable in the event of a short circuit.

The Input Boxes function as "slaves" to the Data Logger, providing data for each channel when the Data Logger requests it. The microprocessor in each Input Box minimizes the Data Logger's computational workload by handling the details of transducer excitation, gain switching, and data conversion. Each Input Box produces "finished" floating-point data in the form needed for storage in the Data Logger's memory. The Vibrating Wire Input Boxes produce data in a similar format, although the data items represent vibration periods rather than signal voltages. Because the data is in floating-point form, no separate record of range or gain settings is needed.

The Intelligent Memory Box provides a way of transporting data stored in the Data Logger memory without removing the Data Logger from the measuring site. The Intelligent Memory Box is carried to the Data Logger location and attached with a cable. Then any newly taken measurements are copied from the Data Logger into the Intelligent Memory Box. The Intelligent Memory Box can then be taken to the surface to transmit the data to a host computer, while the Data Logger is left underground to continue data collection. (Frequently the operator also would bring a freshly charged Power Supply to power the system and take the old one back to the surface for recharging.)

Figure 2 shows how the Intelligent Memory Box, Terminal, and Data Logger are connected for data transfers from the Data Logger to the Intelligent Memory Box. In this configuration, the Terminal can talk either to the Intelligent Memory Box or to the Data Logger, enabling simple coordination of transfers between the units. Data transfers from the Data Logger to Intelligent Memory Box take place at 38.4 kilobaud, so large amounts of data can be transferred in a few minutes.

Figure 3 diagrams data transfer from the Intelligent Memory Box to the host computer. This transfer process requires the use of the Terminal unit, a standard modem, and a telephone line. This setup can be used to either place or answer calls from the host computer, using a standard autodial/autoanswer modem. A 2400 baud modem has been purchased for use with the system, but most other modems with an RS-232 port will work. The Intelligent Memory Box can perform data transfers at standard rates up to 38,400 baud, so it can take full advantage of (more reliable) fast modems as they become available. It is also possible to connect the Intelligent Memory Box directly to a host computer's serial port for high speed data transfers.

Note that the Data Logger itself can also transfer data directly to a host computer, making the use of the Intelligent Memory Box optional if there is no need to leave the Data Logger underground. The setup for these transfers is exactly the same as shown in figure 3, except the Data Logger is used instead of the Intelligent Memory Box shown.

Several tables which follow figure 3 provide additional information on the system. Table 1 provides details of the dimensions and weights of the various system units. Table 2 lists the allowable interconnecting cable lengths for the system, using cables with various wire sizes. A cable of six 24 gage wires is normally used for short distances because of its small size and light weight. The relatively modest cable lengths shown in the table reflect the fact that the power supply unit was designed for minimum size and weight. By using a somewhat larger power supply which provided higher voltage, these distances could be extended by a factor of three or four. A list of the transducers approved by MSHA for use with the data acquisition system is given in table 3. Finally, table 4 gives battery life for a few different configurations of input units and data sampling periods.

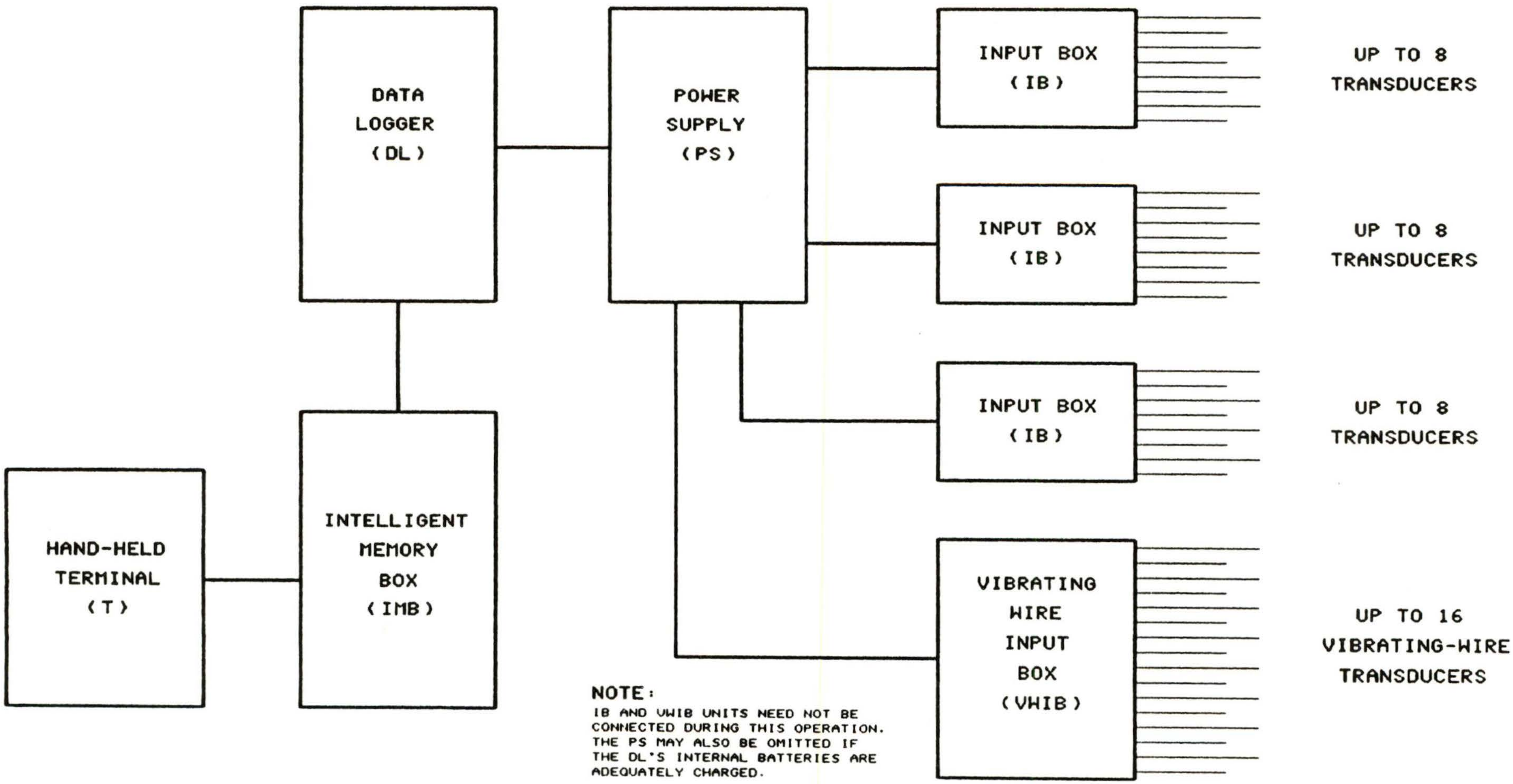

FIGURE 2 - DATA TRANSFER FROM DL TO IMB

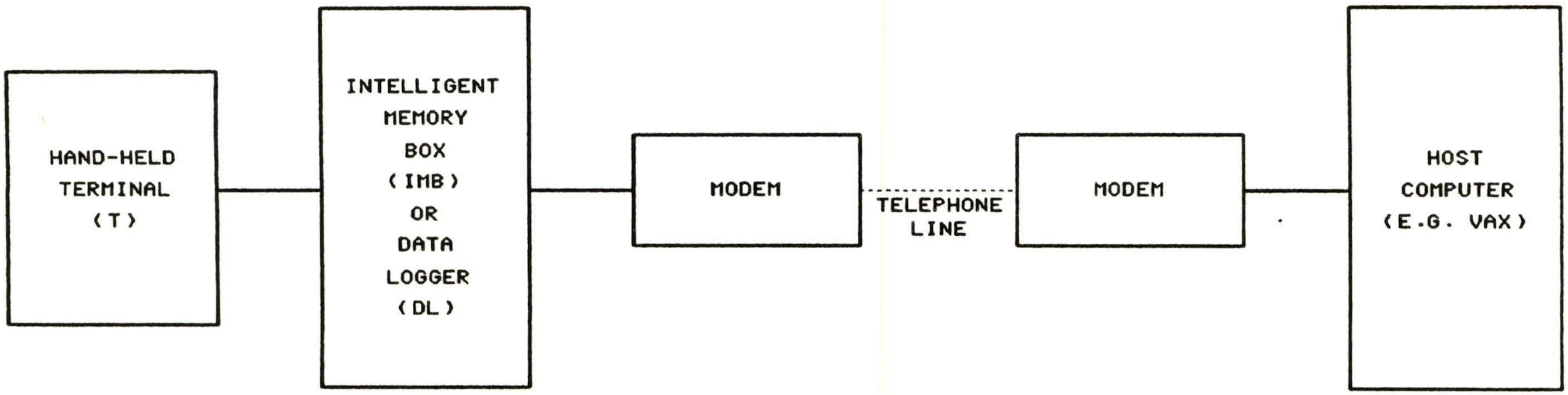

FIGURE 3 - DATA TRANSFER TO HOST COMPUTER

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TABLE 1

DIMENSIONS AND WEIGHTS OF DATA ACQUISITION SYSTEM UNITS

Terminal	10 x 6-1/4 x 1-1/4 inches	4 pounds
Data logger	12 x 9 x 4-1/2 inches	8 pounds
Intelligent Memory Box	12 x 9 x 4-1/2 inches	10 pounds
Input Box	12 x 9 x 4-1/2 inches	7 pounds
Vibrating Wire Input Box	12 x 9 x 4-1/2 inches	6 pounds
Power Supply	12 x 9 x 3-1/2 inches	8 pounds

TABLE 2

MAXIMUM CABLE LENGTHS FOR VARIOUS WIRE SIZES (IN FEET) [1]

	24 gage	20 gage	16 gage
PS to IB	500	1300	3000
PS to VWIB	1200	3000	7500
PS to DL	1200	3000	7500
DL to T	1500	3800	9400
IB transducer cables [2]	100	200	400
VWIB transducer cables [3]	-- see transducer specifications --		

[1] These lengths are calculated and have not been tested.

[2] For highest precision, IB input cables should be kept as short as possible.

[3] Typically, VWIB transducer cables can be up to several thousand feet long. The transducer manufacturer's literature can be used as a rough guide.

TABLE 3

TRANSDUCERS APPROVED BY MSHA FOR USE WITH DATA ACQUISITION SYSTEM [1]

I) Sensors for use with input box unit (connected to IB202 board):

1) Purely resistive sensors which include no capacitors or inductors:

a) Strain gages and strain gage bridges which have a nominal resistance across the excitation terminals of 120 ohms or greater.

b) Potentiometric sensors with a minimum resistance of 200 ohms and a minimum power rating of 1 watt.

c) RTD (resistance thermometer) devices with nominal resistance of 100 ohms or greater and a minimum power rating of 1.5 watts.

d) Thermistors of 1000 ohms or greater nominal resistance.

2) Self-generating sensors which include no capacitors or inductors:

a) Thermocouples

3) Solid-state (integrated-circuit) temperature transducers:

a) Analog Devices AD590/AC2626 [2]
b) National Semiconductor LM34/LM35

[1] This system has been approved as intrinsically safe by the Mine Safety and Health Administration and by the Office of Deep Mine Safety, Department of Environmental Resources of the Commonwealth of Pennsylvania. Any use of transducers not on this list requires appropriate regulatory approvals. The IB can also accept voltage inputs of 0-256 mV or 0-16 V, as well as current inputs up to 20 mA. However, the connection of the equipment producing these signals to the IB would have to be approved by regulatory authorities for each specific case.

[2] Reference to specific products does not imply endorsement by the Bureau of Mines.

TABLE 3 (CONTINUED)

TRANSDUCERS APPROVED BY MSHA FOR USE WITH DATA ACQUISITION SYSTEM

II) Sensors for use with vibrating-wire input unit (connected to VW201 board)

a) Geokon models VSM-4000, VSM-4200, and VK-4100 vibrating-wire strain gages
b) Geokon model 4300 vibrating-wire stressmeter

These devices have previously received MSHA approval number 2G-3623-0.

NOTE: The VWIB can read most (non-intrinsically safe) vibrating wire transducers from other manufacturers. However, these transducers cannot be approved for use in gassy environments since regulatory agencies have no control over subsequent design changes by the manufacturer. Such changes (e.g. increased inductance) might reduce design safety margins or result in a hazardous condition.

TABLE 4

ESTIMATED POWER SUPPLY OPERATION TIMES FOR VARIOUS MEASUREMENT SCENARIOS

EQUIPMENT	INPUTS	SAMPLING PERIOD [1]	OPERATION TIME
DATA LOGGER 1 IB POWER SUPPLY	8 STRAIN GAGE BRIDGES	2 MINUTES OR LONGER	96 HOURS
DATA LOGGER 1 IB POWER SUPPLY	8 STRAIN GAGE BRIDGES	10 SECONDS	48 HOURS [2]
DATA LOGGER 1 IB POWER SUPPLY	8 STRAIN GAGE BRIDGES	.1 TO 1 SECOND	20 HOURS [2,3]
DATA LOGGER 4 IBs POWER SUPPLY	32 STRAIN GAGE BRIDGES	5 MINUTES OR LONGER	48 HOURS
DATA LOGGER 4 IBs POWER SUPPLY	32 STRAIN GAGE BRIDGES	10 SECONDS	16 HOURS [2]
DATA LOGGER 4 IBs POWER SUPPLY	32 STRAIN GAGE BRIDGES	.1 - 1 SECOND	6 HOURS [2,3]
DATA LOGGER 1 VWIB POWER SUPPLY	16 VIBRATING WIRE TRANSDUCERS	10 MINUTES OR LONGER	96 HOURS
DATA LOGGER 1 VWIB POWER SUPPLY	4 VIBRATING WIRE TRANSDUCERS	30 SECONDS	36 HOURS

[1] Time between subsequent measurement cycles recording all channels

[2] Assuming 120 ohm bridge transducers. Use of 350 ohm gages or other transducers using less excitation power will extend operating time 10-20%.

[3] In these cases, the measurement duration is limited by the Data Logger's memory capacity rather than by the Power Supply. For example, 32 channels sampled at a 1 second interval will fill one megabyte of memory in about 3 hours. Eight channels sampled at a .1 second interval will fill the same memory in about an hour.

4.0 UNIT HARDWARE DESCRIPTIONS

This section discusses the detailed design of each unit in the data acquisition system.

4.1 Data Logger

The hardware of the Data Logger consists of 2 printed circuit boards and an internal battery pack assembly. One board, the DDR-201, contains the microprocessor and communications and support functions. The other board, the DDR-202, contains 1 megabyte of static CMOS memory. An internal battery pack is provided for Data Logger operation when it is not connected to the Power Supply unit, and will provide about 20 hours of operation. A standby battery on the memory board provides about a week of protection for the data in mass memory if the main battery back gets completely discharged or temporarily disconnected.

The Data Logger is connected to the outside world through two weatherproof serial port connectors, one of which also supplies power for the Data Logger's operation from the Power Supply. The connectors themselves are LEMO "snap lock" types without threads, to speed connections and to minimize problems with thread fouling and corrosion frequently encountered underground. These connectors can be seen in figure 4, along with a smaller connector of the same type for attaching the unit's battery charger. At the lower left of the panel is a small reset switch, which must be activated with a pencil or similar object. This avoids accidental resetting of the the unit while it is recording.

DDR-201 CPU board

The DDR-201 board contains the central processing unit (CPU) of the Data Logger, an 1802 microprocessor. It also contains sockets for up to 24KB of EPROM (Electrically Programmable Read-Only Memory) which holds the Data Logger firmware (internal program). An additional socket holds a RAM (Random Access Memory) chip for use as scratchpad (temporary) memory for arithmetic calculations, subroutine calls, etc. There is a small nickel-cadmium battery connected to this socket to provide standby power for a special nonvolatile CMOS memory chip (Mostek 48C02L) if it is used. This battery allows the values of critical variables to be preserved for a week or more after the main battery pack is fully discharged.

A three-chip multiply/divide unit is provided on the board to enhance processing speed, and I/O (Input/Output) circuitry such as serial and parallel communications interfaces is also included. Other circuits on the board include a low-battery detector and real-time clock, which provides a precisely timed periodic interrupt for sample timing as well as keeping track of the time of day.

The DDR-201 board has been especially designed for minimum power consumption. Since much of the power consumed by CMOS digital systems is spent in driving the input capacitances of components such as external memories and I/O devices, the DDR-201 board has been designed to isolate these subsystems from the microprocessor bus lines except when they are actually being used. This saves the power that would otherwise be wasted in providing signals to these units during the approximately 90% of CPU cycles which involve only the microprocessor, the EPROMS, and the scratchpad RAM.

The 1802, like most 8-bit microprocessors, can directly address a maximum of 64KB of memory. In the DDR-201 board, the lowest half of this range directly addresses the onboard EPROM and RAM chips and the upper half references the currently selected 32KB bank of a large external memory subsystem composed of DDR-202 memory boards. This scheme is explained further in section 4.1.2.

The DDR-201 board was designed by SGI as a general-purpose subsystem for a new generation of the firm's instruments. It has been enhanced by the addition of a multiply/divide unit for the USBM's relatively computation-intensive application, but retains its multiple-use flexibility. This same board is a component of the input box and vibrating wire input boxes as well as the Data Logger and Intelligent Memory Box. In each application, features which are not needed are simply omitted by not installing their corresponding components on the board. This approach minimizes production costs by sharing a common PC board design among all units in the system.

4.1.2 DDR-202 memory board

The DDR-202 memory board consists of an array of 32 memory modules, plus supporting bus buffering and address decoding circuitry. A standby power supply is also provided to insure that data is retained in the memory array for at least a week if system power fails or is disconnected.

The memory array consists of 32 high-density CMOS memory modules manufactured by Hitachi. Each is a 30-pin ceramic substrate which supports four 8KB by 8 memory chips contained in surface-mount packages. This provides quadruple the capacity of ordinary static RAM chips, for a total of one megabyte per memory board.

Recently, single-chip 32KB by 8 memories have become available at attractive prices. In anticipation of this, the DDR-202 board was designed to use these chips by simple jumper changes on the PC board. Any future boards will use the newer chips rather than the modules, reducing the cost of each memory board by about $1500 compared to the original design using the memory modules.

In addition to the memory array itself, each DDR-202 board contains an address comparator and board address jumpers which allow it to respond to a preset range of addresses within an 8 megabyte address space. The 8 megabytes are divided logically into 256 banks of 32KB each, and the CPU board selects which bank it wishes to access by writing the appropriate number into an 8-bit bank select latch, which is duplicated on each DDR-202 board. Any processor operations involving the top 32KB of the processor address space will then reference a location in the currently selected memory bank. Only the DDR-202 board which contains the selected bank will activate the signals in its memory array. All other boards remain "dormant" internally, thus saving substantial power.

Each DDR-202 board contains its own backup power supply, which is energized by an onboard nickel-cadmium battery. The backup supply insures that data is retained by the memory array for at least a week even if system battery power is lost or the memory board is unplugged from the system bus, which normally supplies its power. The backup battery is continuously recharged whenever the normal power source is present, so it is always ready to "take over" if main power fails. The backup supply gives the CMOS memory board the nonvolatility of a bubble memory system with the additional advantages of simplicity, higher speed, and much lower power.

4.1.3 Internal battery pack

The Data Logger is powered by an internal nickel-cadmium battery pack consisting of 8 "AA" size cells, which provides operating and standby power when the unit is not connected to the Power Supply. The pack is equipped with isolation components and protective covers to meet intrinsic safety design guidelines. The pack provides about 20 hours of operation on each charge under normal conditions.

4.2 Intelligent Memory Box

Despite the different purposes of the Intelligent Memory Box and the Data Logger, the hardware of the two units is essentially identical. Therefore, only the differences will be noted here. Most significantly, the Intelligent Memory Box contains 2 MB of memory rather than 1; therefore two memory boards are needed instead of one. The external packaging of the two units is identical, as can be seen from the Intelligent Memory Box photograph (figure 5).

The Intelligent Memory Box is powered by the same internal nickel-cadmium battery pack used in the Data Logger. The pack capacity is sufficient to support the unit's operation for about 20 hours on each charge. When data is being sent to the host computer (in a fresh air environment), the battery charger may be connected to the Intelligent Memory Box to provide power without discharging the battery pack.

4.3 Terminal

The Terminal unit, like other system units, is based on an 1802 microprocessor. It uses a 40-character by 2 line liquid crystal display, and has a 50-key alphanumeric keyboard with shift, control and escape functions. Figure 6 is a photograph of the Terminal unit.

Except for the display capacity and the omission of some special character keys, the Terminal generally functions like a full size desktop terminal. Incoming text lines (as from a host computer) are buffered and displayed sequentially, with a delay interval between lines to allow comfortable reading. The Data Logger and Intelligent Memory Box menus are formatted to fit entirely in the 2-line display, so do not make use of this feature.

The Terminal's PC board contains the same basic components as the DDR-201 CPU board described in section 4.1.1, but is simplified for compactness by including only those functions needed for the Terminal application. The size and weight of the Terminal unit are further mimimized by drawing operating power from the Data Logger or Intelligent Memory Box rather than an internal battery pack.

The Terminal's display is a liquid-crystal display module which displays 2 lines of 40 characters each, providing enough space to show a compact menu at each step in the system's operation. The display can show the full ASCII character set, including upper and lower case alphabetics and all special symbols.

The Terminal keyboard is laid out "typewriter style" as five horizontal rows of 10 keys each. The keys provide the full alphanumeric character set as well as a subset of special characters. The keys are operated through a flexible protective plastic sheet gasketed into the panel. This sheet provides additional environmental sealing for the keyboard and can be wiped free of grime more easily than the keys themselves.

It was desired to make the Terminal unit as compact as possible, but a sufficiently rugged plastic case of the proper dimensions could not be found. Therefore, a case was custom machined out of a solid block of aluminum. If the unit was produced in quantity, a lower-cost alternative would be found.

4.4 Power Supply

The Power Supply consists of a rechargeable battery pack equipped with protective components (i.e. resistors) to limit output energy to values acceptable under intrinsic safety guidelines. These resistors must be relatively large to maintain safe current levels even in the presence of external fault conditions, such as short circuits in connecting cables. Due to the energy lost in these components during normal operation, the Power Supply must run from higher voltage batteries than would be required in a non-intrinsically safe system.

When losses in the protective circuitry, drops in battery voltage during the battery discharge cycle, and voltage drops in connecting cables are all considered, a battery of about 12 volts nominal is required to reliably supply the needed 6 volts to the voltage regulators of each unit. A four ampere-hour battery capacity was chosen to minimize the bulk and weight of the pack and provide reasonable operating life between charges. This capacity can be handled by a battery of 10 "D" size nicad cells in series. The resulting Power Supply weighs about 8 pounds. The Power Supply is pictured in figure 7. Other system units can be connected to any one of the ten larger connectors which are not already in use. The smaller central connector is for recharging the Power Supply from an AC-line operated battery charger.

Although a 96 hour operating life is a design goal, this Power Supply will support the system for less than 96 hours at high sampling rates. This is unlikely to be a problem, however, because the Data Logger memory will also fill up with data in a much shorter period at high sampling rates. For example, a 32 channel system running at .1 second per sample can fill the Data Logger's 1 MB memory in less than half an hour, but the battery pack could power such a system for about 4 hours. This operational time would increase to over 12 hours for an 8 channel system, since only one input box would need to be powered by the Power Supply. Thus the anticipated Power Supply size represents a good compromise between operational time and weight for the expected use conditions.

4.5 Input Box

Each Input Box consists of a DDR-201 CPU board, described in section 4.1.1, which controls an analog electronics board designed specifically for this purpose. Transducer connections to the Input Box are made via environmental circular connectors, which are protected by dust caps when not in use. A small PC board mounted on each transducer connector provides components for strain gage bridge completion and excitation switching, and connects to the analog board via a ribbon cable. Figure 8 is a photograph of the Input Box unit.

The development of this unit's analog circuitry was a particular challenge. High-accuracy, low noise analog circuits tend to be power-hungry and operate from relatively high voltages. Reducing the power levels to about 1/100 that in typical industrial systems was necessary to allow battery operation and intrinsic safety. Special power supply designs were developed to provide stable, well-filtered operating voltages without the use of components which stored energy levels which were unacceptable from the intrinsic safety standpoint.

In order to minimize power consumption, the Input Box activates and reads only one transducer at a time. In addition to reducing the power consumed by the transducers themselves, this arrangement reduces the power consumption of the signal conditioning electronics since it allows one signal conditioning channel to be shared among all 8 transducers. All of the Input Box analog electronics can also be turned off via a command from the Data Logger. This feature is used to save battery power at low sampling rates.

Because of the relative complexity of the Input Box analog board, the functions of each subsystem will be discussed separately.

4.5.1 Excitation supply

The function of the excitation supply is to provide a programmable, highly regulated voltage or current for all transducers which require it. The supply has been designed for maximum versatility for use with a wide range of DC-excited transducers. It is capable of providing voltages ranging from .1 to 5 volts or currents from 1 to 20 milliamperes. The excitation level for each sensor can be set under system control, requiring no manual adjustments or wiring changes at the Input Box. Each transducer is simply connected to the appropriate terminals of its input connector to obtain either voltage or current excitation.

The voltage excitation mode offers either 2-wire sensing, in which a constant voltage is maintained at the excitation source output, or 4-wire sensing in which a constant voltage is maintained across the remote transducer itself. The latter option requires that an additional pair of wires be run from the Input Box to the transducer, but it cancels out drifts and errors resulting from the resistance of the connecting cable. This provides optimum performance for very-high resolution measurements or those involving long transducer cables.

The current excitation mode maintains a constant current through the transducer despite changes in transducer and cable resistance. The current source can provide up to 5 volts across its terminals.

4.5.2 Zero suppression generator

Although transducer circuits such as strain gage bridges theoretically produce no output "at rest," in practice electrical mismatching of the bridge components can produce a relatively large initial output. This undesired signal can be many times the size of the signal resulting from full-scale mechanical loading of the bridge, and provisions must be made to cancel out this undesired signal electronically to make high resolution measurements possible.

This "balancing" function is conventionally accomplished manually with a potentiometer connected across the bridge's excitation terminals. The wiper of the pot is connected through a high-value precision resistor to one side of the bridge output, introducing a small current which can be varied by adjusting the pot. The pot is then adjusted until this current is of the right sign and magnitude to cancel out the original bridge imbalance.

For both environmental and convenience reasons, such manual controls are undesirable in an underground environment. Therefore, the Input Box replaces the mechanical pot with a digital-to-analog converter (and associated circuitry) which convert a number supplied by the microprocessor to into a balancing voltage at an output terminal on each transducer connection strip. A resistor selected for the transducer model in use is attached between this terminal and the transducer output, providing the appropriate scaling of the balance range.

The microcomputer can then balance the transducer circuit automatically by producing the appropriate balancing voltage to obtain zero input signal with the transducer at its zero point. The digital value corresponding to this voltage is then saved in memory and used to create the same balancing voltage for each subsequent measurement for that channel.

4.5.3 Input multiplexers and preamplifier

Each Input Box channel is provided with differential inputs which respond to the difference in voltage between two input terminals while ignoring any "common mode" signals which appear on both terminals at the same time. This arrangement provides optimum noise rejection and minimum error. The pair of input terminals connected to the transducer in use at any given time is selected by a precision multiplexer and applied to the inputs of a differential preamplifier.

The preamplifier is designed to directly accept input signals from "low level" transducers which produce up to about ± 250 mV differential output at full scale. Additional input terminals are provided on each channel for "high level" signal inputs up to about ± 16 volts full scale; these terminals connect to resistive attenuators which divide the input voltages by 64 before they are applied to the preamplifier. An third pair of terminals accepts currents up to ± 20 ma. The switching between these options is under system control; users need only connect each transducer to the right set of terminals on that channel's terminal strip.

A fourth differential input for each channel, not available to the user, is permanently shorted together to provide a "zero signal" reference. This allows the system to cancel out internal offset errors and drifts by reading the shorted input and subtracting the resulting value from that channel's transducer reading.

Since the shorted input should give a reading of zero, any nonzero reading represents an error term. This error occurs in the transducer reading as well as in the "no signal" reading, since both share the same electronic circuitry. The subtraction therefore removes this error term from the transducer reading. Since both measurements are made within a very short time each time a transducer is read, the correction process remains effective even as the error term drifts.

This autozeroing technique greatly enhances the system's long-term stability by cancelling amplifier offset changes which occur with component aging. It also improves system performance over temperature, because thermally-caused drifts in component offsets are cancelled as well. Note that the cancellation is effective not only for the preamplifier stage but for offset errors in the programmable-gain amplifier and A/D converter too.

Considerable effort was spent in optimizing the performance of the preamplifier, particularly in obtaining the very low noise levels needed to achieve the desired strain gage resolution of 1 microstrain while maintaining power consumption at reasonable levels. Precision wirewound resistors were used in the preamplifier (and other critical stages) in order to achieve good temperature stability and minimize the drift of the electronics over long time periods. For economic reasons, resistors of this quality are rarely used in portable data acquisition equipment.

4.5.4 Programmable-gain amplifier and lowpass filter

The signal from the preamplifier is fed to a programmable gain amplifier (PGA), which can be set digitally to a gain of 1, 2, 4, 8, 16, 32, 64, or 128. In conjunction with the fixed preamplifier gain, the appropriate selection of one of these gain factors can produce a signal of between ± 2.5 and ± 5 volts full scale at the PGA output for any desired input range. The PGA is followed by an RC lowpass filter to limit the noise bandwidth of the signal conditioning channel in order to improve resolution.

The PGA is based on a high-quality D/A converter, which provides good longterm gain stability without adjustments. The use of the PGA allows the system to automatically scale the input signal for the best resolution without the problem of "losing" out of range inputs which is frequently experienced with inexpensive "fixed range" data loggers.

4.5.5 Cold-junction compensation sensor

Thermocouple measurements made with a system at room temperature must be corrected because two undesired thermocouple junctions are formed when a thermocouple is connected to an input terminal strip. These junctions, consisting of the thermocouple materials and the copper input terminals, create error voltages which add to the desired thermocouple signal. These error voltages vary with the temperature of the undesired junctions, so their temperature must be known in order for corrections to be calculated.

The cold-junction compensation sensor is a solid-state device located in the Input Box near the input terminals. It produces an output voltage proportional to temperature, which can be fed to the A/D converter as an alternative to the PGA output. The resulting temperature reading is used in calculations to correct the thermocouple data. The magnitude of the correction is different for each type of thermocouple, but this poses no problems because the correction is made arithmetically rather than with the usual special-purpose analog circuitry.

It is assumed that the Input Box will be used in environments where the ambient temperature changes relatively slowly, so that an "average" Input Box temperature (as opposed to an individual reading at each channel's terminals) will provide compensation of sufficient accuracy for all the thermocouples connected to the unit. It is also assumed linear compensation is sufficient. More sophisticated cold-junction compensation algorithms may be implemented on the host computer if desired.

4.5.6 Analog to digital converter

The analog-to-digital converter (A/D) is a 13-bit successive-approximation design of generally conventional architecture which was developed by SGI. It is built around a high-quality digital-to-analog converter and CMOS successive-approximation registers. This custom design is used instead of a commercial modular or hybrid unit because it provides a better tradeoff between speed and power for this application. It also offers better long-term stability than most commercial low-power units as well as operation from lower supply voltages.

The microprocessor can quickly determine the correct PGA setting for a given A/D conversion by taking a reading at the lowest gain and determining how much of the converter's range was used. Then another reading is taken at the correct higher gain setting which fully utilizes the converter's resolution. This "autoranging" feature allows the system to avoid wasting time on unsuccessful conversion attempts and to continue taking valid readings from an input which has exceeded its initial full scale range. Thus, the complete loss of transducer data due to "going off scale," a common problem in many data acquisition systems, can be eliminated -- provided, of course, that the transducer itself is still functioning properly.

In many practical cases, this 13-bit system, which has a 20-bit dynamic range, can provide the equivalent of several extra bits of resolution compared to normal "fixed range" systems. This is because "headroom" for the largest possible signal need not be allowed when choosing initial gain settings.

This is especially true where the magnitude of the input signal is not known in advance, a common situation in field work. For example, a 50 mV range might be chosen for a strain gage in order to allow for the maximum possible strain, but the measurement data might show that only a 4 mV output change actually occurred. In a fixed range 16-bit system, the smallest value that could be resolved would be the 50 mV range divided by 2^{16}, or about 770 uV. The autoranging system, making full use of its 13-bit resolution, could provide slightly better performance: 4 mV divided by 2^{13}, or about 490 uV.

4.5.7 Power supply and reference voltage generator

Battery power supplied over the cable from the system Power Supply is regulated by the on-board power supply circuit and converted to the various voltages needed by the analog circuitry. The regulator circuit incorporates protection against supply reversal and overvoltage, so that cable wiring errors will not damage the Input Box. It also contains provisions for shutting down the analog board at low sampling rates, saving battery drain during periods when no data is being taken.

The supply additionally powers a precision 5 volt reference generator, whose output is used by the excitation source, zero suppression generator, and A/D converter. Since the excitation source and A/D converter operate from the same reference voltage, errors resulting from reference drift are largely cancelled when transducers such as strain gages or RTD's are used. This advantage, however, applies only to transducers which are directly excited by the Input Box.

Here also, higher quality references, resistors, and other components are used than is usually the case for field equipment in order to provide good thermal and long-term stability.

4.6 Vibrating Wire Input Box

The Vibrating Wire Input Box consists of a DDR-201 CPU board, described in section 4.1.1, and a vibrating wire board designed for this application. The Vibrating Wire Input Box, shown in figure 9, has 16 circular input connectors for vibrating wire gages. As with the Input Box, these are military-grade environmental connectors which are protected by dust caps when not in use.

Like the analog board in the Input Box, the vibrating wire board is interfaced to the CPU board via the latter's parallel ports, and all operations are performed under CPU board control. Most of the functions of the vibrating wire board are accomplished by digital logic rather than conventional analog approaches, in order to provide maximum flexibility to accomodate to various vibrating-wire transducers.

4.6.1 Vibrating-wire circuit description

In order to read each vibrating-wire transducer, a stable vibration must be set up in the transducer's wire. Several approaches to exciting this wire resonance were evaluated by SGI, using the transducer samples provided by USBM. The approach most compatable with low power consumption and intrinsic safety seems to be to feed periodic "bursts" of sinusoidal power to the transducer at a frequency near the wire resonance. The wire will then continue to vibrate after the excitation burst ends, producing a small electrical signal whose period can be accurately measured.

Because the wire resonance is quite sharp, the excitation must be within about 50 Hz of the resonance peak in order to produce a significant output signal. For this reason, an excitation signal source is needed which can be accurately tuned to all frequencies within the wire's vibrational range (and through the ranges of all transducers which might be used with the system).

SGI chose to use digital frequency synthesis to solve this problem. A counter/timer chip divides a high-frequency master clock by a programmable value, resulting in the desired excitation frequency. This square-wave output is filtered to a sine wave by a tunable lowpass filter and sent through an electronic switch to an output amplifier, which boosts it to the power level required to drive the transducer.

This signal also feeds a burst length counter, which is programmed to control how many cycles of excitation will be gated to the transducer for each measurement attempt. During the burst, the microprocessor can also change the excitation frequency slightly in order to "sweep" the excitation through a narrow frequency range.

The output of the burst length counter switches the Vibrating Wire Input Box from its output mode, where the transducer is being driven by the excitation burst, to input mode, where the circuitry is "listening" for any wire vibration that the last burst caused. Other signals from the CPU board to the switching circuitry determine which of the 16 possible transducers is connected to the Vibrating Wire Input Box at any given time.

Any wire vibration in the transducer generates a weak signal, which is amplified by and filtered to eliminate extraneous noise. An A/D converter turns the amplitude of this signal into a number, which the microcomputer uses to determine when a resonance is found.

To read a transducer, an excitation burst is produced at the highest possible vibration frequency. If there is no significant signal in reply, the frequency is lowered slightly and another burst is produced. This process proceeds downward in frequency until a significant signal voltage is returned. Then the unit "homes in" on the resonance by changing the frequency in smaller steps until the peak amplitude is found. The whole process typically requires a second or two per transducer.

At this point, the vibration signal from the transducer is fed to a circuit which converts it into a square wave suitable for driving digital circuitry. This square wave is fed to the vibration cycle counter, which runs until a programmable number of vibration cycles have occurred (100 cycles might be typical). An interval timer measures the time required to count this number of vibration cycles. Simple division of this total period by the number of cycles counted gives the period of each vibration cycle, which is the desired output. This value is converted to a floating-point number for transfer to the Data Logger.

An additional circuit allows the thermistors (temperature sensors) which are sometimes included in vibrating wire sensors to be read. The circuit uses a separate A/D converter, which produces a number based on the signal from the thermistor. This value can be converted into a temperature reading through further calculations based on the thermistor characteristics.

5.0 FIRMWARE DEVELOPMENT AND DOCUMENTATION

In addition to the development of the system hardware, the internal programs which run each unit were developed as well. (These built-in programs are often called firmware because they are permanently contained in special memory chips. These programs thus lie philosophically somewhere between the physical hardware and the familiar kind of software which must be loaded into a computer from a disk before use.)

For this system, all programs were written directly in 1802 assembly language for maximum compactness and code efficiency. Several phases of firmware development were involved. First, a "library" of general purpose arithmetic, input/output, and utility routines was developed for use by all units. Diagnostics were also written to help in getting the newly-built equipment running.

The specific main programs for each unit were then written. Because of their complexity, these programs are typically divided into a number of modules (essentially subroutines) in order to facilitate debugging. This also makes the system much easier to understand for those who must maintain it later. In most cases these subroutines themselves call lower-level subroutines, which in turn may use library routines. Thus the firmware is built in several layers, with each routine having a well-defined and relatively simple function. This structured approach is typical of contemporary programming practice.

Another large task was the production of documentation. Most of the documentation effort was spent in producing documents for the Mine Safety and Health Administration in connection with the intrinsic safety review. Over fifty drawings and several hundred pages of other documentation were produced for this purpose. To carry out its safety regulation mandate, MSHA requires that the construction details of each unit be documented completely and not changed without agency approval. This level of control prevents intrinsic safety hazards from being introduced unintentionally by manufacturing changes. In order to serve this purpose, documentation must be produced in more detail than would be needed for a non-intrinsically safe system. Intrinsic safety evaluation of a system this extensive is a complex and rigorous task, and substantial correspondence was exchanged between SGI and MSHA personnel as part of the review process.

An operating manual was also produced. It explains the setup and use of the system, information on transferring data to a host computer, and troubleshooting procedures for common problems. Wiring diagrams are included for transducers which MSHA has approved for use with the system.

A hardware manual and circuit schematics are provided to explain the electronic design of each unit and provide a reference for system maintenance. Finally, a firmware manual provides an overview of the internal programs of each unit and of the library subroutines used by higher-level firmware modules. The firmware manual can be used in conjunction with the annotated firmware listings to facilitate future firmware modification or development.

6.0 SYSTEM TESTING

Testing of the system units was performed in three ways. First, the units were verified to meet the environmental tests specified by the contract. Then the system was attached to an instrumented longwall shield in the mine roof simulator (MRS) at the Bureau of Mines Pittsburgh Research Center, and readings taken as the shield was loaded. This data was compared to data taken from the same sensors by the control room instrumentation at the MRS. Finally, a field test was performed using an instrumented shield in an underground coal mine.

6.1 Environmental testing

Environmental test criteria for the project came from the work of Dayton T. Brown, Inc., under USBM contract J0100040. The tests from that document which were specified for this equipment are:

- Shock
- Moisture
- High Temperature
- Low Temperature
- Sand and Dust

Of these criteria, the most difficult was the shock test. This test specifies that the units be undamaged after 26 drops from a height of three feet onto a concrete floor faced with 2 inches of plywood. Many military-style cases constructed of fiberglass or metal are rugged enough for this, although expensive. But this "brute force" approach was impractical because these cases normally weigh about 10 pounds in the necessary sizes, more than the desired total weight of the entire units. Since the case itself could weigh only a few pounds, a more elegant solution had to be developed.

Due to the small quantity of cases needed and the high cost of custom mold development, a custom case design was clearly out of the question. Therefore, a number of stock plastic cases from various manufacturers were evaluated by repeated drop testing with internal dummy weights which simulated the masses and mounting arrangements of the final electronic assemblies.

Reinforced plastics were first selected because of their high strength, but these materials suffered fatigue cracking at the point of repeated (corner) impacts. The best overall choice turned out to be an thinwalled, unreinforced ABS case. To avoid problems with stresses at internal mounting points, the case was supplemented with a metal "skeleton" to absorb the loads from internal shock mounts and distribute them to the case. Considerable experimentation and testing was needed to arrive at a suitable arrangement.

The internal shock mounts were chosen to allow the electronics assemblies to deflect about 1/2" in the direction of impact, reducing the effective deceleration to an estimated 50 Gs. This was found to provide adequate cushioning while increasing the case dimensions of the units by only about 1 inch in each dimension.

It was found that PC board flexing under repeated impacts could eventually loosen some of the integrated circuits from their sockets. This was true even though military-grade sockets with high retention forces were used. One solution was to eliminate the sockets, but it was desired to avoid soldering the ICs into the board for reasons of repairability. The approach chosen was to sandwich the troublesome PC boards between stiffener plates of fiberglass-epoxy laminate. This helped restrain PC board flexing and also helped hold the ICs in the sockets.

Other environmental requirements, such as water and dust tightness, were met by standard design approaches. All the electrical connectors used in the system are sealed environmental types, and the connector flanges and all through bolts are sealed by elastomer gaskets. The ABS cases are sealed at the parting line by a tongue and groove closure equipped with an elastomer O-ring gasket. For the terminal unit, a gasketed aluminum case was used and the keyboard was sealed with a transparent, flexible membrane overlay. These measures allowed the equipment to meet the moisture and dust tests without difficulty.

The temperature ranges specified for underground equipment are also within the normal operating and storage ranges of industrial electronic components, and so posed no special design problems. The terminal's liquid crystal display does show some slowing of response and lowered contrast at low temperatures, and greater than normal contrast at the upper end of the temperature range. Neither effect is expected to pose practical problems.

6.2 Laboratory testing

The data acquisition system was tested in February of 1988 at the Pittsburgh Research Center. An instrumented longwall shield was used for the main test, which was conducted in the mine roof simulator. Four hydraulic systems on the shield were each equipped with paired pressure transducers, with one transducer connected to an input box channel and the other to the permanent data acquisition equipment in the MRS control room. Thus simultaneous readings could be taken by the two systems as the shield was loaded.

In addition, eight strain gages attached to various points on the shield were monitored for several loading cycles by the permanent MRS instrumentation, and were then attached to the data acquisition system for several more cycles. Although the data could not be directly compared, the similarity of the shield's behavior on successive loading cycles allowed additional verification that the system was working properly.

The plots from these tests are included as Appendix A. As can be seen from the plots, very close agreement between the two systems was obtained for the simultaneous pressure readings. For the strain gages, performance of the data acquisition system generally appeared at least comparable to that obtained from the MRS equipment.

All of the strain gages had been previously wired with unshielded cable. This is less than ideal, but the additional work of rewiring the existing setup with shielded cable was deemed unnecessary. At very high sensitivities, some noise pickup was occasionally evident in these tests.

Figure 13 shows that the system can achieve its one microstrain design goal with strain-gage transducers. The strain change of about one microstrain over the loading cycle is clearly visible. Note that the performance is considerably better than that of the MRS instrumentation, which is shown in the following figure 14.

Additional testing with a weldable strain gage equipped with a properly shielded cable confirmed that the data acquisition system can meet the one microstrain objective. Shielded cable is recommended for all high-resolution measurements with the Input Box units.

The Vibrating Wire Input Box unit was tested in the laboratory using a GEOKON stressmeter installed in a small hydraulic press. Readings from the Vibrating Wire Input Box were compared with those from a GEOKON manual readout box, and very close agreement was found. A plot of this comparison test is included as figure 27 in Appendix A.

6.3 Field testing

The system was also briefly tested in an underground coal mine in February of 1988. A longwall shield instrumented similarly to the test unit described above was used, and satisfactory results were obtained. Data plots from these tests are included in Appendix A as figures 28 - 35.

Underground testing of the system is currently continuing. Successful measurements have been made with vibrating wire stressmeters in coal pillars and with shield supports instrumented with strain gages and pressure transducers.

7.0 CONCLUSION

In the past, researchers have often been hampered in making measurements in underground coal mines because of the limited capabilities of the available intrinsically-safe data acquisition systems. The system described in this report brings many of the features of high-performance laboratory and industrial data acquisition systems to the coal mine environment.

This system allows investigators to easily set up measurements with a variety of transducers and to record large amounts of detailed data. It is easy to transport and to use. It allows measurement data, including setup parameters and identifying text, to be transferred either directly or indirectly to a host computer with a minimum of manual work or operator intervention. These capabilities should help to make field measurement work more efficient and error-free. The design of the system specifically for coal mine use should provide good reliability and higher quality data than has previously been available.

8.0 REFERENCES

1. National Fire Protection Association. NFPA 493 - Intrinsically Safe Apparatus for Use in Division 1 Hazardous Locations, 1978. 25 pp.

2. Underwriters Laboratories, Inc. Standard for Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division I, Hazardous Locations. UL 913, Third Edition, 1982. 44 pp.

3. RCA Corporation, CMOS-LSI Manual, 1982. 566 pp.

APPENDIX A

DATA PLOTS FROM FEBRUARY 1988 SYSTEM TESTS

NOTE: The first set of plots (figures 11 - 26) which follow are paired. The first plot in each pair (identified as data from Data Acquisition System) is of data taken with the equipment described in this report. The second plot is of data taken by the mine roof simulator control room instrumentation and is provided for performance comparison purposes.

In setting up one of the Data Acquisition System tests, the leadwires from the front right and back right transducers on the shield were accidentally interchanged. This error was corrected in plotting the attached graphs in order to allow direct comparison of the data.

Figure 27 is a comparison of readings from the Vibrating Wire Input Box and a Geokon manual vibrating wire readout. A vibrating wire stressmeter was electrically switched between the two units while being loaded and unloaded in a hydraulic press. The separation between the loading and unloading curves represents hysteresis in the vibrating wire transducer.

The data from an instrumented longwall shield in two underground coal mine test runs is presented in figures 28 - 31 and figures 32 - 35.

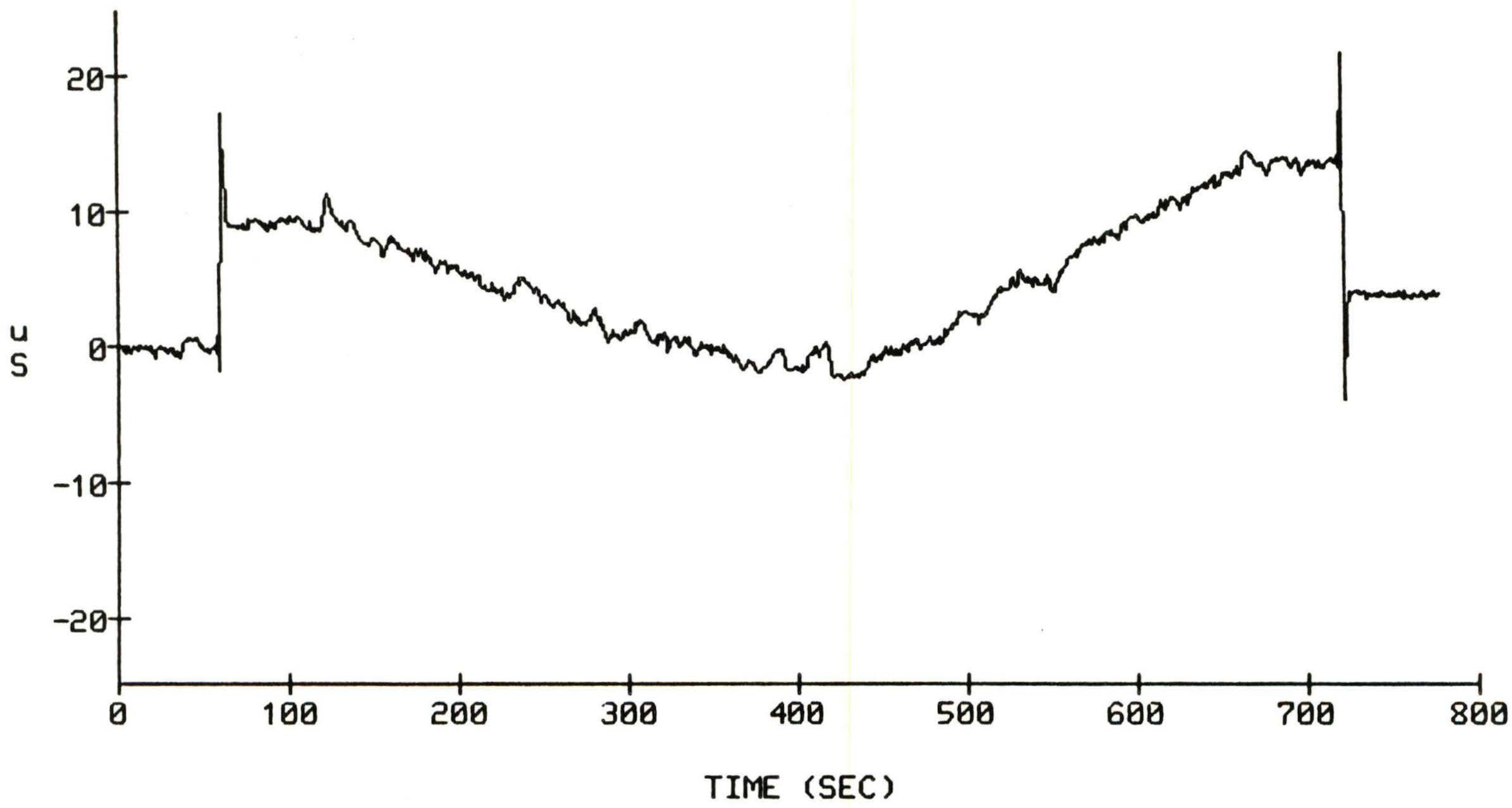

FIGURE 11 - Left rear lemniscate link strain data from Data Acquisition System in mine roof simulator test.

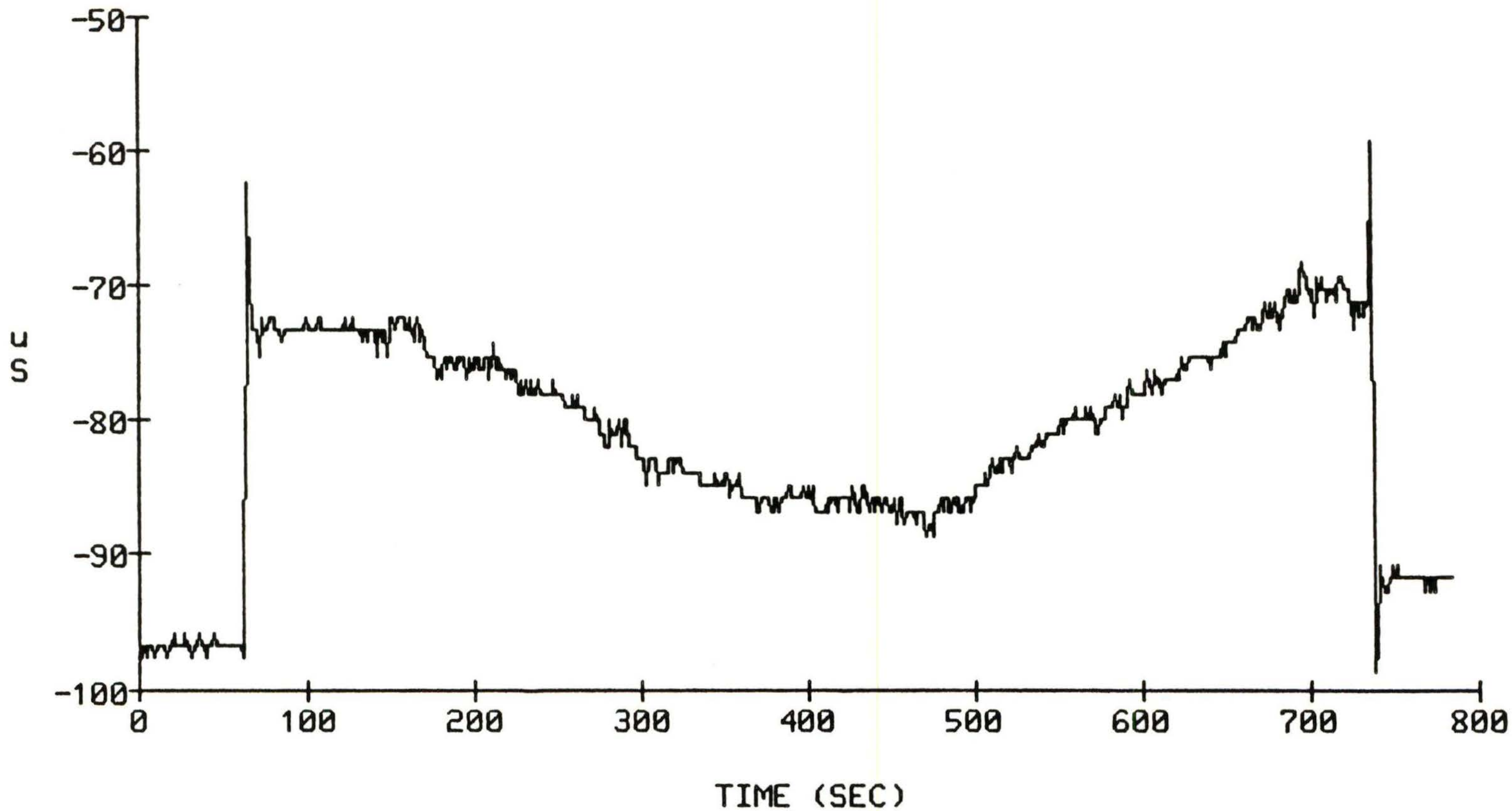

FIGURE 12 - Left rear lemniscate link strain data from mine roof simulator control room instrumentation in mine roof simulator test.

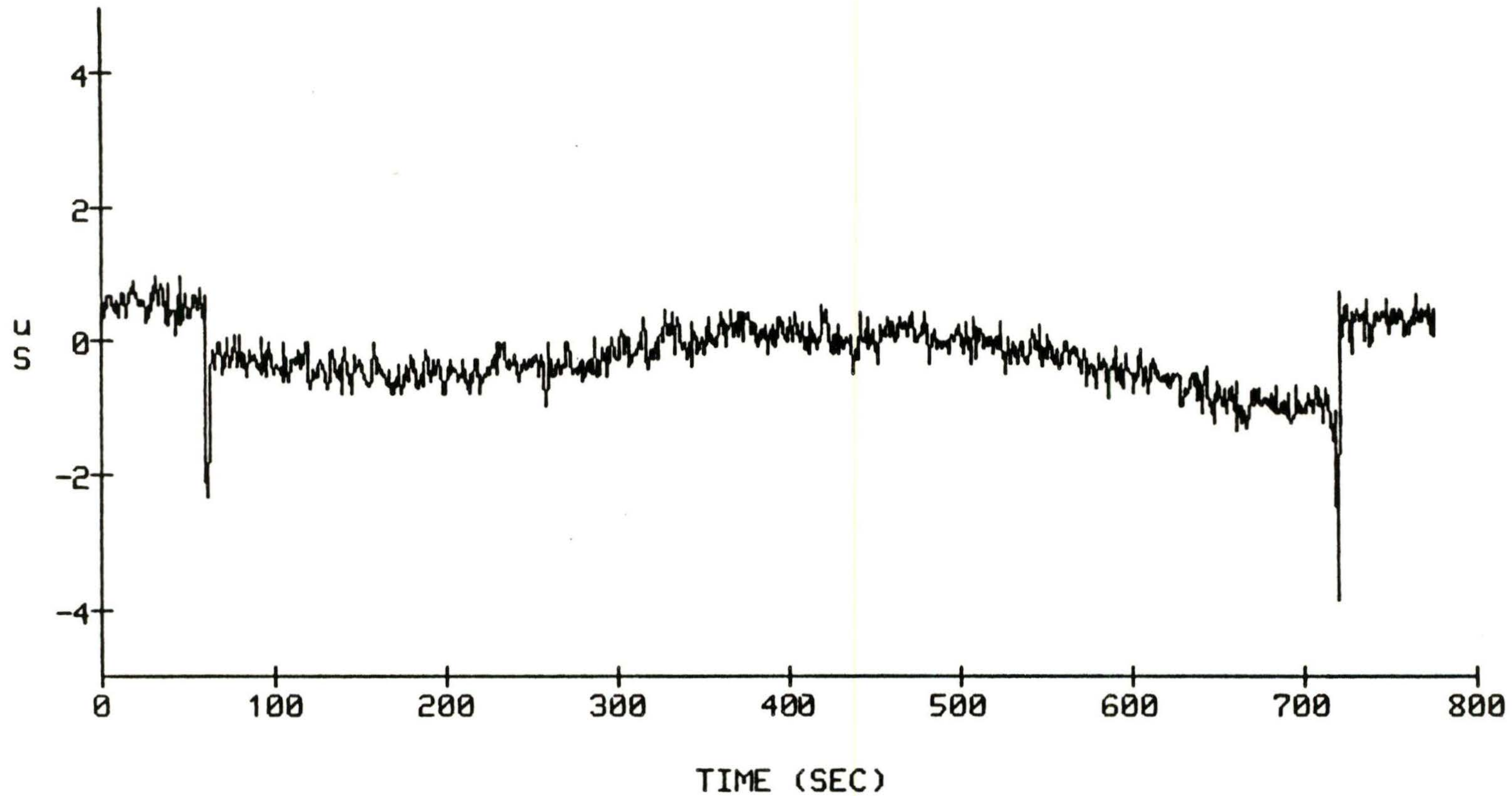

FIGURE 13 - Left front lemniscate link strain data from Data Acquisition System in mine roof simulator test.

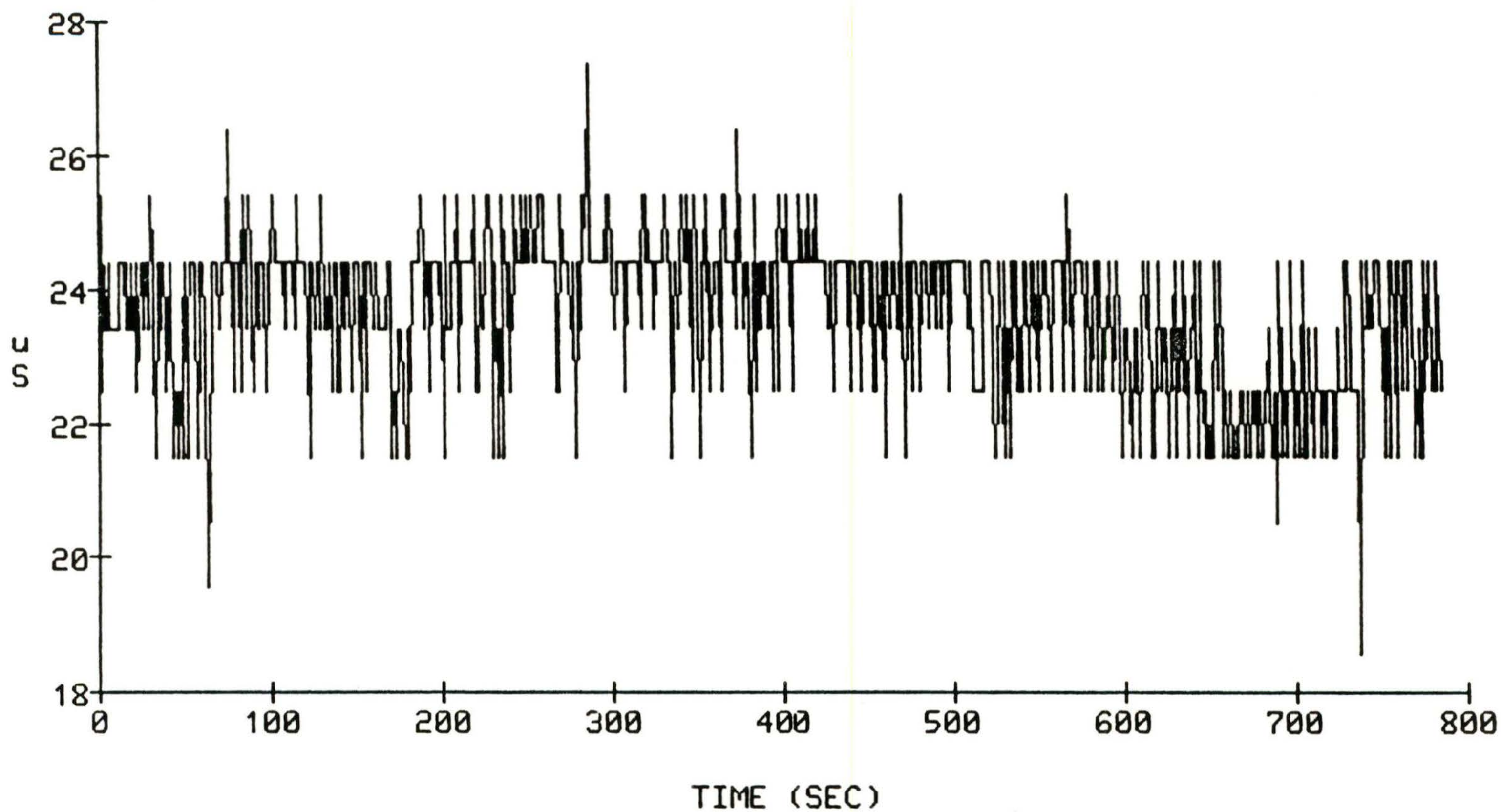

FIGURE 14 - Left front lemniscate link strain data from mine roof simulator control room instrumentation in mine roof simulator test.

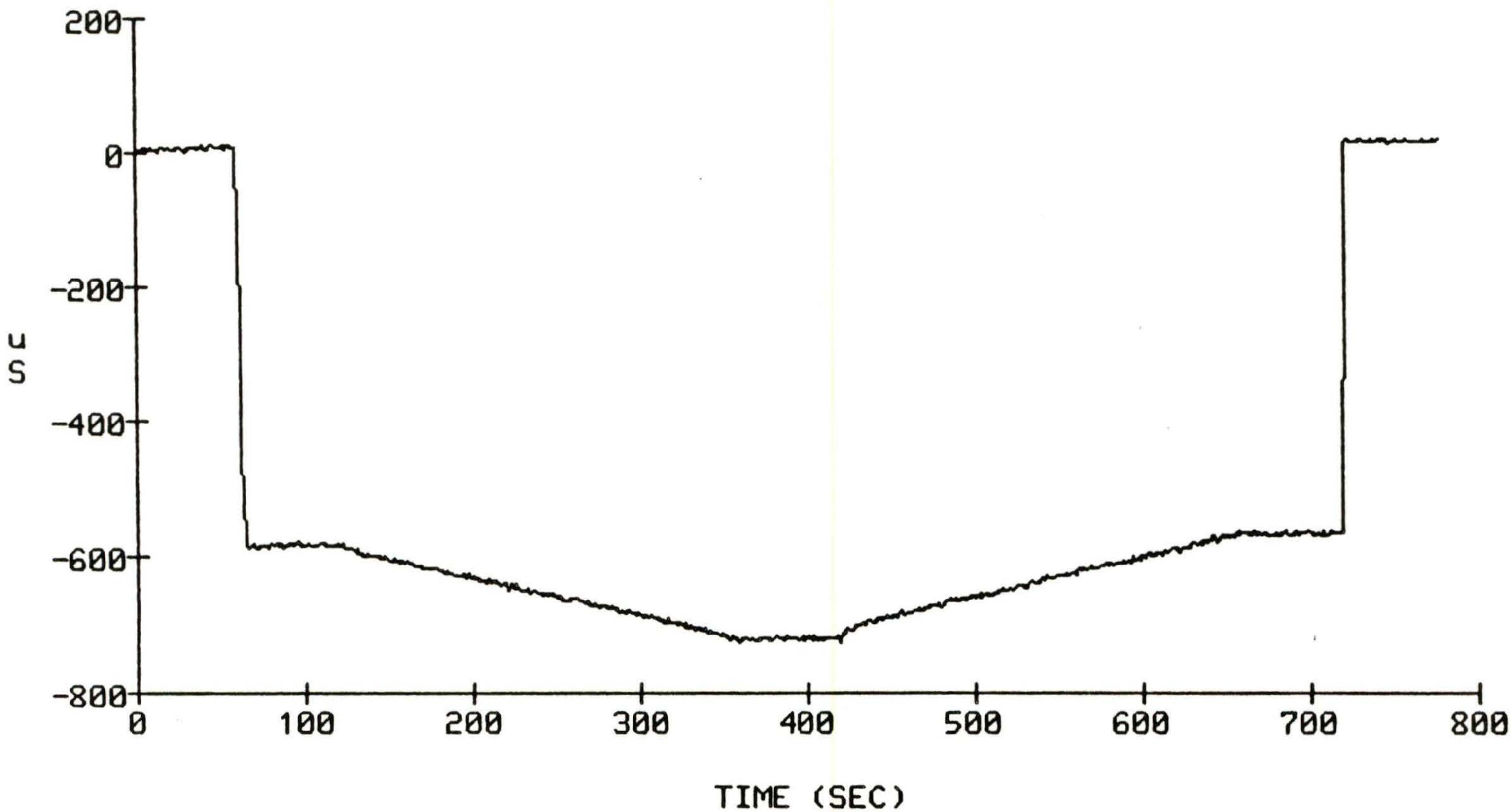

FIGURE 15 - Canopy strain (transducer A) data from Data Acquisition System in mine roof simulator test.

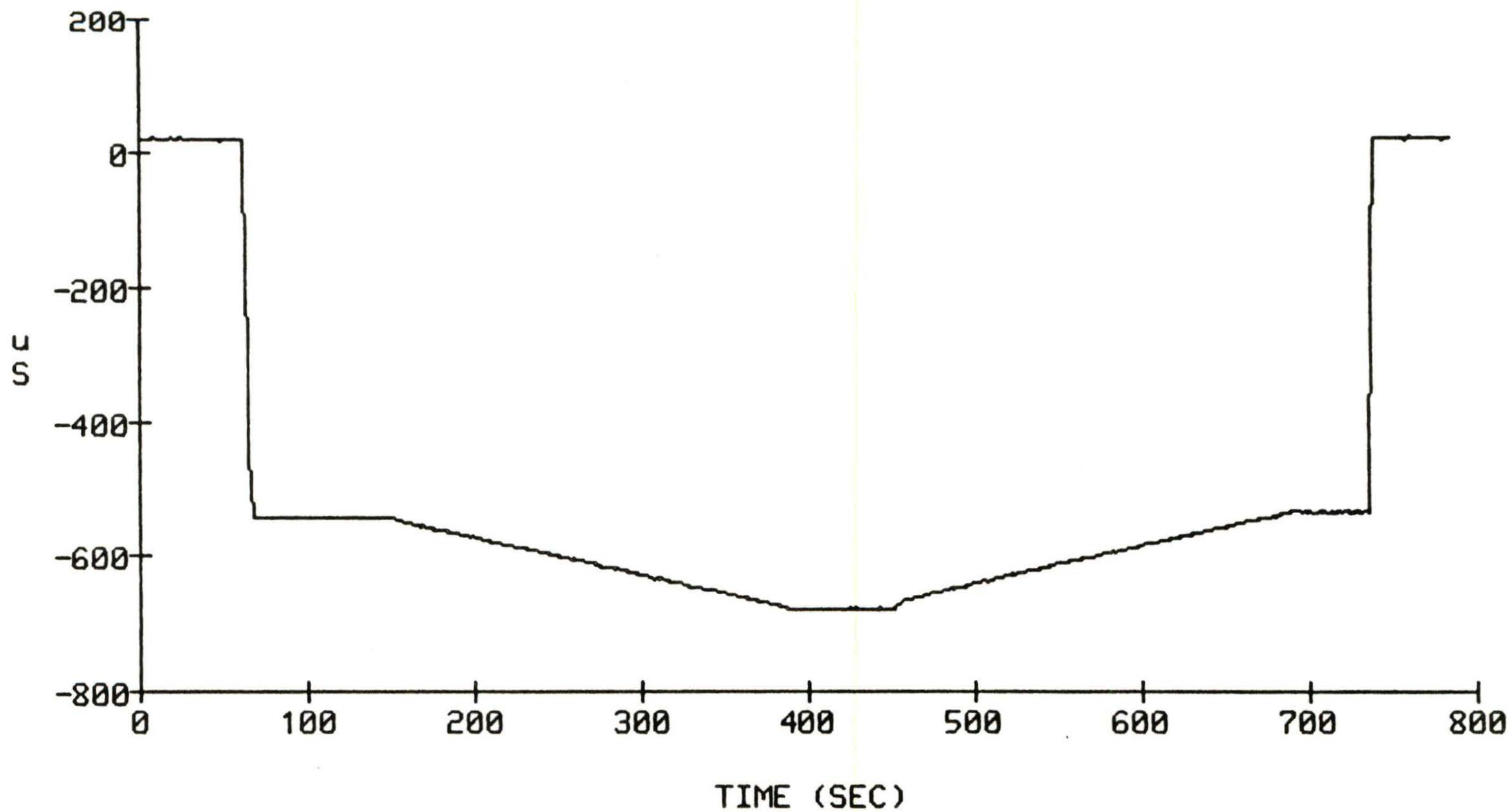

FIGURE 16 - Canopy strain (transducer A) data from mine roof simulator control room instrumentation in mine roof simulator test.

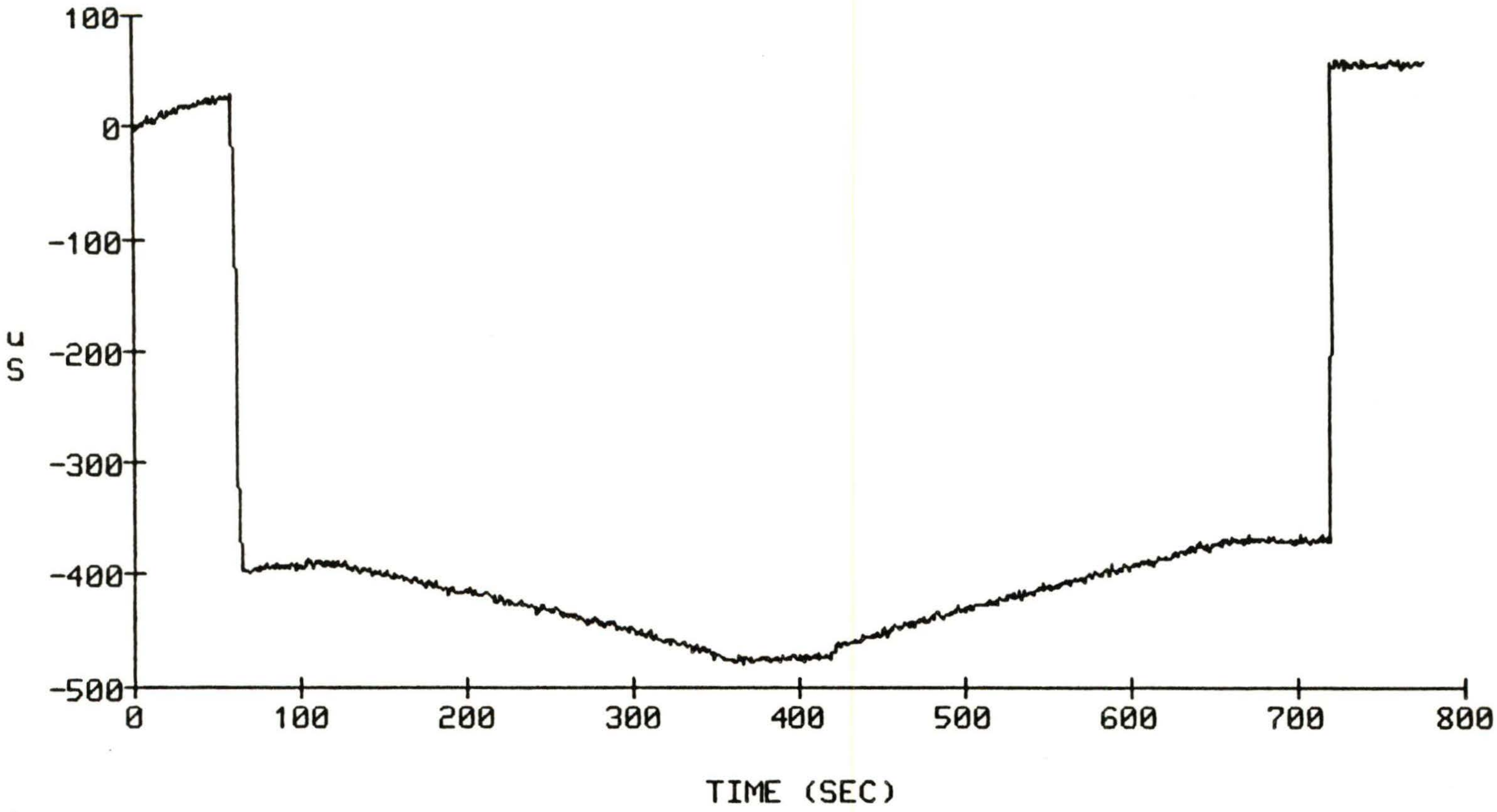

FIGURE 17 - Canopy strain (transducer B) data from Data Acquisition System in mine roof simulator test.

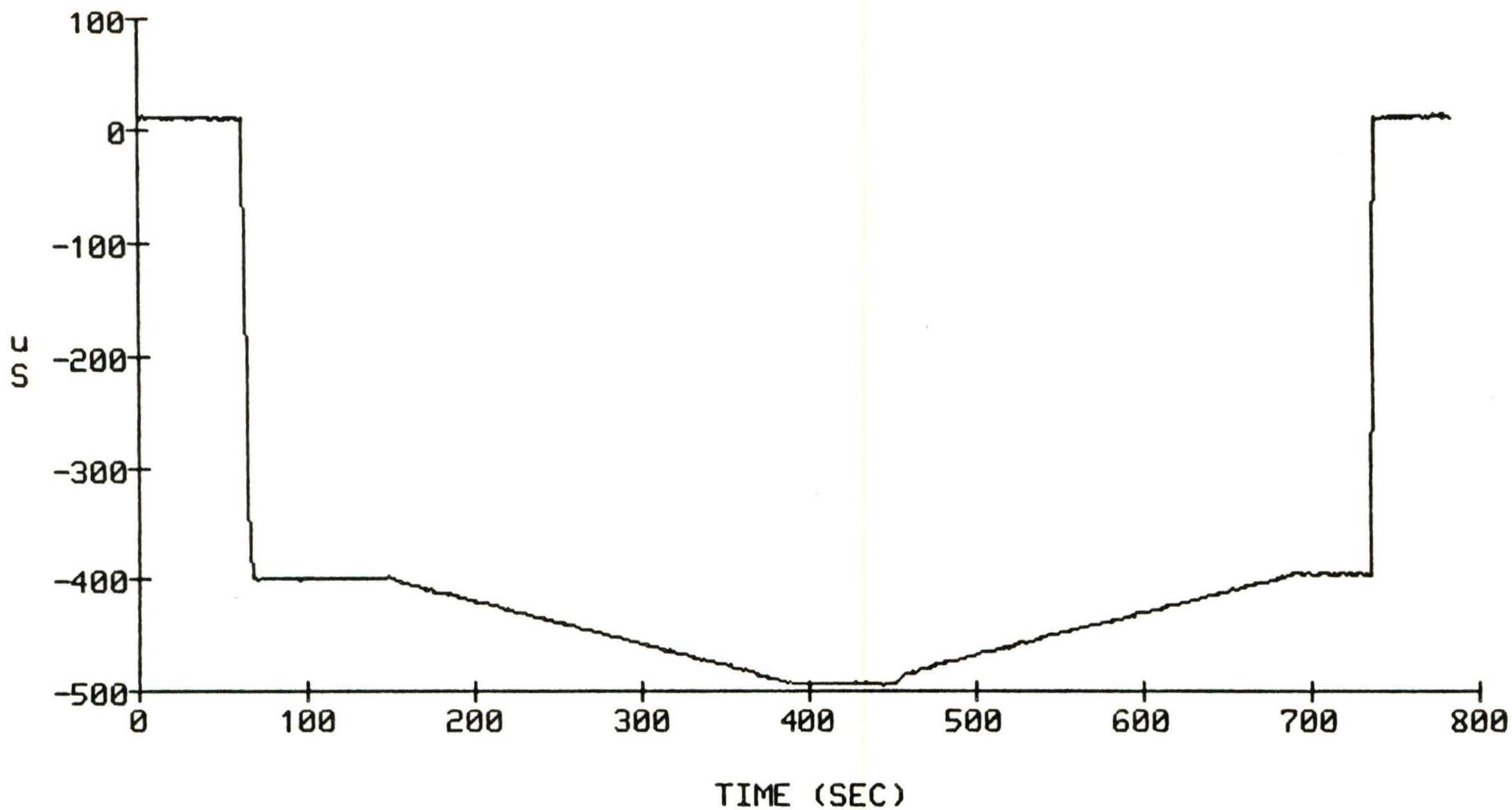

FIGURE 18 - Canopy strain (transducer B) data from mine roof simulator control room instrumentation in mine roof simulator test.

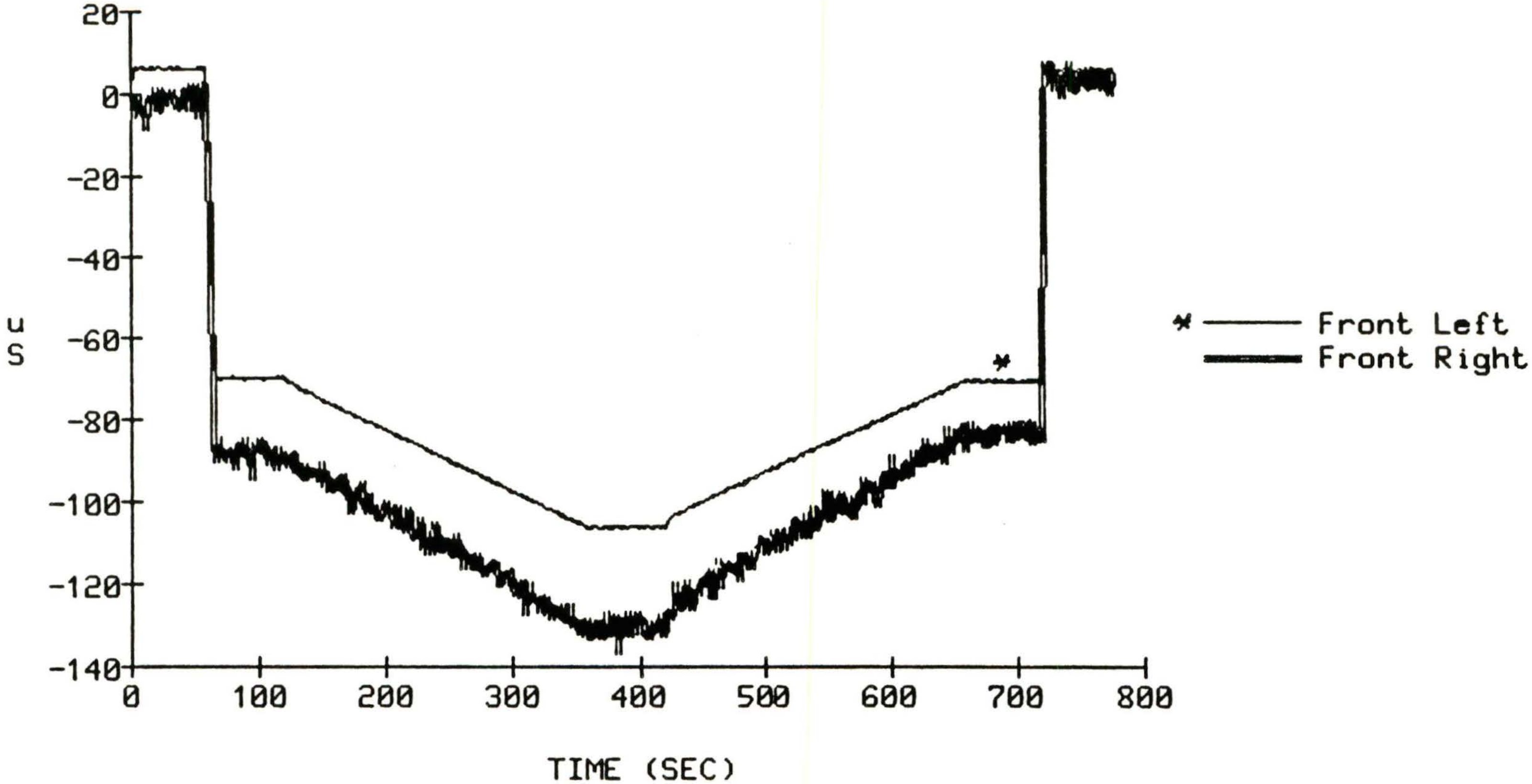

FIGURE 19 - Base strain front left and right data from Data Acquisition System in mine roof simulator test.

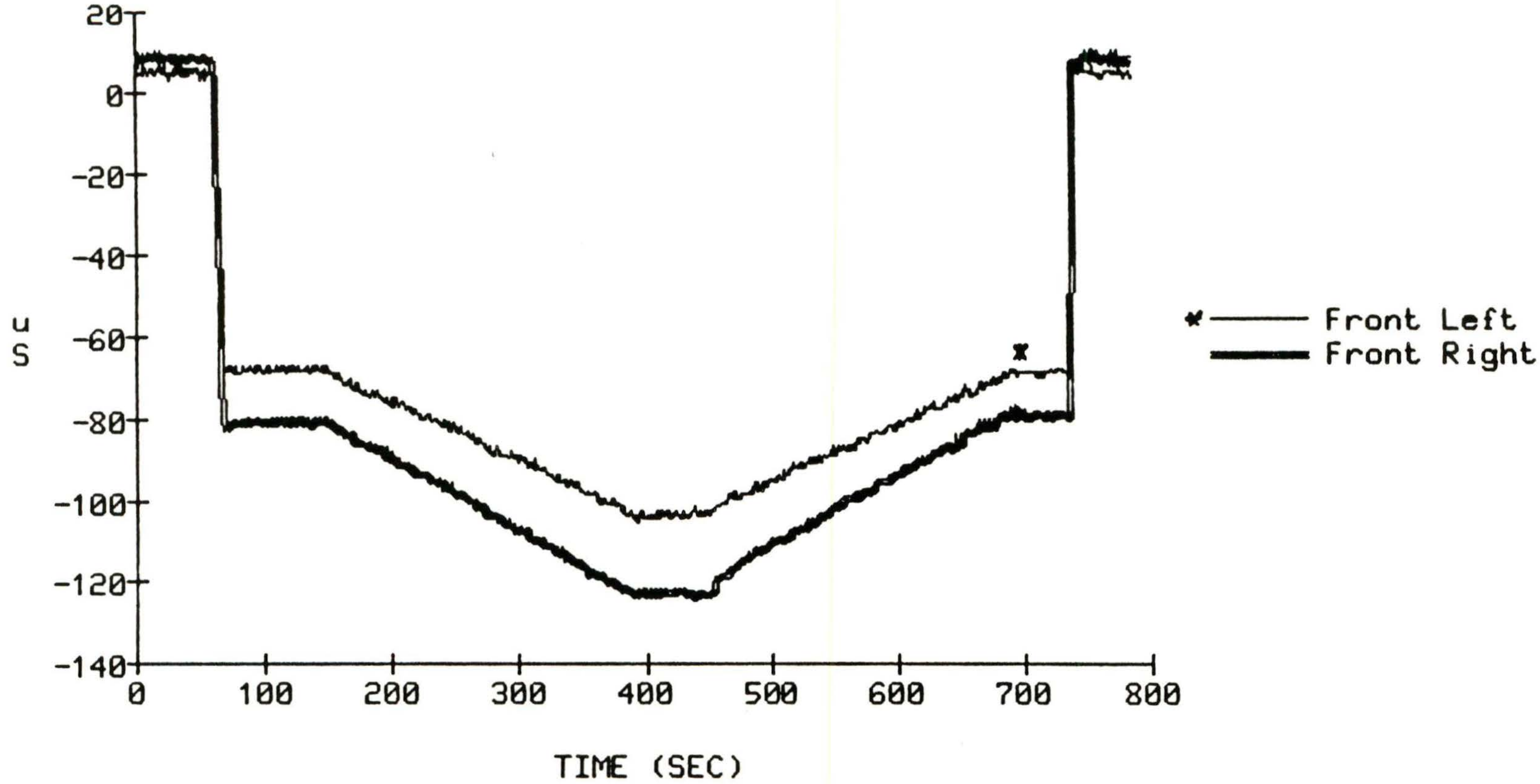

FIGURE 20 - Base strain front left and right data from mine roof simulator control room instrumentation in mine roof simulator test.

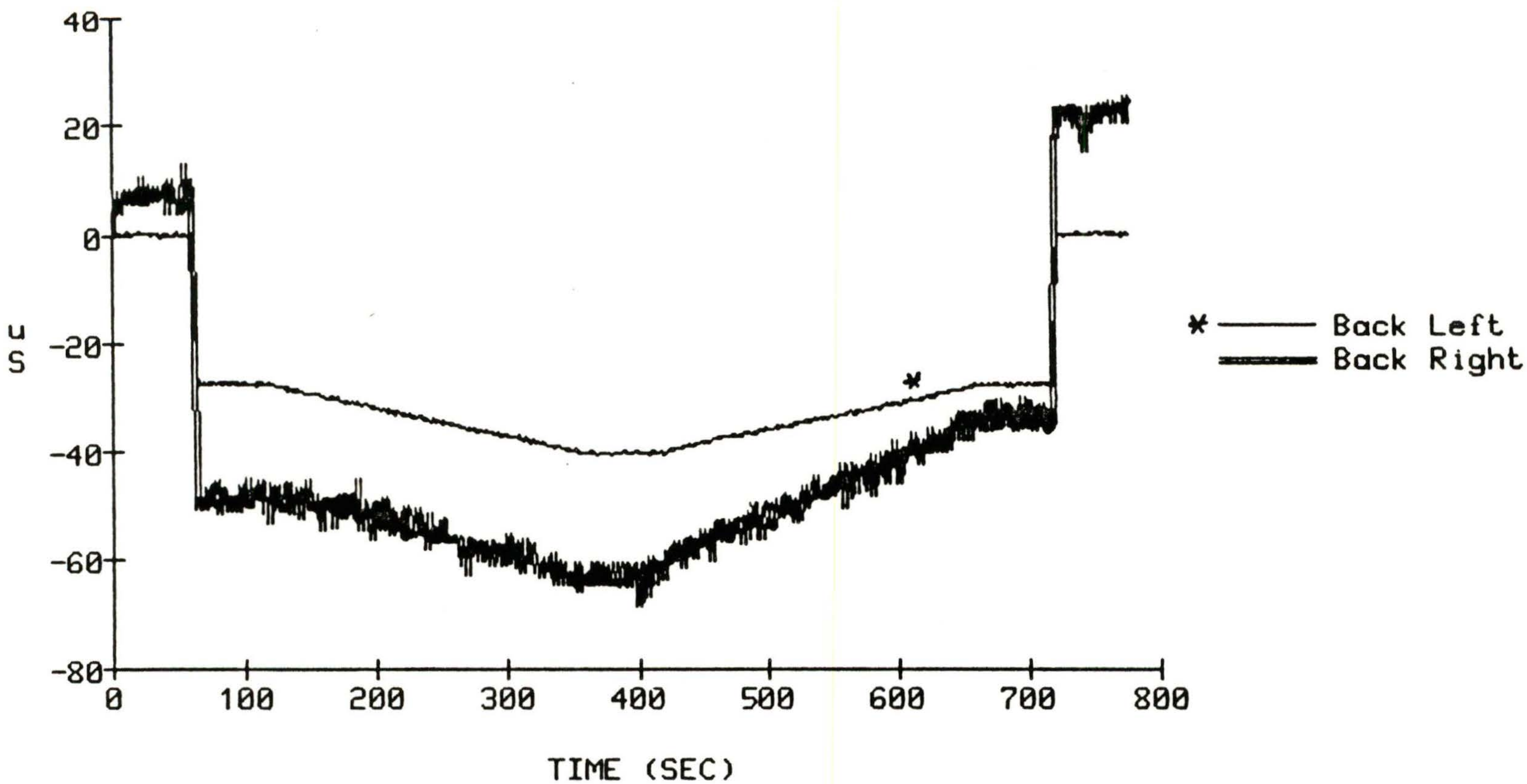

FIGURE 21 - Base strain back left and right data from Data Acquisition System in mine roof simulator test.

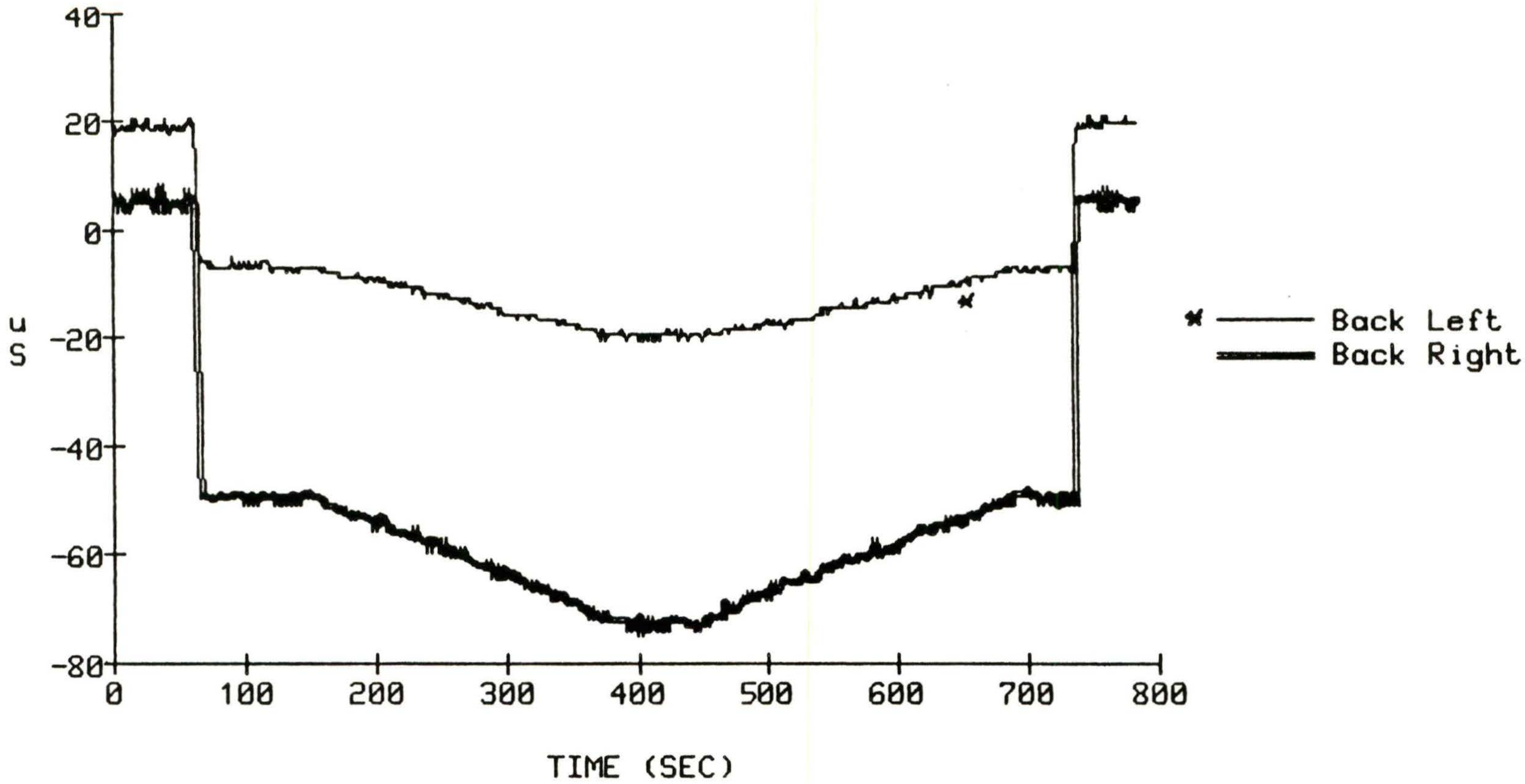

FIGURE 22 - Base strain back left and right data from mine roof simulator control room instrumentation in mine roof simulator test.

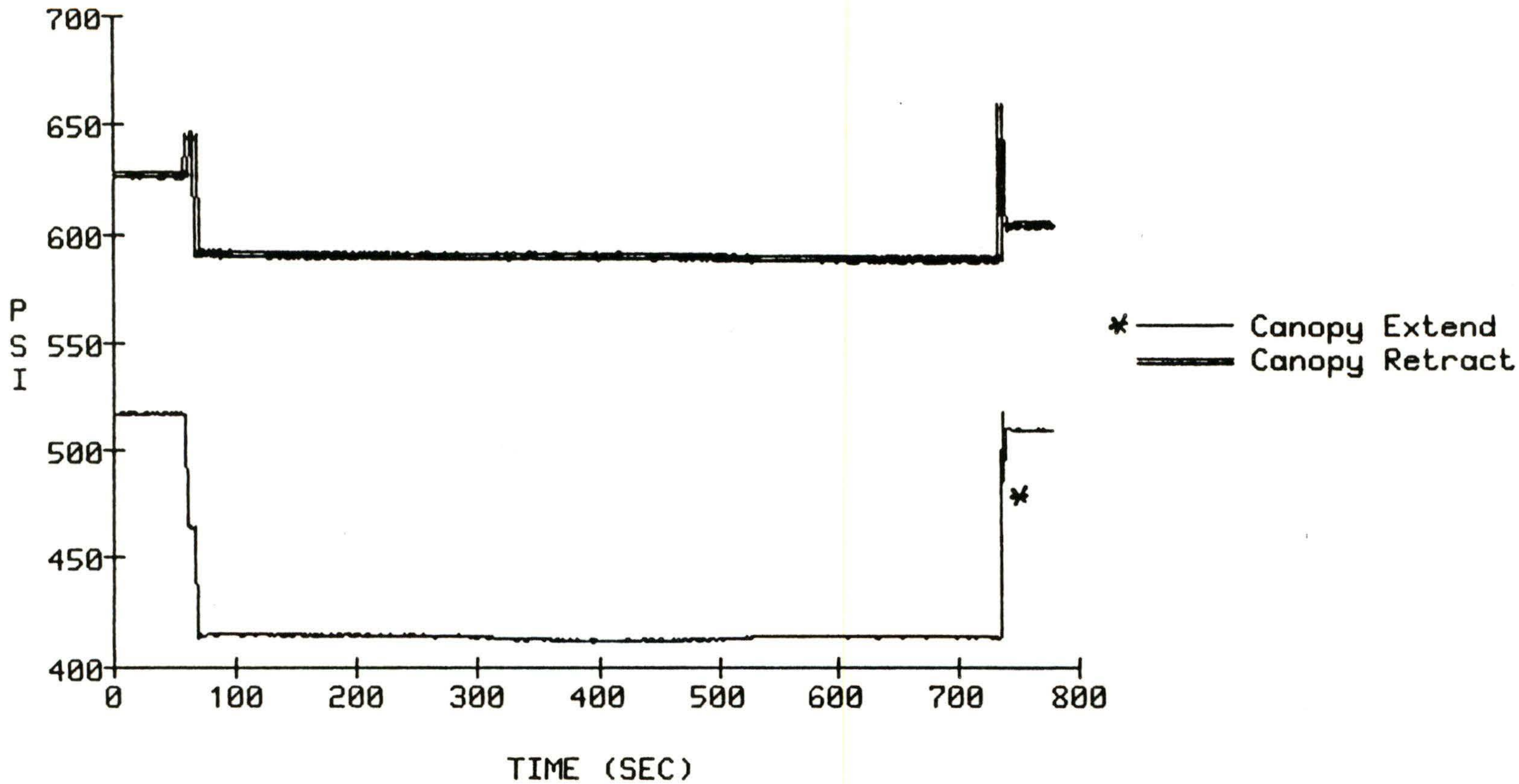

FIGURE 23 - Capsule pressure data from Data Acquisition System in mine roof simulator test.

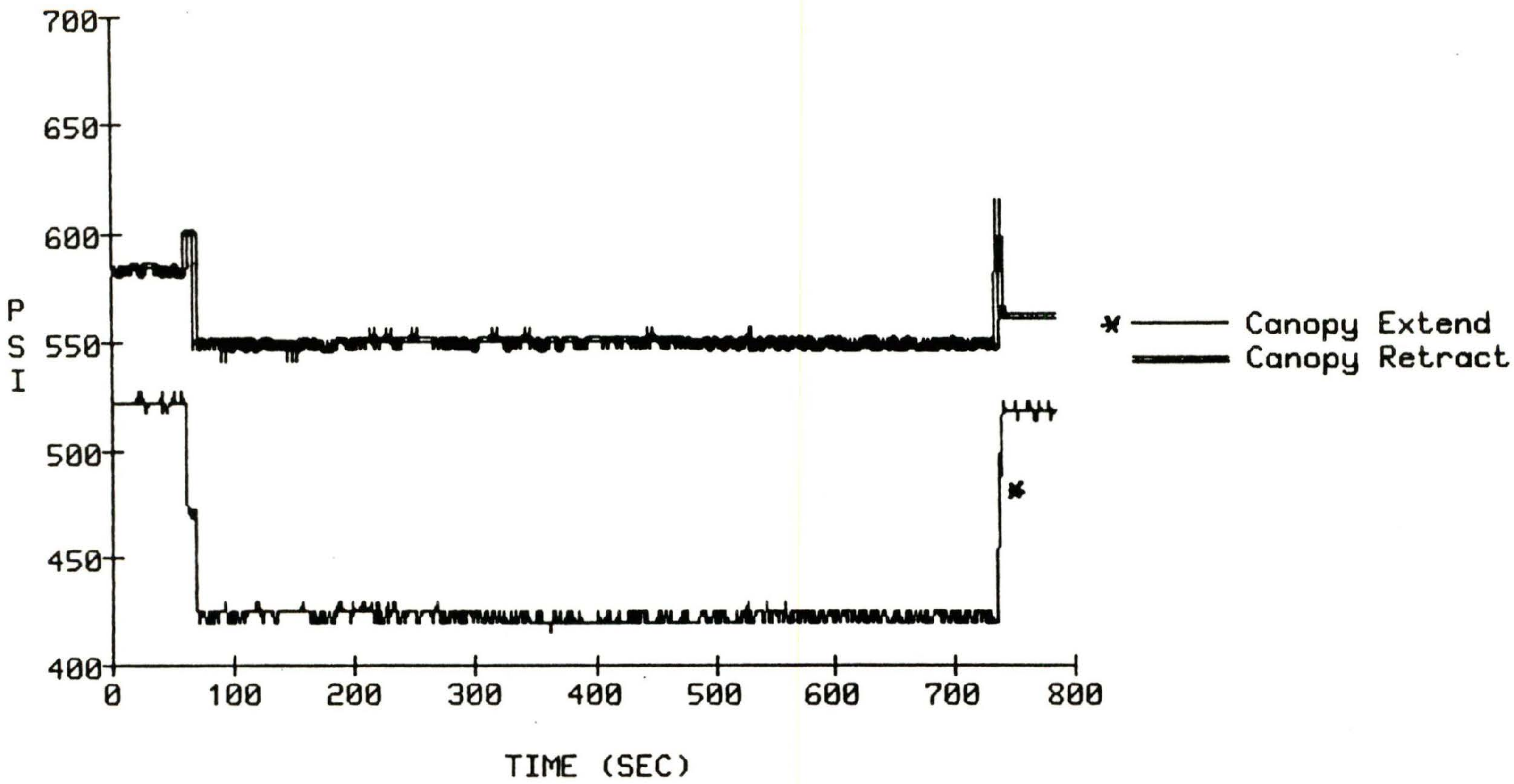

FIGURE 24 - Capsule pressure data from mine roof simulator control room instrumentation in mine roof simulator test.

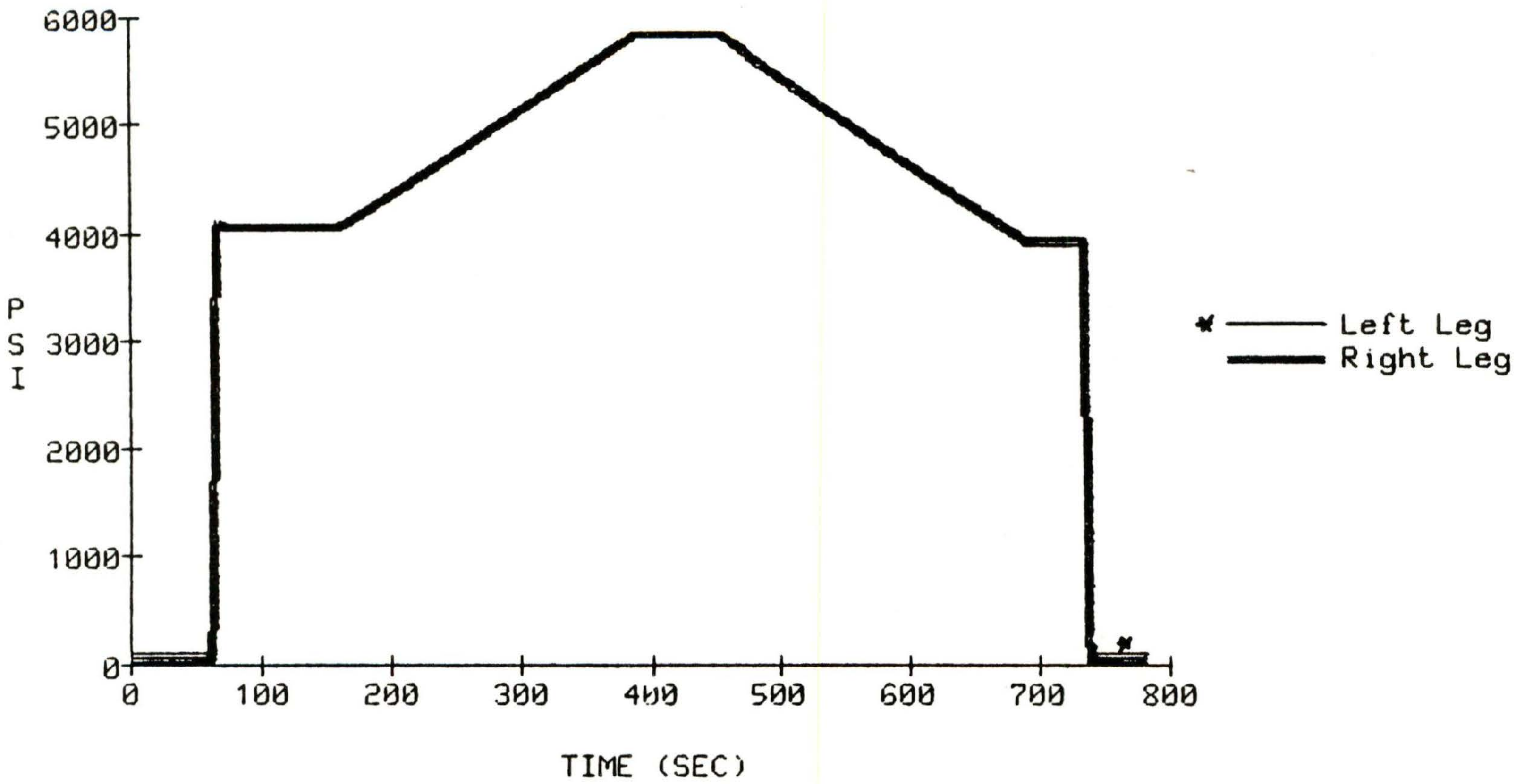

FIGURE 25 - Left and right leg pressure data from Data Acquisition System in mine roof simulator test.

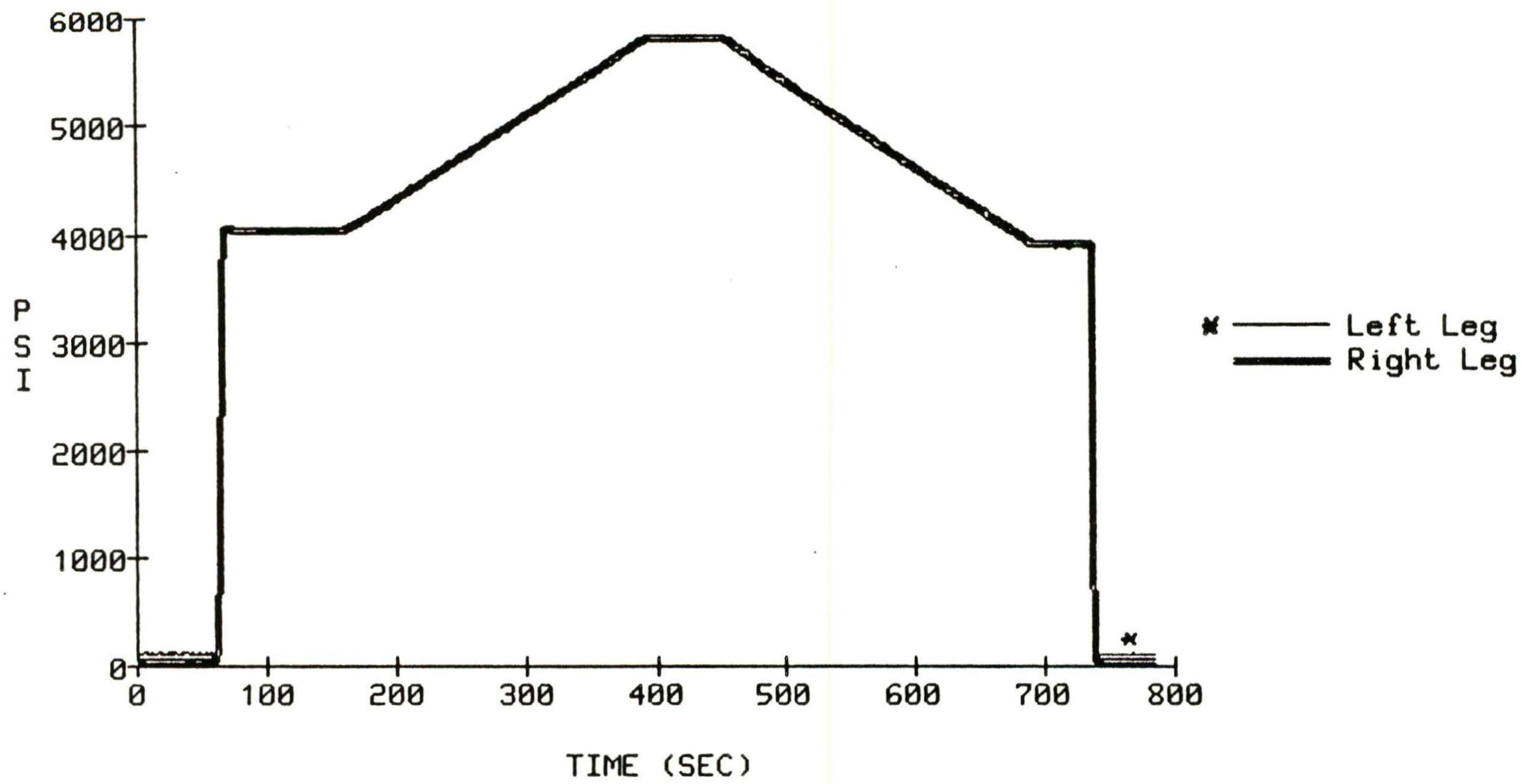

FIGURE 26 - Left and right leg pressure data from mine roof simulator control room instrumentation in mine roof simulator test.

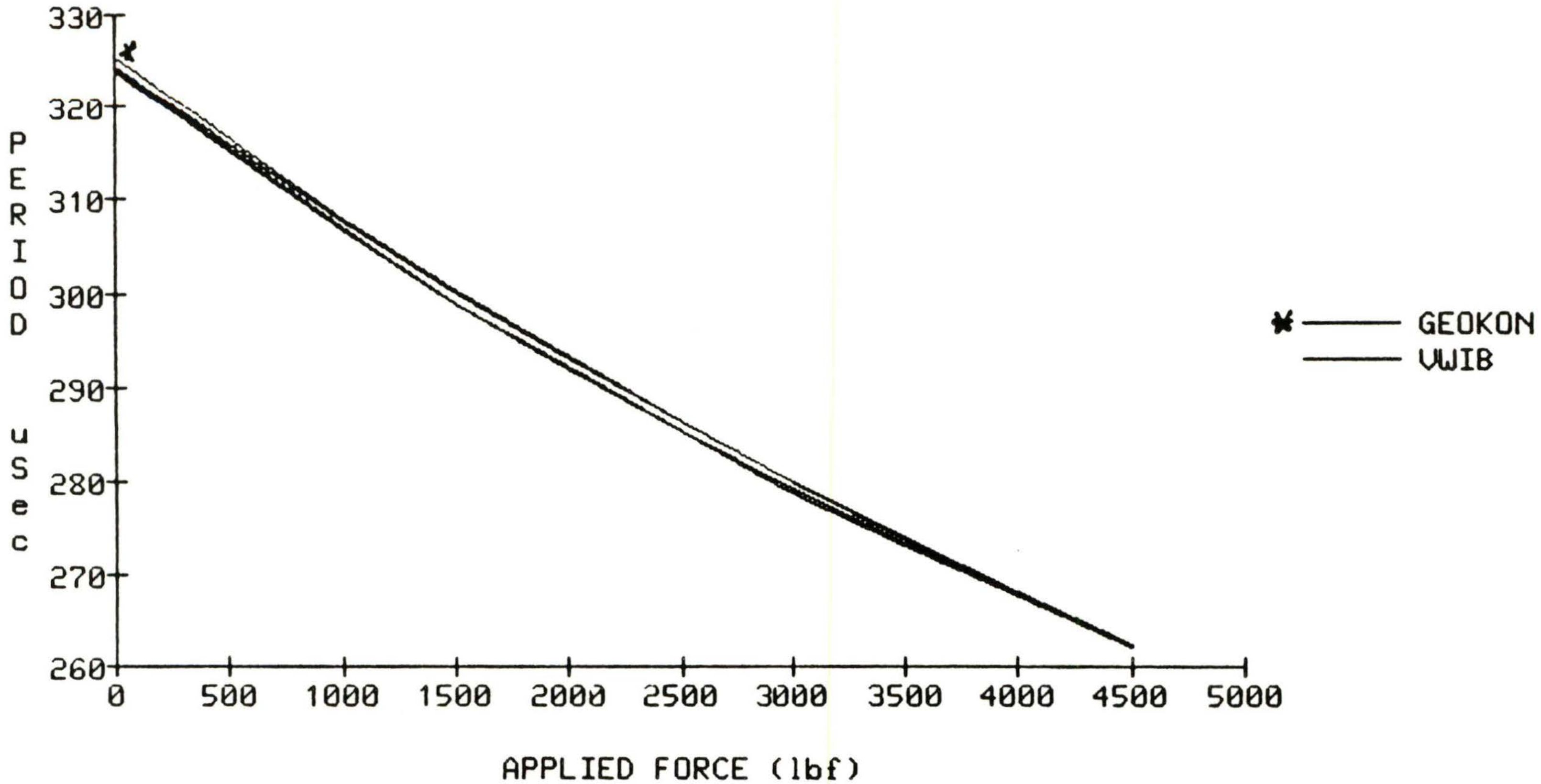

FIGURE 27 - Comparison of Vibrating Wire Input Box (VWIB) data with readings from a Geokon vibrating wire strain gage indicator. Transducer for this test was a Geokon vibrating wire stressmeter loaded in a hydraulic press.

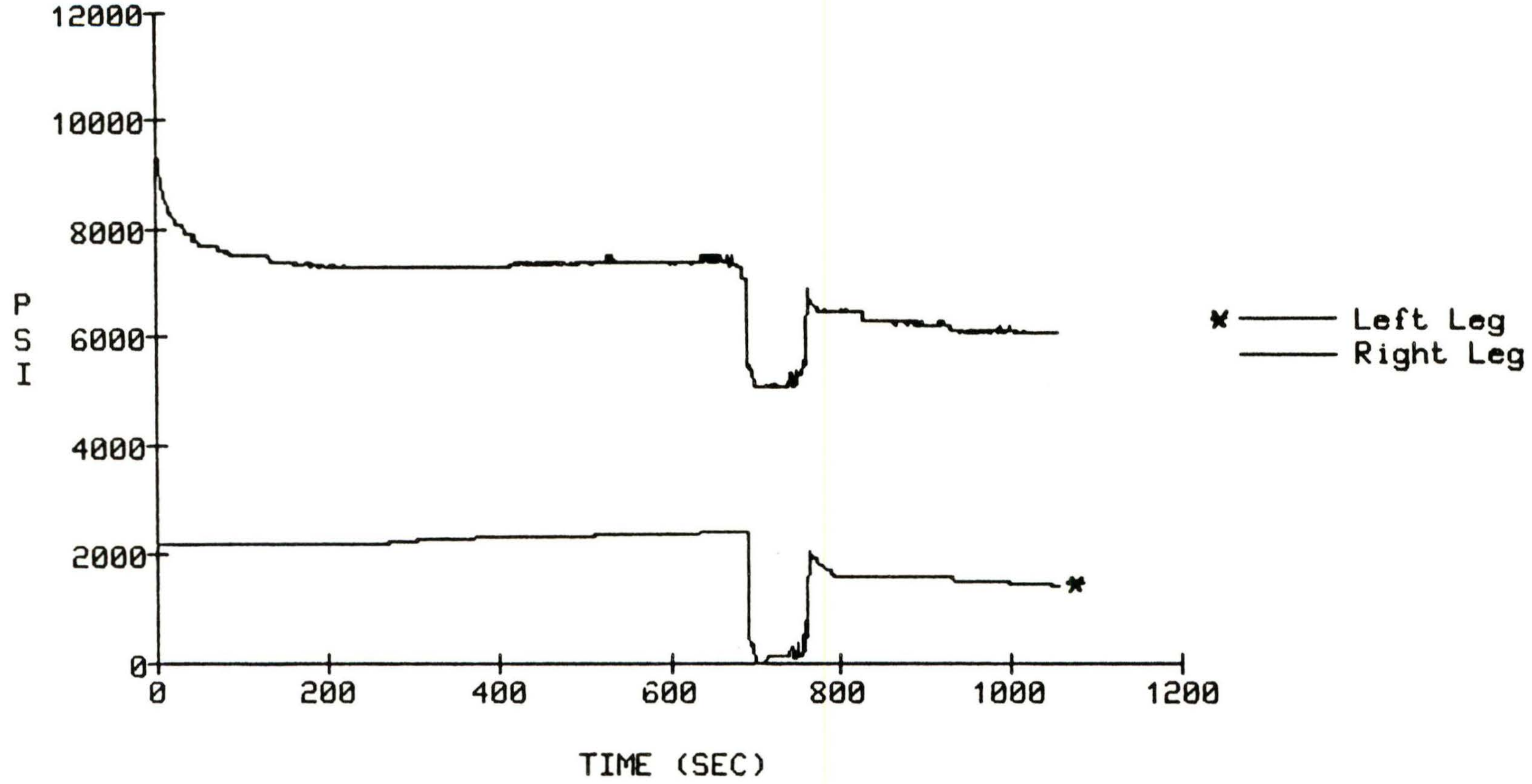

FIGURE 28 - Shield leg pressure in underground coal mine test, measurement #1

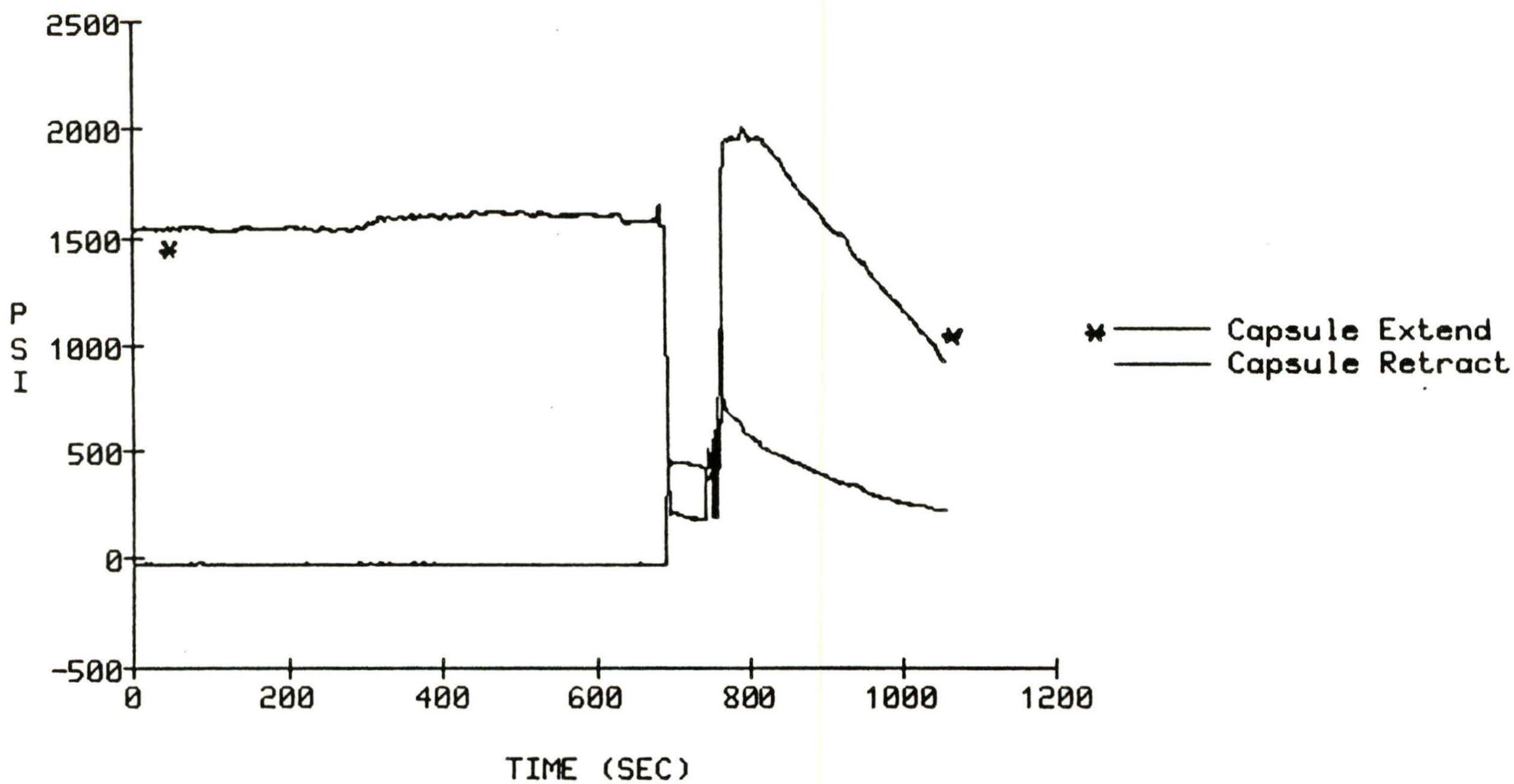

FIGURE 29 - Shield capsule pressure in underground coal mine test, measurement #1

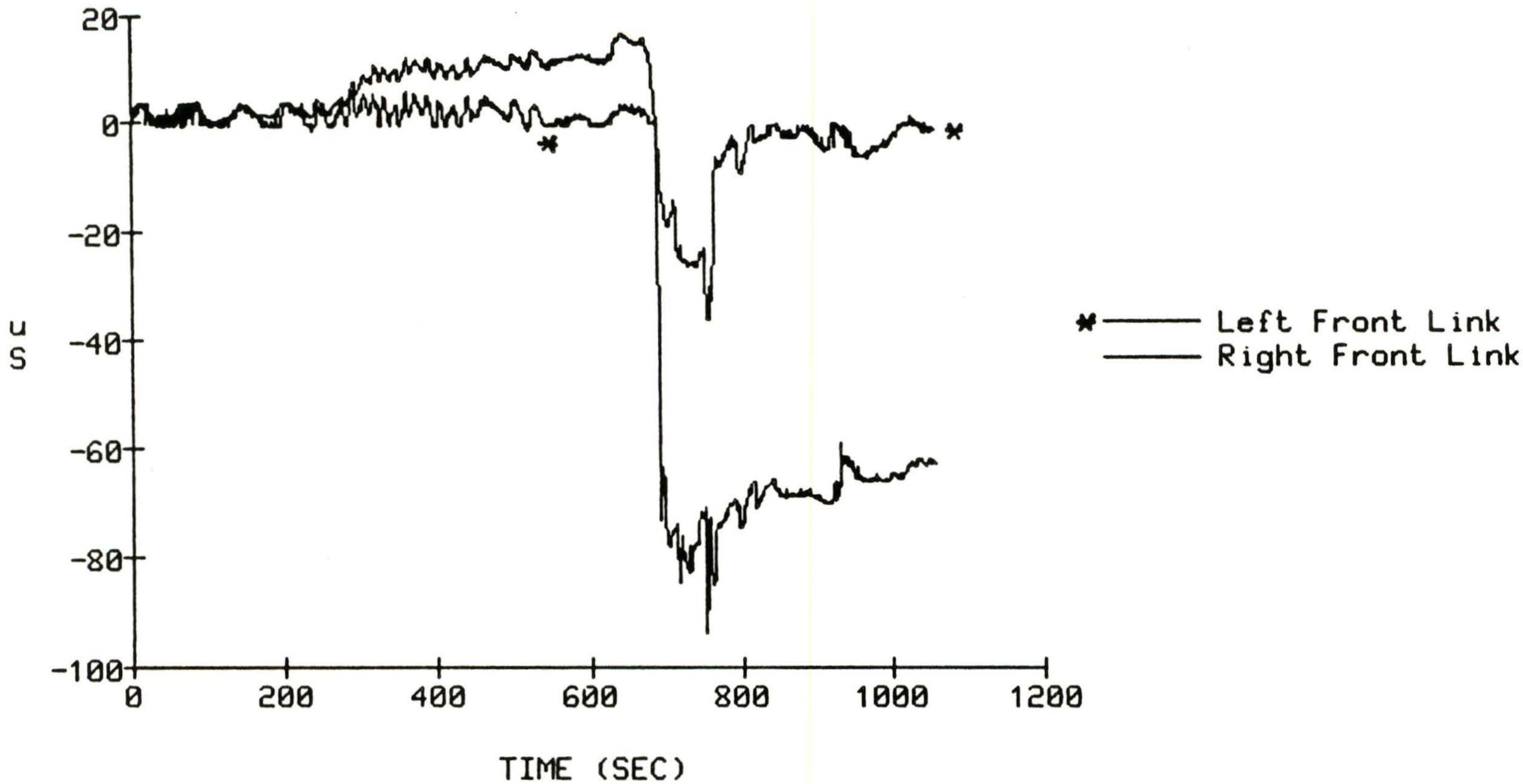

FIGURE 30 - Front link strain in underground coal mine test, measurement #1

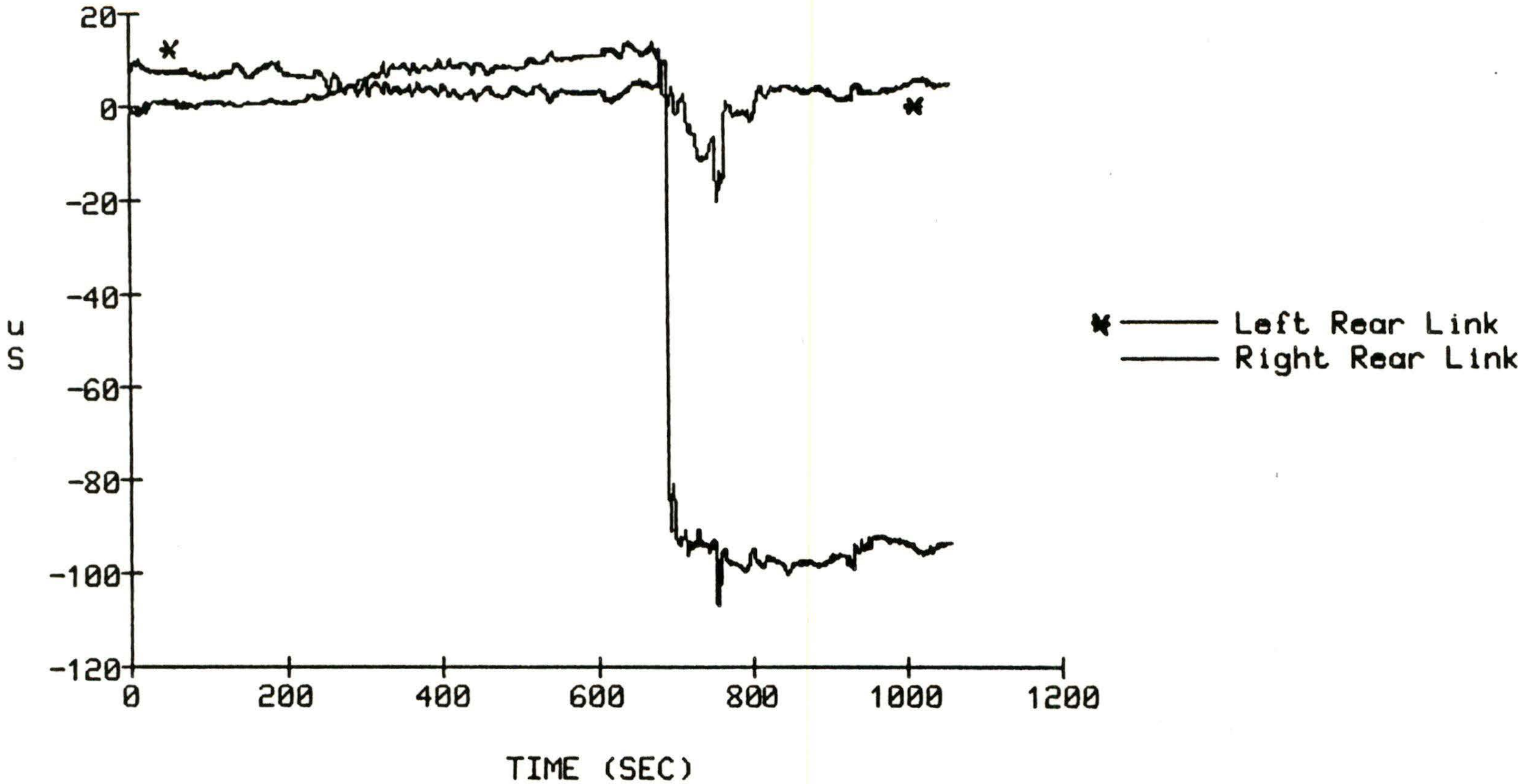

FIGURE 31 - Rear link strain in underground coal mine test, measurement #1

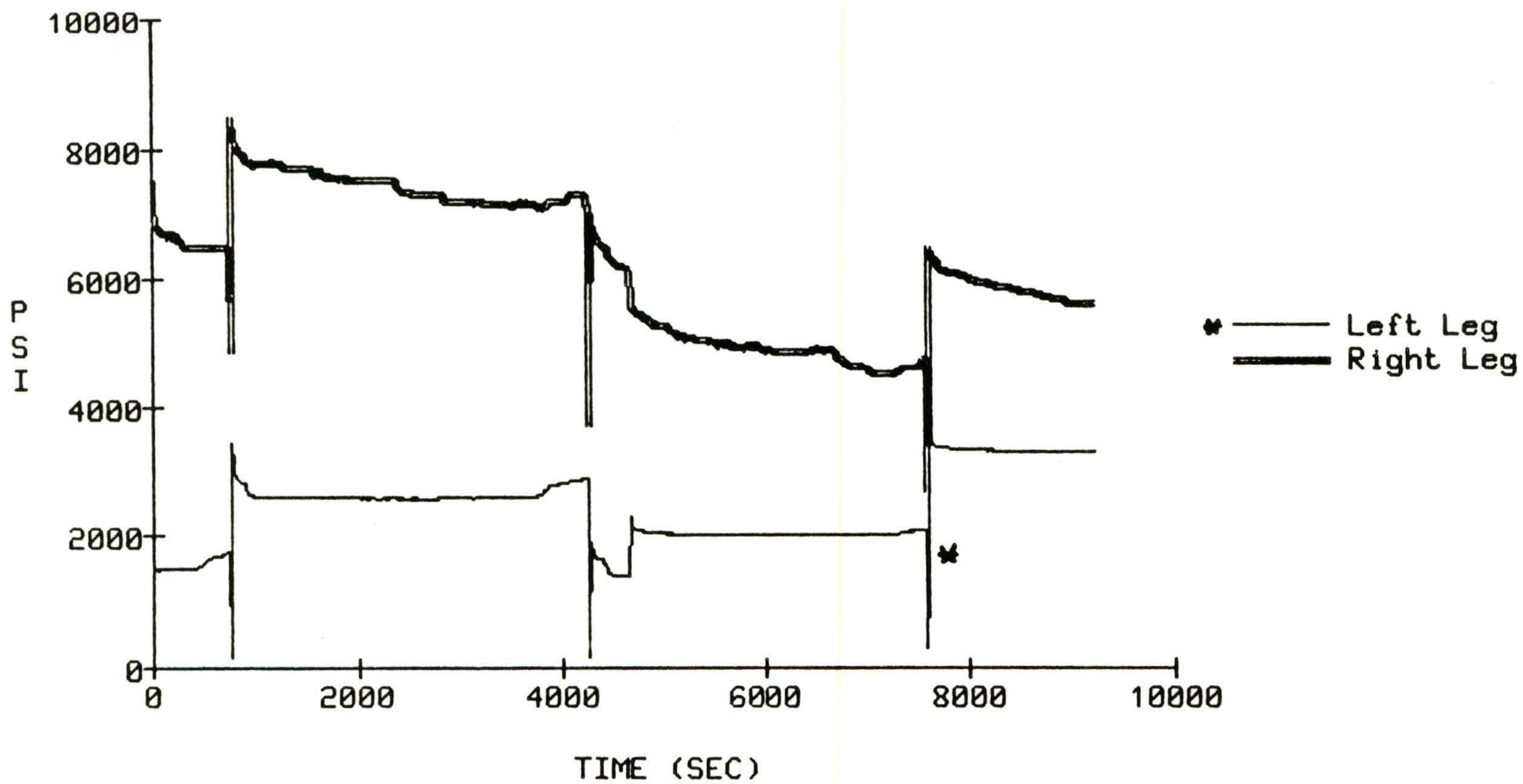

FIGURE 32 - Shield leg pressure in underground coal mine test, measurement #2

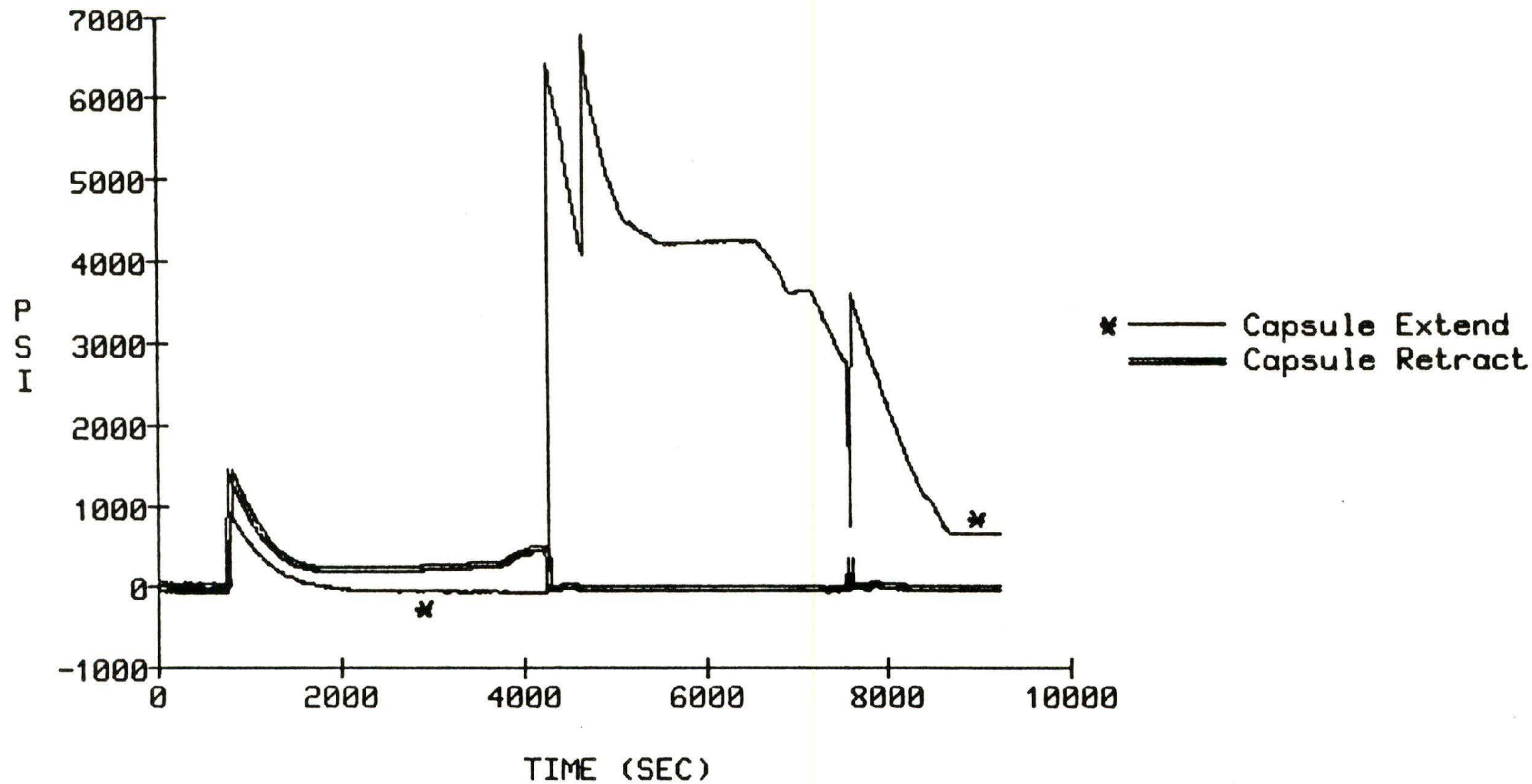

FIGURE 33 - Shield capsule pressure in underground coal mine test, measurement #2

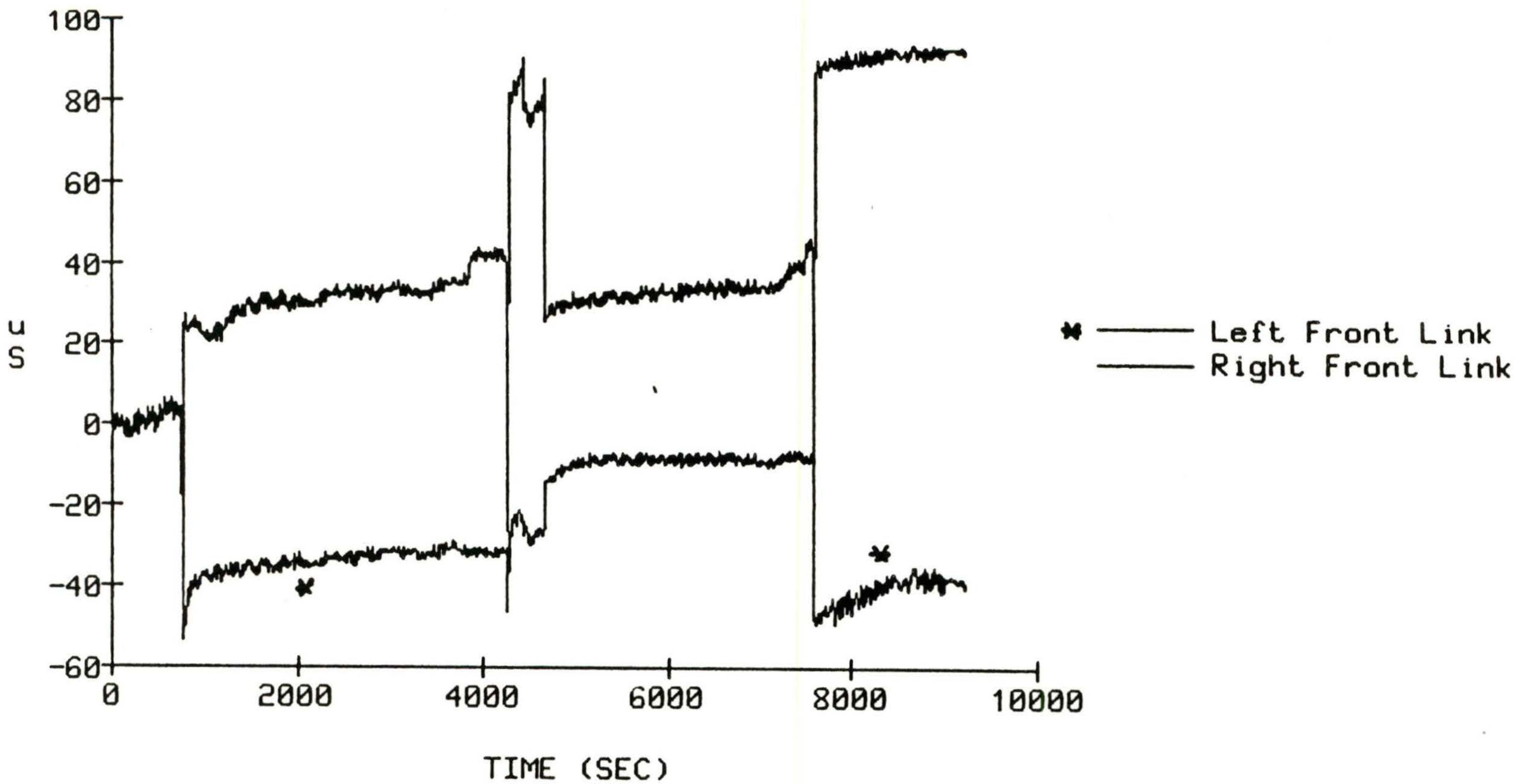

FIGURE 34 - Front link strain in underground coal mine test, measurement #2

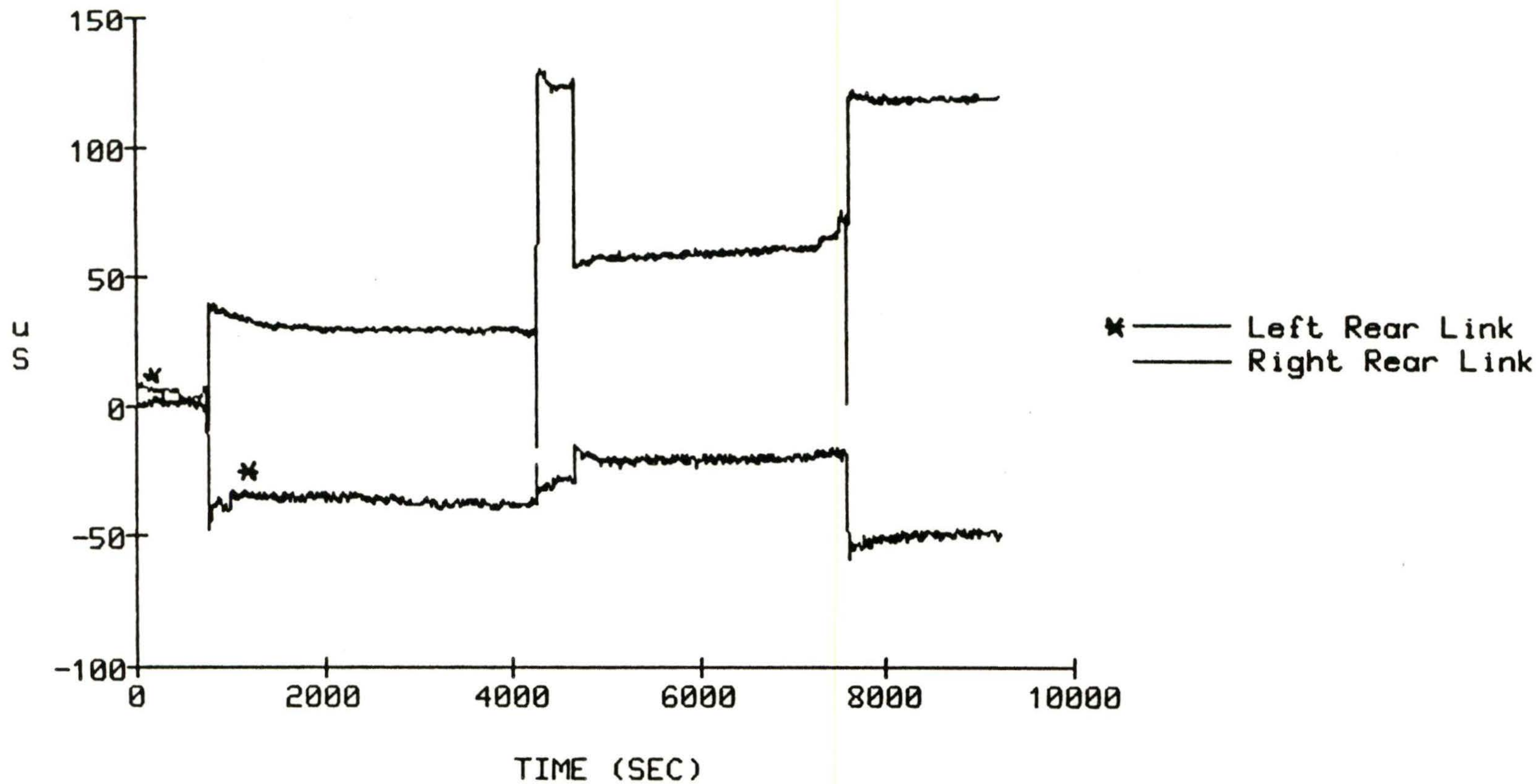

FIGURE 35 - Rear link strain in underground coal mine test, measurement #2