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Preface

The EE Department Quarterly Report has two purposes—to inform readers of various activities within the Department and to promote the exchange of ideas.

The articles, by design, are brief summaries of EE work. For further details on a subject covered, please contact one of the authors listed at the bottom of the first page of the article. The authors are primarily responsible for the content of the article. Inasmuch as most projects are the result of the cooperative efforts of many individuals, the person you contact may either provide the requested information directly or refer you to the appropriate person to answer your question.

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Ultrasonic thermometry in oil shale retorts

The delay in reflection of an ultrasound pulse from a discontinuity in a metal sensing element is a function of temperature. We use this effect to measure temperature ranges to 1000°C in several zones in oil shale retorts.

For in situ oil-shale retorting, the retort temperature profile is a vital process parameter requiring continuous monitoring. Many sheathed thermocouples, each having long cables, are currently used to monitor the temperature. However, the expensive thermocouples fail at a high rate, because the environment is extremely hostile. Not only are there rigorous thermal, chemical, and mechanical stresses acting on the instruments once they are in place, but the emplacement process itself may also produce severe stresses. Because of these conditions, very rugged instruments are needed.

Temperature and position, however, require only moderate accuracy—temperatures can be accurate within 25 to 50°C and positions within 1.5 to 3 m. The ultrasonic thermometer is a good candidate for these functions.

The sensor for the ultrasonic thermometer is an inexpensive, thin rod. Although the rod must be isolated from external forces by a sheath, it is flexible and can be bent or curved without affecting its performance. Also, the single transducer that drives this sensor rod can survive a moderately hostile environment. Because the sensor rod may have up to 16 temperature zones along its length, a 16-region profile of the temperature distribution in a retort can be obtained from a single coaxial cable. In addition, we can measure accurately to ±50°C. Thus, the detector system is simple, inexpensive, and rugged, it minimizes the number of cables needed, and it has sufficient accuracy for in situ measurements.

Ultrasonic thermometry technique

Ultrasonic thermometry is based on the principle that the velocity of sound in a medium is a function of the temperature of the medium. In most solids, as the temperature increases, the velocity decreases—primarily because the modulus of elasticity decreases. One can determine the temperature of a particular region by measuring the time it takes ultrasonic vibrations to travel along a previously calibrated rod (waveguide) in the region under consideration—i.e., by ultrasonic thermometry.

The pioneering work was reported by Bell in 1957. The concept was extended by Panametrics (Panametrics, Inc., Waltham, MA) to multiple zones, and they have been developing and producing commercial versions of ultrasonic thermometry systems since the late 1960s under the direction of Lynnworth.

The multiple-zone technique operates as follows: low reflectivity discontinuities are placed at regular intervals along the total length of the sensor. The time intervals between successive echoes can then be interpreted as temperatures along the waveguide path. The resulting profile represents the average temperature at each zone.

The detector consists of two basic elements (Fig. 1): the sensor and the transducer.

The sensor

The sensor is the element through which the velocity of sound, as a function of temperature, is measured. It is typically notched at the zone boundaries, creating discontinuities.

When the acoustic pulse is transmitted, the notches cause reflections to echo down the element toward the transmitted end. The signal must make a round trip through the temperature zone; therefore, the time intervals between the reflected signals are equal to twice the transit time of the ultrasonic pulse in the specific zone.

The sensor material may also be used to transfer acoustic pulses between a remote transducer and the active area of the sensor (lead-in). However, other material may be used for this lead-in function, depending on the specific arrangement needed for the ultrasonic thermometry.

Transducer

The transducer is an electro-acoustic converter. When electrically energized, it acts as a
transmitter and sends an acoustic pulse down the sensor. The reflected acoustic echoes return to the transducer, which now acts as a receiver and converts them back into electrical signals.

The transducer consists of three major components:

- A solenoidal coil that converts the electrical current into a magnetic field during transmission and vice versa during reception.
- Ferromagnetic magnetostrictive material—a cobalt-iron alloy that deforms when subjected to a magnetic field.
- A permanent magnet. It emphasizes the longitudinal mode of the magnetostrictive material.

The electronics for an ultrasonic-thermometer consists of a pulse generator to interrogate the transducer by sending the ultrasonic pulse down the sensor, a receiver that amplifies and filters the reflected signals, and a mechanism to measure the time interval between these reflected signals. This mechanism can be as simple as an oscilloscope readout or as sophisticated as a computer-controlled digital time intervalometer.

The ultrasonic temperature-measuring technique has some important features:

- The sensor rod is acoustically isolated from surrounding material. If it is not, extraneous echoes can be created that make zone delineations very difficult.
- Attenuation of sound in the sensor and lead-in element increases with temperature.

Therefore, if a very long acoustic waveguide is located at elevated temperatures, the reflected signals may become indistinct as the signal-to-noise ratio decreases.

- The temperature measurement is an average over the entire length of a zone and not a point temperature, as is the case with thermocouples.
- In many cases, particularly for higher-temperature operations, the sensor material may have to be tempered before it can be calibrated and used.
- Some of the most desirable sensor materials, from a temperature standpoint, exhibit a hysteresis-like effect of the transit-time temperature curve when going to very high temperatures. (This problem is discussed below.)

Instrumentation

The experimental setup we used contains three major components (Fig. 2): the detector, the signal processor, and a standard oscilloscope.

Detector

Two different detectors were used in our experiments. The first was a commercial unit and consisted of a transducer housing that drove a 2-cm long magnetostrictive stub. The stub was brazed to a 1.6-mm-diam, 1.4-m-long, 304SS sensor rod. The first notch on the rod was cut 29 cm
from the magnetostrictive stub to the rod joint. Notches were then cut every 7.5 cm along the rod to 1.2 m, resulting in a total of 13 notches or 12 temperature zones. The rod was sheathed with a 304SS tube. The magnetostrictive stub and part of the rod fit inside the transducer housing, leaving the sheath 1 cm longer than the rod at the far end. The tube was open at that end but could be closed, if desired, to keep out contaminants that might affect rod characteristics.

The second detector we employed was constructed at Lawrence Livermore National Laboratory using the transducer housing from the first detector. The magnetostrictive stub was removed from the first sensor rod and brazed to a 1.6-mm-diam. 2-m-long rod of Kanthal A-1 (The Kanthal Corporation, Bethel, CT)—an Fe, Cr, Al, Co alloy that has a melting temperature of 1510°C and is typically used as heater-element material in high-temperature furnaces. The rod was notched at 38 cm and again every 15 cm to 1.9 m. These 11 notches gave 10 temperature zones. The rod was sheathed by a tube of 304SS, which was 2 cm longer than the rod. The tube was capped at the far end.

**Signal processor**

The signal processor was a pulser/receiver designed originally to operate with piezoelectric transducers; but it worked quite well with the electromagnetic transducer we were using. The initial pulse, generated by the pulser and applied to the transducer, was negative-going, 300 V, and 20 ns wide. The reflected pulses from the discontinuities of the zone boundaries had amplitudes of 1 mV at the transducer. (In contrast, the reflected pulses from the end of the sensor had a first-time reflection amplitude of 20 mV.) The pulses reflected from the zone boundaries were about 50 mV at the output, after being filtered and amplified by the receiver. These pulses were then displayed on an oscilloscope; the time interval between them could be determined to within 100 ns.

**Detector calibration**

The detectors were calibrated in a high-temperature furnace. Because of the size of the furnace, only 14 cm of probe could be placed inside. The zones of the 304SS detector were 7.5 cm long, and could be centered in the furnace, allowing for a 3-cm buffer on each end of the zone to the thermal gradient at the furnace wall.

The calibration curve for zone 6 of the 304SS detector (Fig. 3) is typical of the other zones. The solid dots are for points obtained from the first temperature cycle. All the other points are from subsequent cycles. Notice the hysteresis-like effect that occurred when the sensor was heated the first time and that with this sensor rod, the sound transit-time decreased after the initial heat up.

Because the temperature zones for the detector made of Kanthal were longer than our furnace could handle (15 cm), we constructed a duplicate.
sensor rod using the same material but with zones only half the length (7.5 cm). We then calibrated the duplicate and made a polynomial fit to the curve from the sixth zone. We could then mathematically describe the relationship of temperature to the round-trip transit time for various zone lengths. We accomplished this using the resultant curve and the actual length of the zones (15 cm) in the Kanthal detector. The calibration curve for zone 6 of the duplicate sensor rod is shown in Fig. 4. We obtained the values represented by the circles during the temperature rise and those values represented by the squares during temperature fall. Notice that for the Kanthal detector, the sound transit-time increased after the initial heat up. The reason for the directional difference between the first and second detector is not understood.
Experiments

The Lawrence Livermore National Laboratory has two oil shale retorts that are used to experimentally simulate the in situ retorting of shale. The retorts are cylindrical vessels, vertically oriented. The larger retort is 0.9 m in diameter and 6.1 m in length (6-Mg capacity). The smaller retort is 0.3 m in diameter and 1.5 m in length (125-kg capacity). Rubbled and graded shale is placed in the retort, gas is forced through the rubble bed from top to bottom, and the shale is ignited at the top. The kerogen is then pyrolyzed from top to bottom; the entire process resembles a burning vertical cigarette.

Four instrumentation ports, placed circumferentially around the retorts on a level, are spaced every 15 cm along the length of the retort. The levels are numbered sequentially, starting with level 0 at the top. There are 11 levels along the small retort and 39 along the large. Typically, type-K thermocouples are installed through these ports into the oil-shale rubble bed as the shale rubble is placed in the retort.

The first detector (304SS) was installed in the large retort for run L-4 (Fig. 5a), radially through...
the center of the bed at level 8. We chose the detector length to give us 12 each, 7.5-cm temperature zones across the bed.

To determine zone 1 temperatures, thermocouples were placed in the bed at one level above and one level below (levels 7 and 9, respectively). The temperature readings of these three detectors versus time are compared in Fig. 6. Here, we can see that the profiles of the detectors from the thermal pulse match quite well except at the higher temperatures. The largest error occurs at the peak temperature, where the ultrasonic thermometer indicates a temperature 150°C higher than was measured by the thermocouples. Some of the other temperature zones had thermocouples in similar positions, and the same tendency toward a 100 to 200°C error in the peak temperature appeared again. This error seems to be a common problem with 304SS at high temperatures and is probably the reason for the wide scatter at temperatures greater than 800°C on the calibration curve (Fig. 3).

For run S-22 (Fig. 5b), the second detector of Kanthal was installed in the small retort axially through the center of the bed. The detector zones were chosen to give us one temperature zone for each retort level. The result was ten 15-cm zones along the length of the retort with the top end of zone 1 at level 0 and the bottom end of zone 1 at level 1. Therefore, zone 1 was effectively the average temperature at level 0.5, and zone 10 the average temperature at level 9.5.

A typical ultrasonic thermometer zone (zone 6, level 3.5) is compared with bed thermocouples at the two extremities of that zone (level 5 and level 6) in Fig. 7. The three time-profiles in this case match very well; however, the ultrasonic thermometers were low, possibly 50°C at the peak temperature.

The most important thermal data for in situ retort operation is the shape and position (within the retort) of the retorting front. Practically all the hydrocarbons are released from the shale at temperatures found at the front—i.e., at approximately 400°C. The arrival times of the front along the central axis of the retort for run S-22, as measured by thermocouples and the ultrasonic thermometer, is shown in Fig. 8. The match—that is, measurement accuracy—is extremely good.

Recent developments

Encouraged by our results so far, we are working to interface the detector with a computer system that will permit automatic data acquisition,
manipulation, and storage. Recently, we conducted an in situ experiment at a coal site in Centralia, Washington, using an ultrasonic transducer with a 20 m sensor/lead-in containing 12 temperature zones. Preliminary results are very encouraging.

Figure 7. Temperatures from bed thermocouples at retort levels 5 and 6 along with zone 6 (level 5.5) of the ultrasonic thermometer. The data are from a retorting experiment (S-22) in our 125-kg retort.

Figure 8. The arrival times of the retorting temperature (400°C) as measured by bed thermocouples and ultrasonic thermometer. The data are from a retorting experiment (S-22) in our 125-kg retort.
References


An on-board recorder captures the performance of weapons designed for penetration of hard targets

We capture vital projectile performance data with a recorder that mounts in the projectile itself. Novel packaging techniques are required. The recorder has recorded and survived impacts to 20 thousand gravities.

The Naval Weapons Center designs non-nuclear weapons for penetrating hard targets. The shock levels at impact that these weapons must contend with range from about 20 000 g for subsonic bomb impact of earthen targets, to 60 000 g for subsonic warhead impacts against ship targets, to 100 000 g or more for supersonic impact of missile warheads into reinforced concrete targets. An effective testing program must have reliable data on shock levels during penetration. The need for data on shock levels is especially great for high-velocity weapons for defeat of hardened surface targets. One of the critical problems is the extreme difficulty of measuring acceleration during penetration. This report describes the development of a small, rugged, solid-state recorder that mounts on the weapon. Our immediate goal is to develop an on-board recorder for impacts up to 60 000 g and to gain experience with high-shock electronics and packaging techniques for supersonic impacts (>100 000 g) and for the Naval Weapons Center's adaptive fuze program. We anticipate delivery at the end of this fiscal year.

Design method and procedure

The recorder is packaged so that it will fit in the fuze-well of the bomb or warhead. Special techniques have to be used to package the recorder's electronics to allow it to survive the high shock levels of impact with the hard target. Accelerometers measure the accelerations of the warhead. The warhead is recovered after the test, a memory-readout system is connected to the transient recorder's memory, and the information is read out for display and analysis.

The recorder housing is made of high-strength steel threaded to allow mounting in the weapon's fuze well. The electronics is packaged inside in a cylindrical volume 2.6 in. in diameter, and 6 in. in length. The accelerometers are mounted in the aft portion of the recorder housing. All of the electronics are mounted on four

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Figure 2. Machine for shock-testing the on-board data recorder.
printed circuit boards, placed around the batteries and capacitors, and the entire package is potted in micro-balloon-filled epoxy. Commercially available, standard, dual in-line integrated circuits are used. The entire potted assembly is compressed to about 45 kg force when installed in the recorder housing.

The electronic design of the on-board recorder is shown in Fig. 1. It has two digital information channels. The outputs from two piezoelectric accelerometers are passed through a 20-kHz low-pass anti-aliasing filter into an A to D converter and stored in a 2k-word CMOS low-power memory. The A to D converter operates at 200,000 samples per second, allowing 10.2 ms of data to be recorded. Recording the transient waveform preceding the trigger threshold level is accomplished with a combination of a recirculating memory, a settable threshold detector, and a settable delay in the microprocessor. In order to conserve battery power, the microprocessor turns off the power applied to the various subsystems in the recorder (except the low-power CMOS memory) while the warhead is being recovered. The recorder uses commercially available components.

Shock-testing machine

All of our components and subassemblies are certified in a shock testing machine, shown in Fig. 2. The shock machine consists of the test fixture, a carriage, a programmer, and a base. Two large bungie cords accelerate the test fixture and carriage toward the base. Figure 3 shows the components schematically. The test fixture and the carriage are accelerated by the bungie cords towards the programmer. When the carriage strikes the programmer, the carriage's velocity direction is reversed, effectively amplifying acceleration.

We have evaluated several types of battery in our shock testing machine. All the 1/3 AA-size nickel-cadmium batteries survived 40,000 g shock with acceptably small voltage drop and some survived 90,000 g. We also tested 250 mA-hr button-type nickel-cadmium batteries. These batteries suffered unacceptably large voltage drops at 40,000 g shock. We think that the reason for their poor performance as compared to the smaller 1/3 AA-size batteries is that the large sintered mass, held by spring loaded contacts, tends to move inside the case. The 1/3 AA-size battery construction is a rolled metal foil with a separator material and tabs welded to the electrodes.

Modeling

We have used our hydrodynamic computer code modeling capability at the Laboratory to calculate the response of a warhead to a typical ship target. Figure 4 shows a typical trapezoidal-shaped pressure input used to simulate a typical ship target impact. The results of a simulation are illustrated in Fig. 5. We calculate acceleration peaks of 60,000 g of shock due to the high explosive slapping the rear of the warhead. The frequency spectrum of the acceleration pulse is also shown in Fig. 5. The majority of the energy lies between 1,000 and 30,000 Hz.

We have also developed a dynamic model for the shock-hardened data recorder. The inclusion
Figure 4. Typical input information used by the computer model to calculate the response of a warhead to a typical ship target.
in the model of the dynamic characteristics of the transducer is an especially significant achievement, since it allows for the filtering effects of the transducer, which otherwise can be misleading.

Figure 6 shows actual recorded shock data from a typical test.

The project is progressing on schedule with no major problems. We anticipate delivery of one recorder to the Naval Weapons Center at the end of this fiscal year.

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Figure 5. The results of a computer simulation of warhead/fuze striking a target.

Figure 6. Computer display of recorded data from a shock test. The "Volts" of the ordinate are equivalent to "kg."
Pascal software structures achieve definite control of the 24 MFTF sustaining neutral-beam power supplies

Precise control of large, complex systems is not assured unless there is known to be no unintended interactions in the control system. The software controlling the sustaining neutral-beam power supplies of the Mirror Fusion Test Facility accomplishes this feat. The software structures comprise some 16,000 lines of commented Pascal code, distributed among 10 different tasks. Each task may control any of the 24 power supplies. All the tasks are strictly event-driven, and are not subject to any "system mode." Since there is no global information in the software, we know that all the power supplies are controlled independently.

We describe the software structures that control the operation of the MFTF Sustaining Neutral Beam Power Supplies (SNBPS). These codes are components of the Supervisory Control and Diagnostic System (SCDS).

Two members of the Computations Department assigned to the MFTF project wrote 16,000 lines of Pascal code during 1980-81. We built 10 software tasks, each of which performs a different function for any of the 24 SNBPS. No action performed on any power supply affects any other power supply. One tactic to maintain this decoupling of power supplies is the use of an array, indexed by power supply name, of finite state machines in each task. Our use of a modern programming language (Pascal) was practically essential in proving that the power supplies cannot affect each other through their controls.

The other principal activity that SCDS supports in the SNBPS system is the execution of coordinated physics shots. At the maximum rate of one shot per 5 min, the entire 24-beam sustaining system can participate with plasma streaming, startup beams, and diagnostic hardware in an MFTF physics shot. When a physics shot is in progress, conditioning of beams may occur only on those minutes between physics shots.

Actions defined on power supplies

To fire neutral beam shots, the sustaining codes in SCDS implement the following activities:
• Allow an operator to set any of 16 individually controllable setpoints. A setpoint is entered on the control console, and the value is stored in the SCDS database. Values are transmitted to the power supply hardware, and when a shot is fired the values of all setpoints are recorded in the archive data.
• Display the status of any of the 150-odd monitored devices that comprise the feedback defined by the power supply. Any change in the condition of any of the monitors is to be displayed on the SCDS console display screen within a few seconds of the state change.
• Operate the abstract finite-state machine that represents the power equipment. Opening circuit breakers, energizing shunt tube filaments, and testing crowbar circuitry are all examples of transitions on this power-supply-defined abstract state machine.

Event-driven software

All the application tasks in the SNBPS subsystem are strictly event-driven. No task does anything until an event occurs. An event causes
some task to be loaded into computer memory and to begin execution. Depending on the meaning of the event, the task might control some hardware, update the database, or perhaps cause further events to affect other tasks. When the task has finished responding to the event, the task ends and leaves memory.

Problem decomposition

We used a divide-and-conquer tactic to design 10 codes. Generally, these codes are called tasks because they are co-equal software actors that communicate and cooperate by passing messages. A large number of different events affect individual power supplies. It is convenient to describe three general classes.

Operator intentions are transmitted to the control tasks by commands from the SCDS console software system. Control panels are provided for the operator to set electrical and timing setpoints, and to operate the power supply state machine. Tasks that respond to console commands write setpoints into the SCDS database and also command hardware actions. Each of these tasks assures that the command comes from an operator who is licensed to run the power supply, and each task validates the setpoint against limits imposed by the hardware. The tasks also guarantee that no setpoint is changed while a shot is in progress on that power supply (but allow concurrent operation of any other power supply that is not being fired). Improper operator actions, or failure of hardware to respond to commands, is reported to the operator's console. Every operator action, as well as the hardware response to the action, is recorded in a journal in order to provide an audit trail for reconstructing mishaps.

Changes in state of devices (such as safety interlocks) are events arising from the Local Control System. These events come to a SCDS module in the form of monitor reports, and the module responds by writing the new state into the database. Control tasks consult the database for current monitor values asynchronously. There is no coupling between the writing of current data into the database and the reading when a task needs interlock permission.

The final class of event serviced by SNBPS tasks are milestones. These milestones define a shot sequence. A command from the shot synchronizer code tells an application task to do some shot-related activity (e.g., transmit setpoints to hardware) for a set of independent power supplies. The task receiving this command extracts the setpoints from the database and operates the commanded hardware. Because this shot might have been one of several conditioning shots in progress at the same time, the same task might receive commands for some other power supply before it finishes with the first supply. The programming tactic that allows the same task to service multiple supplies concurrently is described in the next section on arrays of finite-state machines.

Individual power supplies are controlled separately until the final shot milestone (about 10 seconds before shot time), so that operators who are conditioning different beams can act almost independently. Only in the last 10 seconds before firing is a shot ensemble closed to further beams and timing-system trigger values are distributed to the hardware. This final arming of timing hardware is the last action that the software performs on the power supplies before the hardware fires the shot. When the shot has been completed (under control of dedicated timing hardware), the shot synchronizer code transmits its final milestone so that the application tasks can acquire and store the data that the hardware collected during the shot.

Arrays of finite state machines

We have been able to reason formally about the behavior of the suite of application tasks by considering each of the 10 tasks in turn from the standpoint of its actions on a single power supply.

An example task

The task AYDINSTM can cause state transitions on the state machine of an individual power supply when it is commanded by an operator. The task is implemented as a finite state machine (FSM) with two states: Idle and Awaiting-Response (from commanded hardware). If the FSM is in Idle state, then it can accept a command.
event from an operator. When a valid command reaches AYDINSTM, the task sends a packet to its subordinate, which is responsible for operating the power supply, and enters the state Awaiting-Response. Returned mail which reports the hardware response causes a report to AYDINSTM's boss, whereupon the task once more enters Idle. See Fig. 1.

This FSM has been implemented in Pascal, and tested as described below; we are fairly confident that the code implements the FSM correctly. It is simple to generalize from this code to the version that controls any of the 24 power supplies. The general code enacts 24 instances of the FSM described above, one for each power supply. By proving that there is no interference between the individual FSMs, we prove that this software cannot cause any crosstalk between any of the power supplies that it controls.

This code has about 1200 lines of Pascal, expressing 21 independent procedures and functions. The procedures are not nested, and none of them references any global variable; therefore we know that the only information available to any procedure comes to it through its actual parameters. Every one of the procedures that knows any piece of the FSM implementation has a parameter citing which power supply to affect. It is

*That is, there is no 'global-variable coupling.'*

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**Figure 1.** Operator 1 has commanded the hardware of SUST1 to open a circuit breaker, and is waiting for confirmation that the equipment has responded. Perhaps another operator (distant figure) is about to command SUSTn. This new action must not interfere with any other operator's work. Because of the way we implemented the finite-state machines in Pascal, we can prove that the operators are independent.
easy to show from the procedure headings that the code does not contain a software error which could cause it to affect any power supply except the intended one.

Programming language

I am persuaded that use of a modern programming language is essential to implementing this software. The language characteristics of strong type-checking and stack-based procedure semantics both contribute to the confidence a software engineer should have in the soundness of these tasks. Old-style languages like Fortran and Assembler simply do not offer the tools for avoiding global-variable coupling that we exploited in the implementation of the arrays of FSM that control the MFTF Sustaining Neutral Beam Power Supplies.

Testing experience

The initial application tasks were ready for execution just after the SCDS environment became available to support them. The environment software and the applications thus served as test beds for each other. The debugging was sometimes distributed over three or four different programmers. Since the components had been reviewed and discussed widely during the year before testing began, the programmers generally knew what to expect of the tests in progress.

Software that emulates hardware

The local control computer program PLEX had been available and was in service with the fusion chamber software before the SNBPS tasks needed it. It proved easy to use PLEX to emulate a couple of controllable devices in software. With PLEX emulation of the power supply finite state machine and one setpoint device, we emulated firing neutral beam shots in order to test display and database functions along with the control tasks.

With about eight weeks of emulation testing behind us, we began operator checkout by delivering the functional software to the project engineer who was configuring the High Voltage Test Stand. We provided two scheduled hours per week of functional availability. We gradually increased the available time for emulation testing as bugs that caused system crashes were gradually exterminated.

When the power supply contractor delivered the real-time Pulse Power Module Controller, along with a power supply hardware simulator, it was fairly easy to establish connections to that component. The next step is to connect our software to actual power equipment.

References

A 7-MHz pulse height analyzer will analyze neutron spectra to measure plasma characteristics

As a tool for measuring plasma characteristics, we have developed a high-speed pulse height analyzer of neutron spectra. Histograms of pulses collected over 10 ms reveal plasma buildup and decay. We can identify the particle, digitize the energy, and store the data at better than 7 MHz, above which the slowness of the detector becomes limiting.

The energy of neutrons escaping from a plasma can be measured and used as an indicator of the internal temperature of the plasma. To be of value, these measurements must be made at short time intervals (10 to 100 ms apart). The neutron energy can be determined from an unfolding of a PHA spectrum. The data rate must be very high to build a histogram in this short time frame. A scintillation pulse is about 20 ns wide (FWHM) at the output of the buffer amplifier. The pulse is integrated and applied to the digitizer. A new integrator design clears the charge rapidly. The high data rate forces a shorter integrating time than is normally used in particle-identification circuits, resulting in tighter timing requirements for these circuits. Flash digitizers are the only options for this high-speed application, but they have very poor differential linearity. To correct this problem, a post-experiment correction scheme was devised.

**System configuration**

The block diagram shows the system interconnections (Fig. 1). The system described contains all of the electronic components, up to the system interface, within the neutron shield. The details are described in the following paragraphs.

**Detector/amplifier**

A pinhole imaging shield passes the neutrons to a NE213 detector and photomultiplier (Fig. 2). An 8850 PM tube with its dynodes driven from an FET (VPO-40-N2) divider string drives a buffer amplifier (LM0033) into delay lines, as shown in Fig. 3. The FET dynode drivers provide a low output impedance without the load of base currents associated with bipolar devices.

**Discriminator**

A constant fraction discriminator is used to provide the starting pulse for the system. This pulse is delayed and used to trigger the ADC module; it is also sent through a programmable digital delay to the pulse shape identifier circuit.

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Figure 1. System block diagram.
Figure 2. Imaging shield.

Integrator

The delayed linear signal is integrated by R and C of Fig. 4 and buffered to the ADC module. After conversion C is discharged with a VP0104N FET, which is a power FET with an on-resistance of about 30. The internal capacity is used in parallel with the integrating capacitor. The gate-to-drain capacity of about 40 pF is neutralized by Cn. Initially, the FET is “on”, shorting the integrator to ground. The start pulse sets the flip-flop (FF), turning off the FET. Capacitor C can now begin to integrate the linear pulse input. Figure 5 shows the linear pulse crossing over the integrated pulse. At this time, the FF is reset, turning on the FET, which rapidly discharges C. The large gate capacity makes the turn-on time of the device a function of the driving source. The FF (74S74) has enough drive to turn on the FET and discharge the capacitor C in less than 10 ns.

Pulse shape identification

A comparator between the delayed input pulse and the signal on the integrator detects the tail crossover. Gamma pulses have a shorter tail than neutron pulses, causing them to cross the integrated signal before neutron pulses. The time difference in this circuit is 1.4 ns. A time window is generated from the starting pulse by the computer-controlled delay circuit. The time window is applied to the “D” input of a FF whose clock is triggered by the tail crossover (Fig. 6). The coincidence of these two signals sets the FF and routes the data to the neutron half of the memory. Figure 7 shows the neutron/gamma separation obtained by this particle-identifier circuit. The data were obtained using a time-to-height converter driving a PHA with the time referenced to the starting pulse and plotted at the tail crossover.

Analog-to-digital conversion

The analog-to-digital converter (ADC) is an 8-bit flash converter with a 30-ns conversion time.

Figure 3. PM tube, constant-fraction discriminator, and buffer amplifier.

Figure 4. Integrator control.

Figure 5. Shape determination by constant fraction crossover.
(TRW TDC-1007). This converter type has very poor differential linearity. For given conditions, the bin widths are quite reproducible, so post-correction of bin widths is possible. If the manufacturer's specification of ±1/2 lsb (least significant bit) is used, then one bin can have three times as many counts as an adjacent bin in a worst case situation. In both static and dynamic tests the existence of possible disparity was verified. The static and dynamic characteristics of this unit are not the same but if a correction table is made under operating conditions, then the bin widths can be linearized. This is the approach we took.

Memory

The memory is organized in a 10 X 16-bit array. The memory IC used is a 2115-H-3. As soon as an address is applied to the memory its output is channeled through a set of arithmetic-logic unit ICs in an add-1 mode. The timing for the read/write operation was determined by the gate delays in the data path (i.e., from data output through the latch and the ALU circuits, as seen in Fig. 8). The memory can cycle at more than 10 MHz. The most significant bit of the memory address is used as a routing control to provide two memory storage areas, one for gammas and one for neutrons. The Compton edge of the gamma spectrum can be used to provide energy calibration for the neutron data.

Control

An on-board microprocessor controls the lower level discriminator, delay timing, and high voltage. It also sets time intervals for data acquisition and changes the mode for serial transmission of data to the remote interface.

Interface

All power supplies are isolated from the control center (which is located more than 300 feet away) by transformers. All signal lines are optically coupled. The transmission rate of the data output is 20 MHz.

Results

The system analyzed a rotating target neutron source at various count rates. To create a correction table for the ADC, the high voltage was increased on the PM tube and a spectrum gathered. This spectrum (Fig. 9) approaches white

$\text{ADC} \rightarrow \text{ADD CNTR} \rightarrow \text{MEMORY} \rightarrow \text{LATCH}$

Figure 6. Pulse shape identification.

Figure 7. Neutron/gamma separation.

Figure 8. Memory.
noise. A least-squares fit of the spectrum is used to make a bin correction table, which is shown in Fig. 10. A spectrum was then taken with the proper high voltage and corrected by the bin correction table (Fig. 11). The corrected spectrum was then unfolded to produce the neutron data of Fig. 12. The data in Fig. 12 were taken at a rate of 4.9 MHz. Good data were taken to 8 MHz. The circuitry is stable at input rates up to 15 MHz (Fig. 13) but pile-up, due to the width of the NE 213 scintillator pulse, degrades the data.
Figure 11. Corrected neutron spectrum.

Figure 12. Unfolded neutron spectrum.
Figure 13. Pile-up at 15 MHz.

References

A modified teletypewriter, controlled by a simple interface, converts messages to Braille

Braille teletypewriters (TTYS) used on Lawrence Livermore National Laboratory’s large timesharing network for the past 14 years have some disadvantages. They are limited to 110 baud, they do not translate system messages, and it is not easy to use them with a different computer system. We have overcome all of these disadvantages with our new Braille terminal. It uses standard, inexpensive parts and easily interfaces with any computer system. We use a standard TTY, modified to print Braille characters.

Visually impaired computer programmers have long used standard keyboards to input information to computers. However, these programmers need a way to read the computer output.

For 14 years at Lawrence Livermore National Laboratory (LLNL), we have used a teletypewriter Braille-embossing system to receive computer output from our timesharing system. We accomplished this through a relatively simple conversion to the teletypewriter. Although voice output is becoming more common and less expensive, the vocabulary for this process is limited. This limitation and the continuing need of hard copy keep Braille output desirable.

Modified teletype

A modified Model 33 Teletype produces our Braille output. Each whole Braille character (see Fig. 1) is made by sending three American Standard Code for Information Interchange (ASCII) characters to the teletypewriter, one for each half of the Braille character and one for a space. The teletypewriter was modified by installing a special Braille embossing cylinder that has sets of pins for the Braille characters instead of letters or other symbols (Fig. 2). The cylinder embosses the paper, which is later tactiley read from the back.

![Figure 1](image1.png)

**Figure 1.** Examples of Braille, a system of writing for the blind that uses characters made up of raised dots. Two columns of three dots each comprise 63 characters in the Braille system.

![Figure 2](image2.png)

**Figure 2.** A teletypewriter modified by installing a special Braille embossing cylinder that has sets of pins for the Braille characters instead of letters or other symbols.
The software for our first system consisted of imbedding the Braille conversion process in each program and utility routine we used. This was a tedious operation and was never used extensively.

The software for our next system, used until a few months ago, consisted of a software controller containing the Braille conversion routine. This controller, run as an ordinary user program, enabled us to get Braille from any program or any utility routine. The controller intercepted all messages from the programs and converted them to Braille. In addition, the controller passed all control messages between the programs and the teletypewriter. However, some operating system messages, such as operator and status information going directly to all terminals, were not converted to Braille.

Because the LLNL Computation Department is converting 110-baud terminal lines to much higher speed lines, WP needed another implementation system for Braille. Toward the end of 1981, we developed a system that is not hampered by the higher input rates of up to 9600 baud.

The new system receives normal asynchronous signals from the LLNL timesharing network, Octopus. All the special software mentioned previously is eliminated from the host computer. Instead, a microprocessor accepts the ASCII code and converts each character into the three-ASCII-character Braille equivalent (see Fig. 3). The microprocessor is an LLNL-designed modular system based on the Intel 8080 CPU. The various elements of the system are constructed on standard-sized circuit cards.

Since three characters must be typed for each ASCII character received, the teletypewriter output cannot keep up with ASCII characters arriving at a speed of even 110 baud. Therefore, an input buffer is installed to hold as many as 12,000 characters. This buffer also allows input at the higher baud rates. Braille characters occupy three print positions in a line, so the program must automatically insert a carriage-return/line-feed at the end of each line of 23 Braille characters.

Figure 3. Schematic of the microprocessor conversion of Braille for the new LLNL Octopus network or for a minicomputer. The end result is the conversion of 3-1/3 Braille characters per second.
High-level language used

The program, written in the high-level language PtVM, looks to see if the input buffer is empty. If it is not, the program takes a character on a first in, first out (FIFO) basis and outputs it. Although the program is in a loop and is outputting characters or waiting for more characters, it can be interrupted to send a character from the keyboard to the host. It can also be interrupted to enter another character into the input buffer. If the buffer is full, the overflow characters are ignored, and a bell rings on the teletypewriter.

The new interface has several other features. The most important one is that it can be used with any ASCII character source; it no longer depends on a system specific to a given computer. All information on the line can now pass through the converter to be output as Braille. Even operating messages, system messages, and input echos are converted to Braille. In addition, we can develop other features to enhance operations. For example, so-called canned messages can be sent by pressing a button for a log-on or execute line. A typical setup is diagrammed in Fig. 2.

Because it is simple to modify the Model 33 Teletype, the cost of the entire system is relatively low. Also, there is no cost for microcomputer development, because the microprocessor we start with is a standard item.

Reference

The aluminum-air battery may be able to replace gasoline as a power source for automobiles

The aluminum-air battery is an advanced electrochemical energy source being developed for use in electric vehicles. The battery promises to give to an electric vehicle the long range, rapid acceleration, and fast refueling of today’s automobile. A complete vehicle battery has projected energy and power densities better than 300 W-hr/kg and 150 W/kg (compared to the best lead-acid battery values of 40 W-hr/kg and 110 W/kg). The Laboratory leads this DOE-funded program, with a major part of the research being conducted by commercial laboratories.

The aluminum-air concept

The nation still depends on oil from unreliable foreign sources. We all recognize the particular vulnerability of the transportation sector of the U.S. economy and the lack of alternatives for petroleum-derived fuels. However, there are two long-term options that might eventually improve our situation and permit us to retain the great freedom of personal mobility that we now enjoy. One of these options is the development of synthetic liquid fuels to replace petroleum. The other is the development of the use of electric vehicles recharged by electricity generated from abundant or renewable resources.

It became evident to LLNL in the 1970s that the electric vehicles then being proposed could not substitute for gasoline-fueled vehicles. None of the existing or proposed electrically rechargeable batteries could give vehicles the long range, rapid acceleration, and fast refueling of contemporary automobiles. Because these batteries lacked sufficient energy and could not be rapidly recharged, they could serve for only short-range duties, such as shopping, commuting, urban delivery and some fleet operations. They could not compete with gasoline-powered vehicles of relatively low purchase price and fuel consumption.

In the 1970s LLNL researchers investigated various types of batteries. Reactive metal-air batteries looked promising. This type of battery had previously been explored for various civil applications, but it had been rejected because of low power densities, electrochemical inefficiencies, and difficulty of recharge. However, by the mid-1970s the outlook for high-performance metal-air batteries had significantly improved because of advances in aluminum-alloy electrochemistry and air-electrode performance. Under DOE sponsorship, LLNL started a small metal-air program in 1976, first using lithium and calcium anodes, and later aluminum-alloy anodes.

In 1979, in recognition of the potential of metal-air battery technology and of LLNL’s role in its development, DOE asked LLNL to manage metal-air research.

Aluminum-air concept

The aluminum-air concept has been described in a number of reports. The battery operates as a fuel cell with periodic addition of the two reactants (aluminum and water) and removal of the benign reaction product. The basic building block of the battery is the unit cell shown schematically in Fig. 1. It consists of an aluminum-alloy anode separated at a fixed distance (1.5...
Galvanic cell reaction: \[
\begin{align*}
\text{anode} & : & \text{Al} + \text{NaOH} + 3\ \text{OH}^- & = \text{NaAl(OH)}_4 + 3\text{e}^- \\
\text{cathode} & : & 3\text{e}^- + 3/2\ \text{H}_2\text{O} + 3/4\ \text{O}_2 & = 3\ \text{OH}^- \\
\text{net cell} & : & \text{Al} + \text{NaOH} + 3/2\ \text{H}_2\text{O} + 3/4\ \text{O}_2 & = \text{NaAl(OH)}_4
\end{align*}
\]

Crystallizer reaction: \[
\text{NaAl(OH)}_4 = \text{NaOH} + \text{Al(OH)}_3 \downarrow
\]

Net reaction of the battery: \[
\text{Al} + 3/2\ \text{H}_2\text{O} + 3/4\ \text{O}_2 = \text{Al(OH)}_3
\]

Parasitic anode reaction: \[
(\text{approximately 10\% energy loss}) \quad \text{Al} + 3\ \text{H}_2\text{O} + \text{NaOH} = \text{NaAl(OH)}_4 + 3/2\ \text{H}_2
\]

Figure 2. Electrochemical and chemical reactions of the aluminum-air battery. Reactions occur in both the cell stack and the crystallizer unit, and some energy is lost due to a parasitic anode reaction.

to 3.2 mm) from an air cathode. The typical air cathode is a semiporous mixture of carbon, wet-proofing agents, and catalyst. It also contains a metallic screen that provides a low impedance path for current collection. Flowing electrolyte and flowing air streams are required to transport reactants and to control cell temperature. The battery operates between 50° and 70°C and has a cell voltage at least 1.6 V at a current density of 150 mA/cm².

A summary of the chemical and electrochemical reactions of an aluminum-air battery is given in Fig. 2. The battery reacts water from the electrolyte, oxygen from air, and aluminum metal to produce electrical energy and a reusable reaction product, aluminum trihydroxide. In addition to the energy-producing reaction, a parasitic anode-corrosion (water-reduction) reaction is present that produces hydrogen gas and consumes aluminum at a low rate (approximately 20 mA/cm²). This corrosion reaction necessitates the safe disposal of the hydrogen produced and the draining of the electrolyte (sodium hydroxide and sodium aluminate) from the cells during extended periods of battery shutdown.

A simplified diagram of the battery system is shown in Fig. 3. Various components store and circulate reactants and remove and store the reaction product. The air supply is scrubbed to remove carbon dioxide, which is potentially harmful to the air cathode. A moisture exchanger reduces battery water loss that normally occurs via the warm moist air-exhaust stream. A complete 40-kW, 70-kW·hr battery based on this design would weigh in the neighborhood of 240 kg and occupy a volume of approximately 440 liters.

Comparison to other systems

How the aluminum-air battery compared with other vehicle propulsion systems is shown in Fig. 4. This chart shows specific peak power, which is proportional to vehicle acceleration, and specific energy, which is proportional to range. All systems include an energy-conversion device such as an electric motor, internal-combustion-engine (ICE) or fuel cell, as well as the energy-storage device or fuel. The comparisons are made in terms of mechanical energy and power at the input to the vehicle's transmission. Each envelope encompasses the range of characteristics for all possible devices of a generic propulsion system, and the range of values varies from measured characteristics of actual devices to optimistic projections of future technology.

The aluminum-air battery is evaluated using the time-average battery mass for the normal refueling schedule (designated n = 4), in which water is added and reaction product removed every 400 km, and where aluminum is added every 1600 km. Gasoline ICE vehicles are the standards of comparison. Aluminum-air propulsion can provide as much energy as liquid-fueled ICE vehicles, but lacks their peak power. Secondary batteries, fuel cells, and the hydride storage ICE systems offer a wide range of power capabilities at low
and intermediate specific energies. Flywheels offer extremely high powers but have low energy content.

**Technical status**

This program follows two parallel paths of research and development. The first path involves the development and eventual demonstration of full-scale battery hardware. This path determines the least amount of time to produce a vehicle battery, and the effort incorporates, as models for hardware development, commercially available anodes and cathodes developed for widely different applications.

The second path pursues the development of compatible and cost-effective anodes and air electrodes suitable for the duty cycle required of a vehicle power source. Anode development involves adding controlled impurities to the metal or electrolyte, in hopes of achieving higher efficiency and power from the anode. Air-electrode development requires the reduction or elimination of noble-metal catalysts and the development of structures capable of operating for extended periods under road conditions.

A series of 25- and 50-cm² aluminum-air cells was tested in 1979, and mass and enthalpy...
analyses of various complete battery systems were also conducted. Subscale cells are now routinely operated to test components and to measure cell characteristics. In 1980, full-size cells (1000 cm$^2$) were successfully tested both at LLNL and at the Lockheed Missiles and Space Company. In late 1980, a large cell was operated for extended periods during which the composition of its electrolyte was stabilized by a crystallizer through the precipitation of aluminum trihydroxide [Al(OH)$_3$]. This experiment demonstrated the compatibility of cell and crystallizer, the two critical components of the aluminum-air battery.

In 1981, we tested rapidly refuelable cells of several designs and sizes. This work culminated in the successful operation at LLNL in January 1982 of the 6-cell battery module shown in Fig. 5. Current plans call for the operation in the near future of a basic battery system consisting of a multicell, crystallizer, and heat-rejection system. By 1984 or 1985, we expect to test a complete battery system, including all required components and controls.

Electric vehicle analysis

A continuing part of the aluminum-air program is the analysis of battery and vehicle systems and their projected performance, cost, and
energy use. The basic modeling starts with a well-defined ICE vehicle. The model removes the ICE propulsion system (fuel, engine, transmission, etc.) and replaces it with an aluminum-air propulsion system (battery, motor, motor controller, etc.) that provides the required energy and power for the vehicle to meet the range and acceleration specified for the electric vehicle. The model compensates for changes in propulsion-system mass and volume by using a 30% mass-compounding factor and empirical mass/volume relationships to correct for these changes. The result of this modeling procedure is an electric vehicle having a previously specified range and acceleration, but whose mass, volume, cost, and energy use differ from the baseline ICE vehicle.

Figure 5. Multi-cell module containing six, 167-cm² cells. Cells are refueled by inserting a new anode with its attached support plate. Sealed cathode modules contain a movable air cathode.

Figure 6 compares vehicle weights for three, five-passenger vehicles: the baseline ICE vehicle, an aluminum-air vehicle designed for the same power-to-mass ratio (acceleration) as the ICE vehicle, and an aluminum-air vehicle designed for acceleration equivalent to some of the newer diesel vehicles (30 W/kg). Vehicle mass is a figure-of-merit indicating how well a particular propulsion system meets a set of performance goals. In addition, vehicle weight is roughly proportional to cost of the vehicles. The results shown imply that aluminum-air vehicles will be capable of providing both the range and acceleration of present-day automobiles at reasonable initial costs. All three vehicles have a range of 400 km, measured at the point where 80% of the fuel is exhausted. Since
aluminum-air vehicles require two fuels, aluminum and water; the 400 km range is determined by the addition of water, the limiting reactant. Both aluminum-air vehicles contain sufficient anode aluminum for 1600 km of operation, at which point 80% of the anode would be consumed.

As shown in Fig. 6, aluminum consumption per kilometer per unit mass is found to be nearly invariant with power; consumption is 31 tonne-km per kg of aluminum (extrapolated from cell results obtained in early FY 1980 using commercially available cell components). At this value of vehicle efficiency and an installed cost for aluminum anodes of $1.80/kg, the fuel cost of a 1-tonne aluminum-air vehicle will be 5.8c/km (9.3c/mi). This transportation cost is about twice that of an ICE vehicle that gets 30 mi/gal of gasoline at $1.40/gal. In addition, approximately 1.4c/km (2.2c/mi) will be required for periodic replacement of air electrodes. While operating costs for an aluminum-air vehicle are high compared to today's liquid-fueled automobiles, these costs may become competitive when this technology has matured and synthetic liquids enter large-scale production.

**Conclusions**

Aluminum-air battery research has advanced to the point where rapidly refuelable multicells...
have been successfully operated. However, a number of difficult problems must be resolved before the technical and economic viability of the concept can be demonstrated. Two parallel development paths are being followed. One is hardware development using model electrodes, and the other is research directed toward cost-effective anodes and cathodes. Projections indicate that the aluminum-air vehicle can provide the acceleration, range, and rapid refueling characteristics of current automobiles. The program's objective is to provide a full-performance electric vehicle in a time frame in which synthetic liquids will enter large-scale production.

References


