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BATTERY PACK/CONTROLLER FOR HIGH TEMPERATURE APPLICATIONS

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ABSTRACT

At temperatures in excess of 300°C, standard conductive wirelines cannot be used for signal or power transmission in geothermal wells. At such temperatures, a mechanical slickline can be used to raise and lower instrumentation, but the instrumentation control and power must then be self contained. This paper reviews the development of a battery and timing circuit to control a motor in a Los Alamos National Laboratory sampling tool. The battery pack-controller circuitry enclosed in a dewar was used in the Salton Sea Scientific Drilling Project (SSSDP) for temperatures approaching 400°C.

INTRODUCTION

Most downhole samplers require conducting wirelines for operation. These wirelines work well at temperatures up to approximately 300°C, but beyond this temperature insulation breaks down and the cable is damaged. The SSSDP required a means of obtaining liquid samples at temperatures in excess of 300°C. A battery pack and timing circuit was suggested to address this problem. Table 1 summarizes our design features and requirements for the battery pack/controller.

Table 1. Design Requirement for Battery Pack/Controller

Feature	Requirement
Operating Temperature	To a maximum of 400°C
Time in well (round trip)	Four Hours
Power source	Rechargeable batteries
Power to motor	100VDC and 150mAmps for a maximum of 1 minute (15 watts)
Motor protection	Maximum current of 300 mAmps
Electronics	Components must withstand maximum load of one amp steady state.
Battery protection	Limit battery output to 500mAmps
Valve open/close time	3 turns (approximately 18 seconds)

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A dewar (vacuum heat shield) houses a battery pack and the electronics to control a motor that operates a valve in the Los Alamos designed sampler. The dewar maintains the operating temperature of the battery pack and electronics near room temperature for at least four hours.

The heat shield allowed the use of low temperature electronic components. Rechargeable batteries were used to power the sampler motor and to enable several samples to be taken over a period of time. The Los Alamos sampler requires current in one direction to turn a DC motor to open an intake valve, followed by current in the opposite direction to close the valve. A relay was used for this operation, but precautions were taken to assure satisfactory operation. For example, if the tool is traveling at speeds up to 300ft./min. downward for 10,000 feet, the relay contacts could bounce and cause false operation of the circuit. Similarly, the operation of the DC motor in the sampler tool requires 100VDC, but continuous application of 100VDC to the relay contacts would cause them to be welded closed. A circuit using commercially available solid state timers and relays was designed to overcome this problem. In addition, a current cut-off circuit was designed to protect the battery, electronics, motor and mechanical moving parts of the sampler.

This report reviews the development, testing and successful use of the dewared electronics package.

TIMING CIRCUITRY

The main timer in the circuit is an Artisan 115V 438A solid state timing module delay-on-make controller. The particular one selected had a timing range of 30-8000 seconds ±10 percent and the maximum time delay was set using a 10 meg ohm resistor. For our purpose, this allowed approximately two hours and thirteen minutes of delay before the sampler tool valve opening operation. The Figure 1 block diagram shows switch SW1 is closed to start the main timer. The switch is closed just prior to attaching the stopper which supports the electronics and battery pack and seals the dewar section of the tool. The current diagram just below the block diagram in Figure 1 indicates a very low current starts to flow when SW1 is closed. This low current operates the timing circuitry in the main timer DT1.

After the main timer runs down, maximum negative voltage from the battery is gated to the inveral timer IT1. IT1 is an 120V IDEC interval timer adjustable in 10 second increments from 10 seconds to 630 seconds using binary dip switches. Although the timer is set for 60 seconds, actual operating time is 65 seconds. As noted by the current diagram in Figure 1 and schematic in Figure 2, when the negative voltage is gated to IT1 by DT1, interval timer IT1 allows maximum negative voltage thru R2 to the normally operated contacts of a Potter & Brumfield relay RL1 and in turn to one lead of the motor. Since the positive voltage is already applied through another set of normally operated contacts of relay RL1 and RL4 to the other lead of the motor, the polarity of the voltage causes the current to flow through the motor to turn it in a direction to open the valve in the sampler tool. IT1 also applies maximum negative voltage to a Potter & Brumfield delay timer DT3. This starts the timer DT3. After approximately 16 seconds, the timer in DT3 runs down and applies maximum negative voltage to one side of the operating coil in relay RL1. Since there is already positive voltage applied to the other side of the operating coil, relay RL1 operates, opening the normally closed pair of contacts and voltage is removed from the motor. Reversed polarity from the battery is applied to the motor through a different pair of newly closed relay contacts and would cause the current in the motor to reverse direction and close the valve in the sampler tool. The positive voltage to the motor is delayed, however, by another Artisan solid state timing module delay-on-make controller DT2 to prevent relay chatter. It is identical to DT1 but is set for the minimum time of 31 seconds. After the 31 seconds, DT2 allows current through the motor in the opposite direction and the valve starts to close. After approximately 18 seconds for valve closing, interval timer IT1 runs down and maximum negative voltage to DT3 and RL1 is removed, effectively removing all negative voltages from relay RL1 and stopping the motor from turning the valve. The relay is again isolated from battery voltage and cannot adversely effect the sampler as the tool is hoisted out of the hole.

CURRENT CUT-OFF CIRCUIT

Figure 2 shows the current cut-off circuit outlined by the dashed lines. A 500mAmp fuse in the positive lead from the battery will prevent damage to the electronics if a short should occur in the interface between the motor and electronics. During normal operation, the cut-off circuit will prevent excess current through the electronics and motor should the valve stop be encountered in the opening phase. The valve in contacting the stop would increase the load to the motor and cause it to gradually draw more current until approximately 300mAmp is reached. On the closing phase, especially since we now have more closing time than opening time (by 2 seconds), the sampler bottle valve could be broken at the end of the closing cycle due to the high torque potential of the motor. Again the current cut-off circuit will remove current from the motor at approximately 300mAmp. The size of resistor R2 determines the maximum allowable current. Initially the motor requires greater than 300mAmp but less than 500mAmp to start (see current diagram Figure 1). DT4 is set for 2 seconds to prevent the current cut-off circuit from operating during the initial motor start current level. After 2 seconds, silicon controlled rectifier SCR1 is switched into the circuit by RL2. Excessive current to the motor causes a voltage drop across R2 greater than 0.7 volts and switches on SCR1. The anode to-cathode voltage of SCR1 in the conducting region is approximately 2V. This voltage, also across the relay RL4 coil, is far below the relay's holding voltage (15V). Consequently, the relay opens, disconnecting the motor from the battery. On the valve closing cycle, DT4 has voltage removed during the delay time of DT2 and causes relay RL2 to release and reset the current cut-off circuit. The current cut-off circuit operates again identical to the valve opening cycle. The four diodes CR1-CR4 insure the correct voltage polarity is applied to the DT4 timer.

BATTERY PACK

Previous experience dictated the use of a rechargeable battery to power the sampler motor. Since NiCad batteries had been used successfully in an Inertial Navigation System for Directional Surveying (See Sandia Report SAND82-1668), the decision was made to use them in the battery pack for the sampler tool as well. NiCad cells have been found to be safe in a high temperature environment. The batteries did not exhibit any dangerous adverse effects in our oven at temperatures to 185°C. Industrial type 1.2V NiCad cells were initially used to build the battery pack but later tests with commercially available 7.2V batteries (each with 6 1.2V NiCad cells) proved to be more reliable at high temperatures. To keep the size of the battery within reasonable limits, a 110mAh cell was selected. This cell had a 0.55" diameter and was 0.65" in height.

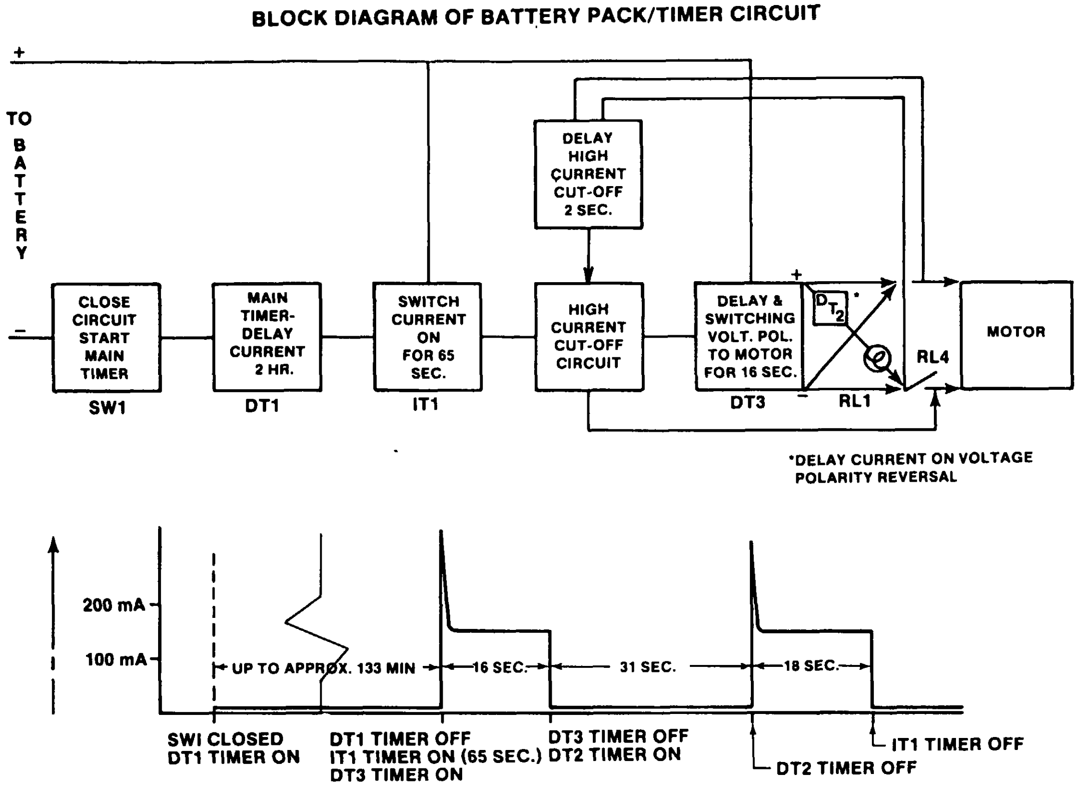

Figure 1. Block Diagram and Current Flow of Battery Pack/Controller

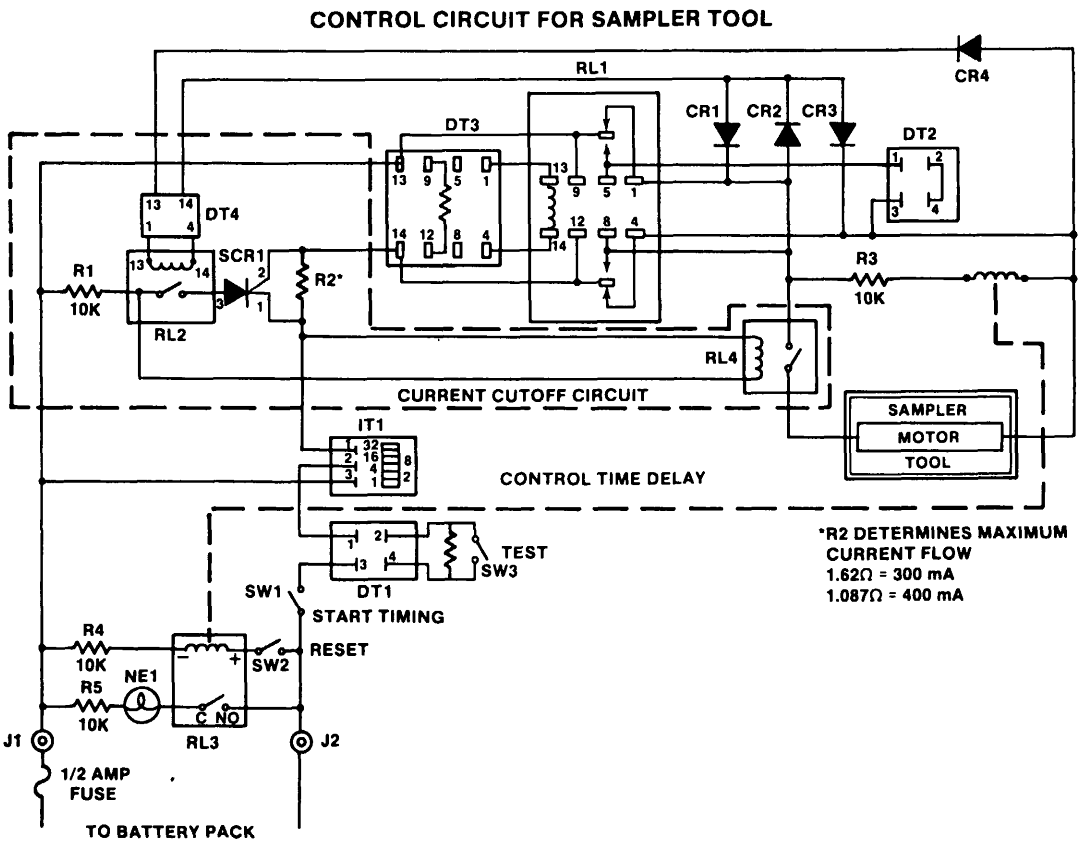

Figure 2. Control Circuit for Sampler Tool

Eighty-four of these cells were used in a circular form of 14 layers with 6 cells in each layer (See Figure 3). The forms are made of teflon. A maximum discharge current of 150mAmp would occur for a maximum period of 34 seconds (16 seconds opening the valve and 18 seconds closing the valve). It is calculated that two downhole runs of the sampler tool could be made between battery charges using the 110mAh capacity cells. Although the NiCad cells are rated at 1.2V, the cells can be charged to approximately 1.35V. We learned that the cells discharge rapidly after discharging to 1.2V. Thus, our 84 cells would provide an initial voltage of approximately 114V and would discharge rapidly at voltages less than 100V. It is important not to discharge rapidly below 84V to prevent cell reversal. Cell reversal will generally occur at or below 1V/cell. The industrial 1.2V NiCad cells were tested in the oven and rapidly discharged and lost their capacity at 70°C. They are no longer rechargeable after this occurs.

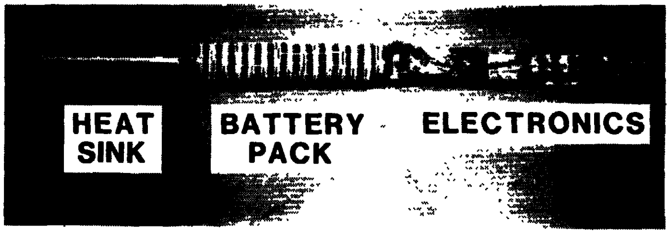

Figure 3. Battery Pack/Controller

Commercial 7.2V NiCad batteries were tested in the oven and surprising results were obtained. Three different brands were tested with a 100 ohm resistor load and all three operated at temperatures in excess of 180°C although their cases were distorted as seen in figure 4. The batteries would operate at 100°C and still recharge (see Figure 5). The batteries would not recharge when operated at 150°C but still performed satisfactory. Figure 6 shows a battery pack constructed with the 7.2V commercial batteries.

Figure 4. 7.2V Batteries after 180°C Heat Test

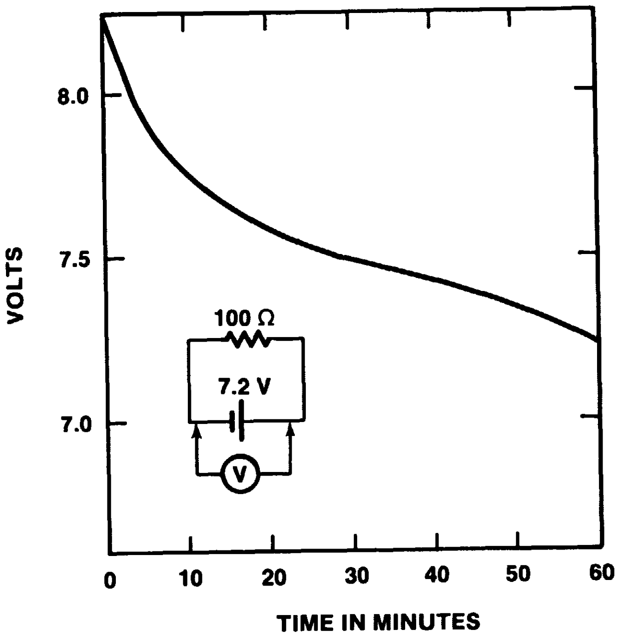

Figure 5. 7.2V Battery Discharge at 100°C

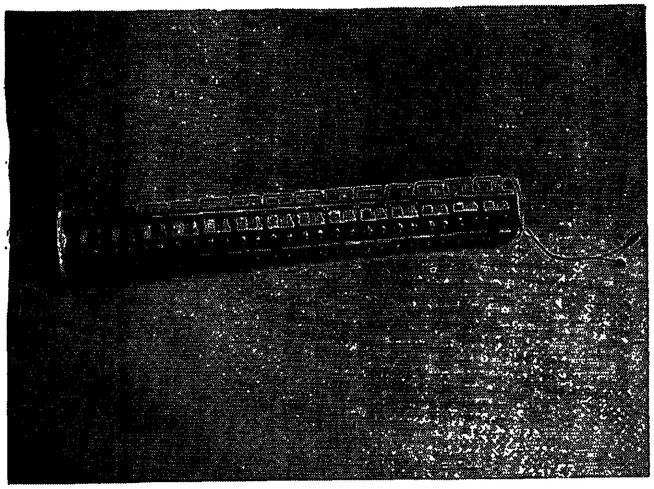

Figure 6. Battery Pack with 7.2V Commercial Batteries

TESTING

The battery pack/controller as a unit was tested in our laboratory with an identical motor used in the Los Alamos National Laboratories sampler. The motor was mechanically loaded to simulate actual operating conditions. The current cut-off circuit was adjusted at this time by selecting the value of resistor, R2 (see Figure 2), to cause relay RL4 to release when the shaft of the motor was mechanically stopped and the current amplitude was 300mAMP.

A diagnostic test circuit consisting of switches SW2, SW3, magnetic latching relay RL2 and neon lamp NE1 per Figure 2 were incorporated into the design. The operation of switch SW3 shortens the main timing to 31 seconds and allows a quick check of the unit's operation by observing lamp NE1. The lamp will light if the last timing cycle in the sequence is missed.

The battery pack/controller was tested in the oven at a temperature of 69°C for four hours without being enclosed in a dewar and operated successfully. Before operating it in the field, the unit was taken to LANL and successfully operated their sampler tool several times while the tool was in an oven heated to 300°C.

FIELD RESULTS

The sampler tool was operated successfully on March 25th 1986 at the SSSDP when 1500ml of fluid was obtained at 10,200 feet and 340°C. The main timer was started and the sampler tool held on the surface until there was just enough time to send the tool to the desired depth at 300 feet per minute before the valve opened. The tool was allowed to remain at a depth of 10,200 feet for twenty minutes and returned to the surface at 300 ft./min. This maneuver was successful in preventing the motor from overheating. The motor in the sampler was outside the dewar and had minimum protection against the heat. The motor was still operational after the sampler was removed from the hole.

CONCLUSIONS

1. A dewared electronic package was designed to open and close the valves in the sampler tool at temperatures up to 400°C for 4 hours.

2. The system design included safety devices to prevent motor burn out, full battery discharge and damage to the sampler valves.

3. The electronic and battery package performed successfully in laboratory tests for 4 hours at a temperature 50°C above room temperature without being enclosed in a dewar.

4. The sampler tool was operated successfully with the battery pack/controller at the SSSDP on March 25, 1986.

5. This electronic package has the potential for application to other downhole operations at extreme temperatures.