ELECTROHYDRAULIC EFFECT

By L. GEORGE LAWRENCE

Intense mechanical shock waves that are produced by underwater discharges of stored electrical energy, may be used to work metals, split rock, or propel marine vehicles.

WHEN stored electrical energy is suddenly released by high-speed electronic switches and electrodes immersed in water, an intense mechanical shock wave is created. The wave is characterized by a steep leading edge and a minor bubble pulse trailing at the end. Termed *electrohydraulic effect,* it's an easy way to convert electrical energy into a moving force. It can be used to press hard-to-handle metals like titanium and niobium into dies, spall cathode plates, split hard rock, and propel marine vehicles. The number of possible uses is restricted only by the imagination of the practical engineer.

Principles of Operation

Electrohydraulics apparently originated as a technical parlor demonstration. Decades before the turn of the century, educated experimenters contrived various types of so-called "electric pistols" and "Leyden artillery." These potentially very dangerous devices consisted of little more than an elongated cylinder containing two insulated spark-gap electrodes and some water. A lightweight stopper or projectile sealed it off. Then, by discharging a battery of Leyden jars through the electrodes, both water and stopper would blast free.

This seemingly primitive principle contains the basic components of modern energy-discharge systems: (1) d.c. energy-storage capacitor, (2) discharge electrodes, (3) force-transfer liquid, and (4) a tank. The technique, taken together, was refined by the Russian scientist L. A. Yutkin and demonstrated, in 1938, as an industrial tool for metal forming.

A basic electrohydraulic system is shown in Fig. 1. The necessary high voltage, about 20 kV, is obtained from a line-operated d.c. power supply and charges a capacitor storage bank rated from 1 to 15 microfarads. Safety devices "bleed" the circuit *via* high-resistance discharge paths. When the electronic trigger circuit is activated, energy is rapidly dumped into concentric or opposing spark-gap electrodes submerged in the water-filled tank. The resulting shock wave is directed at the work piece, as shown in Fig. 2. In this example a metal sheet (at the left) is being forced into a prepared forming die.

Although the outward appearance of the electrohydraulic effect is that of a simple chemical explosion (*i.e.,* flash of light, noise, hefty splash of water), its constituents are much more complex.

Unlike a chemical explosion whose dynamics are measured in terms of milliseconds, the electrohydraulic event takes place in microseconds. The sudden release of stored energy results in the generation of a small vapor bubble which, for all practical purposes, acquires the characteristics of a plasma. Its temperature can be as high as 30,000° C, accompanied by pressures estimated to peak out at approximately 20,000 atmospheres. Active chemical species generated by the short-term plasma include hydroxyl (*HO*) radicals, ozone, hydrogen, and oxygen. This attendant electrochemistry is recognized as an effective method for destroying harmful micro-organisms in water and it might, in time, lead to the development of economical methods for treating polluted rivers and streams.

An electrohydraulic discharge unit suitable for laboratory applications is shown in Fig. 3. The safety spark gap, C_s, protects the main storage capacitor (C_e) from rupture caused by overvoltage.

The energy stored in capacitor C_e is calculated as: $W = ½(QE) = ½(CE^2) = Q^2/2C$ where W = energy, expressed in joules (or watt-seconds); Q = charge in coulombs; C = capacitance in farads; and E = applied voltage.

Using this equation, it can be shown that the efficiency for converting electrical input power to the electrohydraulic assembly is about 50 percent, that is, 2 kWh of power will provide 1 kWh or 3.6 x 10^6 joules of effective energy.

This energy can be fed to a variety of high-speed release devices, such as the ignitron or triggered spark-gap, to provide a rapid dumping cycle.

The spark-gap switch, as shown in Fig. 3, is triggered by a high-voltage pulse to start conduction. The pulse is supplied by transformer T_t which, in turn, has its primary pulsed by energy stored in capacitor C_t and released by the firing of the SCR.

If switch S1 is opened, the entire system can be triggered manually by a push-button. If S1 is closed, the UJT and its timing network are connected to the gate of the SCR and automatic pulsing is possible.

However, automatic pulsing—which requires an exact determination of power-supply capabilities—is not too common in simple electrohydraulic applications. The flasher can be used to trigger the UJT. This provides additional assurance

Table 1. Constituents of prepared "Sea-Rite" electrolyte.

Sodium	30.577 %	Chloride	55.035 %
Magnesium	3.725 %	Sulphate	7.692 %
Calcium	1.178 %	Bromide	.1868%
Potassium	1.099 %	Bicarbonate	.405 %
Strontium	.0382%	Fluoride	.0039%
Boron	.0135%		

Mixture of 35 grams to be dissolved in 1 liter of clean tap water.

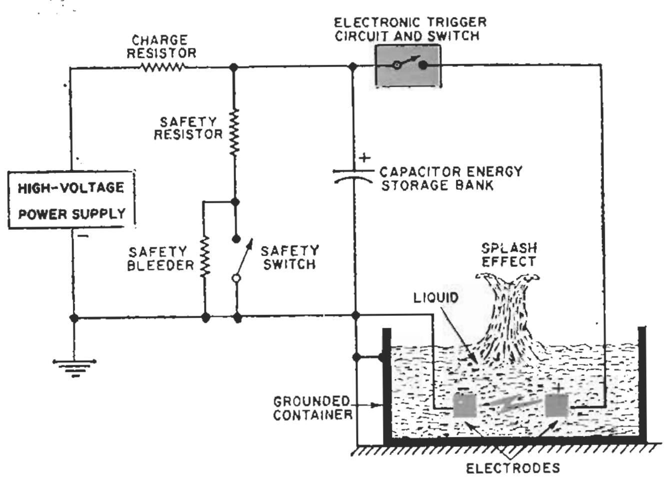


Fig. 1. Electrohydraulic system has power supply, trigger, storage capacitor, and submerged electrodes in circuit.

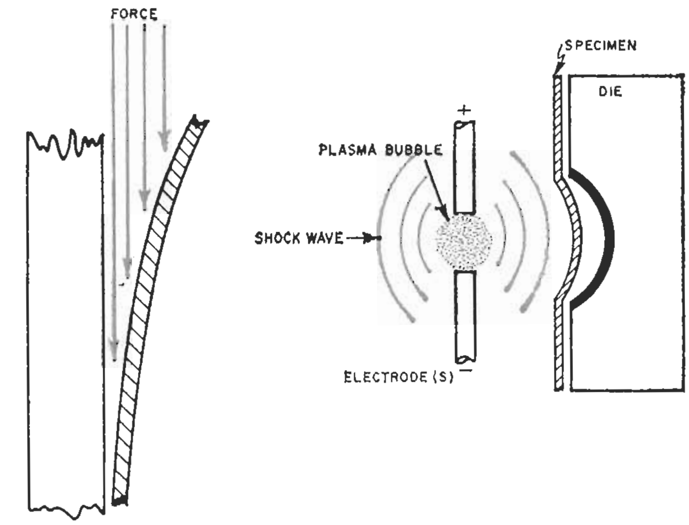


Fig. 2. Shock wave used for shearing (left), metal forming (right).

that the energy-storage capacitor C_e has been charged to its maximum design potential. The method, as drawn, depicts a non-synchronized, free-running triggering mode. The UJT trigger circuit and C_e's charging rate must be synchronized for marine and related applications.

Marine Electrohydraulics

Spark-type electrohydraulic systems have been used with great success in sea-bottom profiling. Typically, sparkers in a floating container are towed behind a research vessel. With input voltages of about 12 kV, the electric spark gives out a broad-frequency sound pulse. This noise, which sounds similar to the detonation of a small blasting cap, is directed toward the sea bottom. Hydrophones pick up the return echo and feed electrical signals to a graphic recorder. The method is similar to sonar, but considerably less complex and expensive.

The use of electrohydraulics for marine propulsion purposes is, at this time, entirely experimental. Although a very noisy method of propulsion, its main advantages are that rotating propellers and drive trains are not needed to move a ship.

However, underwater electrohydraulics are being used as "sounding" marker buoys. Sea-water batteries, samples of which are described in U.S. Patents 3,036,141 and 3,036,142, are used as system energizers. A typical sea-water battery may consist of 12 paralleled magnesium plates and 13 steel plates with a flash nickel plating, also connected in parallel. A battery having a total effective area of 8.7 square feet has an output power curve like that shown in Fig. 4B. The data was obtained with simulated sea water (see Table 1). Sold under the tradename "Sea-Rite," chemicals for making this water may be obtained from *Lake Products Co.*, St. Louis, Missouri.

Since the sea-water battery's output voltage is very low (about 0.25 volt at 10 amperes, or 2.5 W), a tunnel-diode type converter is employed to generate the potential necessary for the electrohydraulic effect. An intermediate acoustical chamber, filled with distilled water and coupled to the surrounding sea by means of a diaphragm, may be used to reduce corrosion and other damaging effects, including system electrolysis.

Squib Systems

Exploding bridge wires, connected to electrodes of a high-voltage discharge system, are technically known as "squibs." The device is popular in rocketry and certain areas of electrohydraulics. Squibs permit the use of low system voltages, typically below 5 kV. Using thin wire of 1 ohm per millimeter and not longer than 3 mm, an acceptable vapor envelope can be generated by discharging an 80 μF, 150 V d.c. capacitor through it.

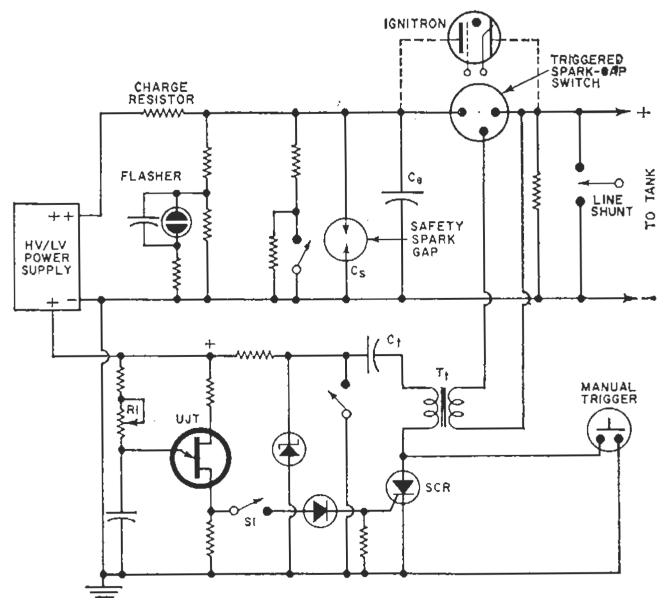
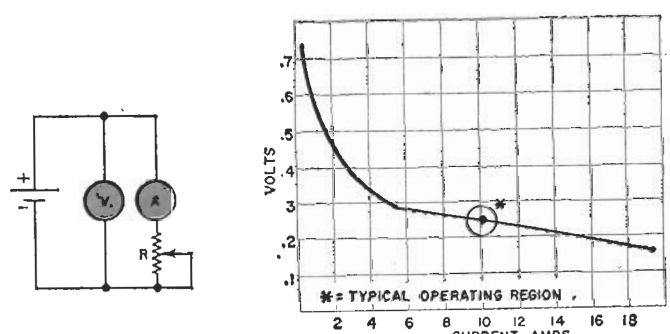


Fig. 3. Power unit schematic diagram. Either a triggered spark gap or ignitron can be used to discharge capacitor C_e into an external work circuit. See text for the details.



(A) (B)

Fig. 4. (A) Load-test circuit used to develop sea-water load curve. (B) Typical operating point is at 0.25 volt/10 amperes.

Because of their mechanical makeup, squibs necessarily limit the repetition rate of an electrohydraulic system. Self-arming spark gaps can be constructed by feeding exploding bridge wire (EBW) through and between insulated forks. However, the process consumes time and requires the use of threading mechanisms. But the technique is useful when working in liquid insulators such as oil.

Squibs and related EBW systems (*Continued on page* 86)

Electrohydraulic Effect

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can be checked by paradynamic switches, a principle of which was evolved by the author and shown in Fig. 5.

Paradynamic switches differ from classical switches in that a specimen under test is short-circuited rather than turned off. The effect is the same. Large currents are not allowed to pass through the specimen, since the switch provides an ultra-low shunt resistance. Contemporary crowbar circuits, used in some power supplies, are similar to this. During the short-circuit mode, a buffer protects the battery-type power supply from overloads. Paradynamic switches, equipped with high-current SCR's and timers, can stop test currents at any point of the dynamic "on" cycle, thereby permitting investigations of the glow and burn characteristics of squib wires intended for small-scale electrohydraulics and/or missile ignition systems.

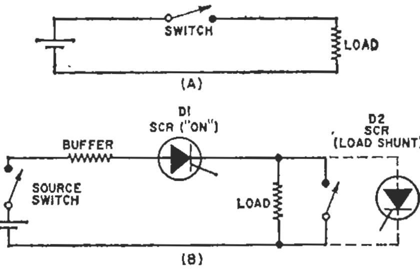

Fig. 5. Paradynamic switch is connected in shunt with power source and load. The buffer is used to protect power supply from overloads caused by short circuit.

Our discussion, which cannot be all-inclusive, might help to point out the features of various types of electrohydraulic systems and peripheral devices. The technology is a fluent one, offering much promise for now and for the immediate future. ▲

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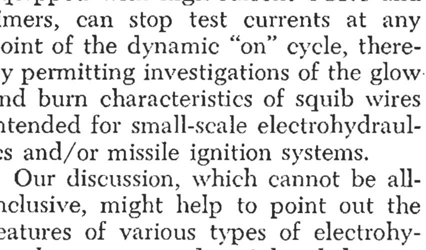

"It's your wife, again, with her nasty ultrasonic voice."