ELECTROPHRENIC RESPIRATOR: DESCRIPTION OF A PORTABLE ALL–ELECTRONIC APPARATUS

Recently Sarnoff and his collaborators have reported results of their experiments indicating that the respiration of laboratory animals and human beings may be artificially maintained by electrical stimulation of the phrenic nerve (1, 2, 3). The additional discovery by them of the possibility of providing artificial respiration in the human being by stimulating the phrenic nerve through the intact skin of the neck has caused sudden increase in interest in this investigation (4, 5).

With the apparatus used by these workers a stimulator is employed which produces a biphasic pulse of 3 milliseconds duration at a frequency of 60 per second. By means of a special type of motor driven potentiometer the intensity of the stimulus may be continuously cycled from zero to maximum to zero at any rate from 8 to 60 cycles per minute. Such a stimulus, when properly applied to the skin overlying the phrenic nerve, produces phasic contraction and relaxation of the diaphragm quite like that which occurs during natural respiration.

While equipment of this type has been shown to perform in a satisfactory manner, it nevertheless has several disadvantages in that it is cumbersome, contains moving parts which must be specially constructed and is not easily made sparkproof. To meet the criteria without these disadvantages, an all electronic, stable, inexpensive electrophrenic respirator was designed. Its performance has been found to be equally satisfactory.

The Instrument.—This electronic stimulator (fig. 1) operates from 115 volt AC power, using 20 watts. Since portability has been one of the objectives, the instrument is housed in a 4 inch by 7 inch by 10 inch sheet metal box with a handle, and weighs less than 7 pounds. The power
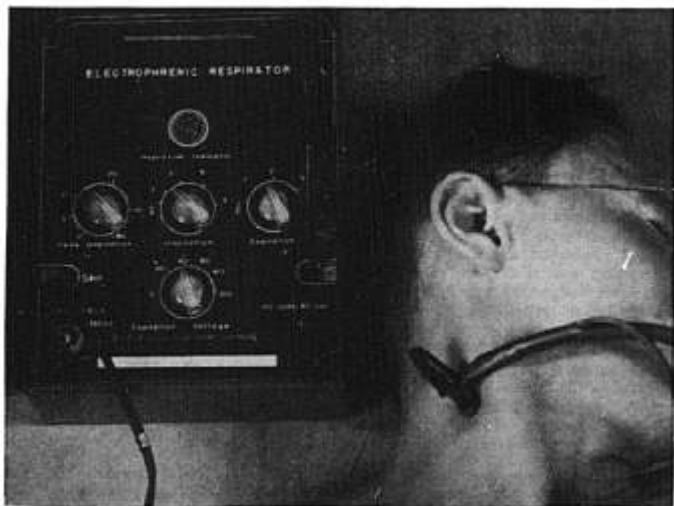

FIG. 1. Electrophrenic respirator showing the neck clip in place over the phrenic nerve.
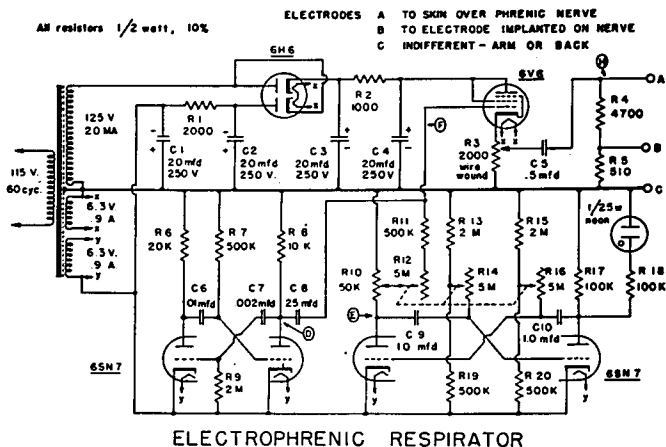
ELECTROPHRENIC RESPIRATOR

Fig. 2. Circuit diagram.

cord, electrodes and a bottle of saline solution are carried in the box. To prevent the occurrence of sparks, no switches are used, the electrodes are wired directly to the apparatus without connectors, and tubes were chosen which are available in unbreakable metal types. There are four controls on the model shown in figure 1. Peak Inspiration controls the depth of inspiration by varying the voltage output at the peak of inspiration from 0 to 40 volts. Inspiration and Expirations controls are used to adjust independently the actual time duration of inspiration and expiration. Together they control the respiratory rate. Expiration Voltage is a compensation control for loss of power in the skin, helping to produce a longer, smoother expiration. This control may be omitted as will be explained in the section on the circuit. The Inspiration Indicator is a small neon glow lamp which lights during inspiration.

Circuit Operation.—The circuit (fig. 2) consists of three units. One produces the stimulus, one turns it on and off slowly and rhythmically and the third amplifies the power of the stimulus. In addition, a standard power supply is used to provide direct current. Figure 3 demonstrates the

voltage wave forms representing the output of each of the three units. Letters D, E, F, and H refer to the corresponding points on the circuit diagram (fig. 2).

The first of these three units, producing the stimulus, is the left hand dual triode type 6SN7 multivibrator. It is a free running multivibrator that provides 2 millisecond positive pulses of frequency 70 per second at point D. These pulses are flat-topped and rise and fall in less than 0.05 milliseconds (fig. 3D). The second of the units is the right hand dual triode type 6SN7. It is also a free running multivibrator which provides the "envelope" that cycles the stimulus on and off to give inspiration and expiration. Its output is a square wave pulse appearing at point E (fig. 3E). Control R16 labeled Inspiration (seconds) varies from ½ to 4 seconds, the time duration of the pulses producing the inspiration phase. Control R14, labeled Expiration (seconds) varies the time between these pulses over a range of ½ to 4 seconds.

As an alternative method of construction, these two controls, R14 and R16, may be mechanically connected together by using a 3 gang, 5 megohm potentiometer (the

third being R12 to be described). A single knob then controls the respiratory rate, varying it from 8 to 60 per minute.

The outputs of these two units are mixed together at point F by connecting both to the control grid of the 6V6 power amplifier (fig. 3F). The 2 millisecond stimulus pulse is applied to this grid through a condenser C8 while the cycling pulse is applied to the grid through a variable resistor R12. C8 and R12 form a low pass filter for the square wave cycling pulse from point E. As a result, the inspiratory pulse coming through R12 slowly charges up C8 from − 80 volts to zero volts (average) measured at point F. During the expiratory phase the charge on C8 falls slowly

again to − 80 volts. The rate of rise and fall is controlled by R12 which is ganged with R16 (Inspiration), and with R14 (Expiration) if desired. For a long inspiration R12 is large and C8 charges up slowly; for a short inspiration, R12 is small and C8 charges up rapidly. It is desirable to have the charge on C8 reach maximum just at the end of inspiration to obtain the smoothest diaphragmatic descent. These circuit constants achieve this result. Thus, although the stimulus pulses are continuously applied to the 6V6 grid, during expiration the voltage on C8 is so far negative to ground that the stimulus pulses never cause the 6V6 to conduct. As
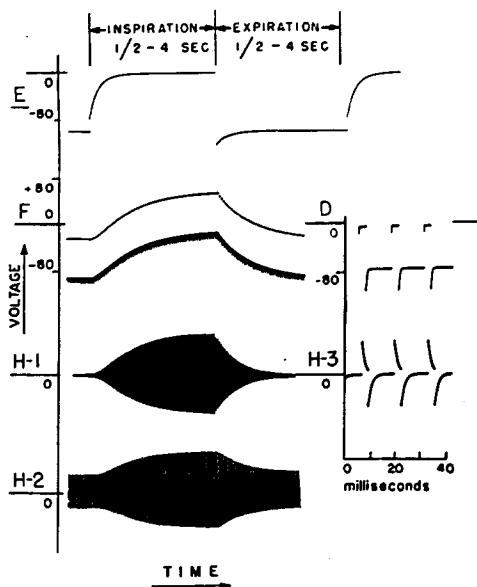

Fig. 3. Oscillograph tracings of voltage wave forms at points D, E, F and H in figure 2. D: The 2 millisecond stimulus pulse occurring at 70 pulses per second. E: The variable pulse used to cycle respiration. F: The sum of D plus the low frequency components of E (the low pass filter is made of R12 and C8). H-1: Output across 2000 ohms (the approximate skin resistance with the Expiration Voltage control R10 set at 0 per cent (of peak inspiratory voltage). H-2: Same as H-1 except the Expiration Voltage control is set to 50 per cent (of peak inspiratory voltage). H-3: Output as in H-1 or H-2, plotted on an expanded time scale.
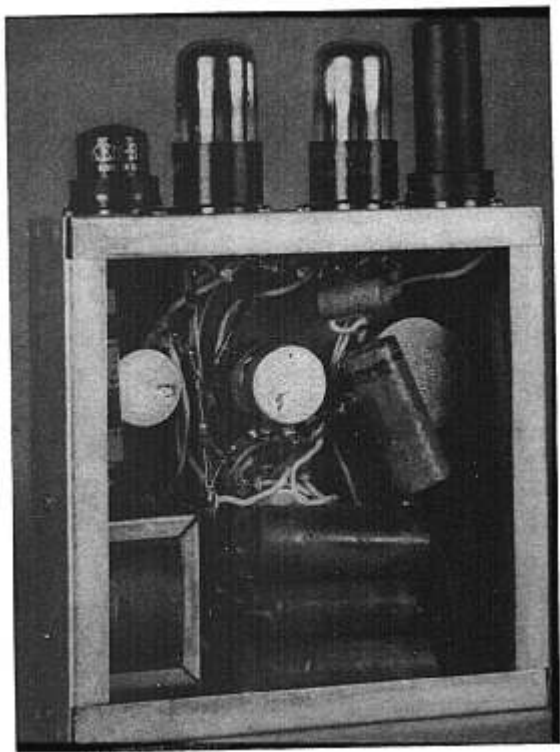
FIG. 4. Rear view of electrophrenic respirator.

the average voltage at point F rises during inspiration, each succeeding 2 millisecond pulse drives the 6V6 grid more positive, resulting in a series of increasing current pulses through the tube.

The 6V6 power amplifier is a cathode follower. Since the grid is never driven positive to the cathode, it never draws grid current. The power output is taken from the cathode resistor R3 which is a potentiometer voltage divider labeled Peak Inspiration (volts), controlling depth of respiration.

The output is coupled to the skin electrode through C5. The flat-topped positive pulse (fig. 3D) is differentiated into a biphasic decaying stimulus (fig. 3H–3) by an R–C circuit composed of C5 and the skin resistance in parallel with R4 and R5. Skin resistance varies with electrode contact, but is usually around 2000 ohms.

For use with an electrode implanted directly on the phrenic nerve, the voltage is reduced tenfold by the voltage divider R4–R5 to prevent nerve damage by overstimulation.

As has been previously indicated, the voltage wave forms are shown in figure 3 for circuit points D, E, F, and H. Figure 3H represents the output of the electrophrenic respirator. 3H-1 is the output wave form when the expiration voltage control is set at 0 per cent, or when R-10 is replaced by a 50K fixed resistor. In figure 3H-2 the expiration voltage control is set at 50 per cent, so the voltage of each stimulus pulse during expiration is held constantly at 50 per cent of the peak inspiratory voltage. The purpose of this control is to overcome the loss due to traveling through the tissues so that the diaphragm begins to contract at the beginning of the inspiratory phase instead of waiting while the pulse voltage rises slowly from zero to the point where it begins to stimulate the phrenic nerve. It also helps to prolong expiration as may be seen on comparing figure 3H-1 and 3H-2.

If this control is set at 100 per cent the stimulus voltage remains constantly at the setting of Peak Inspiration voltage. This may be useful for searching for the phrenic nerve, or for manual control of respiration, moving the Peak Inspiration control to cause each diaphragmatic descent.

If, for simplification, R10 is omitted, it is replaced by a 50K resistor and the lead from R12 is connected to point E. The disadvantages of omitting it are minor, and for most uses do not outweigh the simplicity derived from having only two controls—rate and depth of respiration. Figure 3H-3, on an expanded time scale, shows the shape of the differentiated pulses making up figure 3H-1 and 3H-2.

Power Supply.—The use of resistance coupling from the envelope multivibrator to the 6V6 control grid requires that the multivibrator be operated from a negative supply voltage and the 6V6 from a positive voltage. By using a 6H6 and single wave rectification these two supply voltages, plus and minus 130 volts, are obtained with one transformer winding of 125 volts AC and one rectifier tube. The current drain for each side is 8 milliamperes, maximum. Two separate filament windings are needed because of the 130 volt difference in cathode potential of the 6V6 and the 6SN7s.

Electrodes.—The indifferent electrode is a metal plate covered with cloth and wet with saline solution. This is at ground potential, and is placed under the back or strapped to the arm.

The phrenic nerve skin clip-on electrode is shown in figure 5. It contains a small saline reservoir to keep the cloth tip wet.

RUBBER DROPPER
SALINE RESERVOIR
COPPER TUBING 1/4" O.D.
SPRING-WIRE NECK CLIP
LATEX TUBING 3/8" O.D.
LEAD WIRE
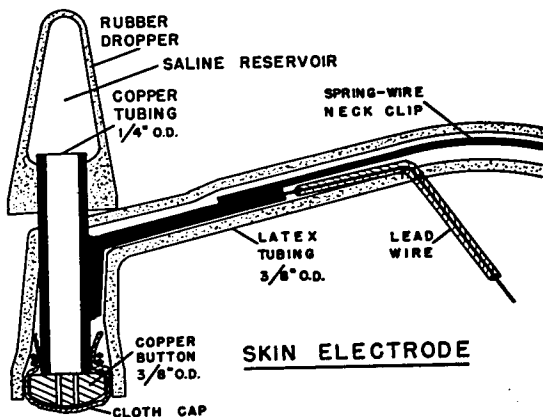COPPER BUTTON 3/8" O.D.
SKIN ELECTRODE
CLOTH CAP

Fig. 5. Detail of the skin clip-on electrode with saline reservoir.

The tip is a perforated, rounded button soldered to the end of the tubing reservoir. The spring clip, reservoir and the sides of the electrode tip are covered with a single piece of latex tubing. In some cases, manual control of the electrode is needed to prevent it from slipping off the phrenic nerve.

For emergency use and short term stimulation, a probe electrode is more satisfactory than the clip-on type. The probe (not shown) has the same construction at the point where it contacts the skin.

SUMMARY

An inexpensive, portable all electronic electrophrenic respirator has been designed to eliminate some of the disadvantages of electrophrenic respirators using motors. The operation of the circuit and the construction of clip-on neck electrodes are discussed briefly.

REFERENCES

1. Sarnoff, S. J.; Hardenbergh, E., and Whittenberger, J. L.: Electrophrenic Respiration, Science 108: 482 (Oct. 29) 1948.
2. Sarnoff, S. J.; Hardenbergh, E., and Whittenberger, J. L.: Electrophrenic Respiration, Am. J. Physiol. 155: 1-9 (Oct.) 1948.
3. Whittenberger, J. L.; Sarnoff, S. J., and Hardenbergh, E.: Electrophrenic Respiration. II. Its Use in Man, J. Clin. Investigation 28: 124-128 (Jan.) 1949.
4. Sarnoff, S. J.; Gaensler, E. A., and Maloney, J. V.: In press.
5. Sarnoff, S. J.; Maloney, J. V., and Whittenberger, J. L.: In press.

JOHN W. SEVERINGHAUS, M.D.,
Department of Physiology,
Columbia University,
College of Physicians and Surgeons,
New York, New York.

SERIAL STELLATE GANGLION BLOCK

Many technics of blocking the stellate ganglion have been described. We wish to report a case in which the stellate ganglion was continuously blocked for a period of ninety-six hours through a plastic catheter placed in the region of the stellate ganglion.

A 65-year-old colored man was admitted in a semicomatose condition as 7:30 a.m. on January 17, 1950, with right hemiplegia of about one hour's duration. The diagnosis of cerebral thrombosis was made by members of the medical service. At 8:30 a.m. a left stellate ganglion block was carried out with 2 per cent procaine, with no results. At 3 p.m., using the anterolateral approach, a 22 gauge 3½ inch spinal needle was placed on the anterolateral surface of the seventh cervical vertebra and its position confirmed by fluoroscopic examination. A 15 gauge needle was then passed beside the 22 gauge needle to the same location. A small plastic catheter was passed through the large needle to the surface of the vertebra and the large and small needles were withdrawn. A

small amount of neo-iopax was injected through the plastic catheter and, on the roentgenogram, diffusion was seen in the tissue at the level of the seventh cervical and first thoracic segments just to the left of the midline.

Procaine, 5 cc. of a 2 per cent solution in 1 to 1500 pontocaine, with out epinephrine, was injected every four hours for ninety-six hours. The patient was able to eat in twenty-four hours and had recovered much of the motor power of the right leg in forty-eight hours. The catheter was removed ninety-six hours after its insertion.

This report is intended not to demonstrate the value of stellate ganglion block but only to present a method of prolonging the block without destruction of the ganglion.

WARREN F. SERGENT, M.D. AND
JOHN J. OWEN, M.D.,
Department of Anesthesia,
St. Joseph Hospital,
Lexington, Kentucky