ELECTROFISHING BOATS

IMPROVED DESIGNS AND OPERATIONAL GUIDELINES TO INCREASE THE EFFECTIVENESS OF BOOM SHOCKERS

Technical Bulletin No. 73 DEPARTMENT OF NATURAL RESOURCES Madison, Wisconsin 1974

ABSTRACT

The first segment of this manuscript presents basic concepts and design guidelines for electrofishing boats including a summary of problem areas, descriptions of the basic aspects of electrical, safety, and electrode systems, and general design and operating guidelines.

Experimental and operational ac-pulsed dc and ac electrofishing boats designed during the project are described in detail in the second segment. Electrofishing performance and operating guidelines based on actual field operation as well as design information on power supplies, controls and electrode systems are presented. Supporting information on electrofishing safety, calculation of electrode resistance, wiring diagrams, and lists of components used in the newly designed electrofishing boats are included in the appendixes.

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Improved Designs and Operational Guidelines to Increase the Effectiveness of Boom Shockers

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Madison, Wisconsin
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INTRODUCTION

The use of electrofishing equipment mounted in small boats to sample fish populations in freshwater lakes and rivers has been an accepted and useful practice for many years. The equipment employed is nearly always locally designed and great variations in techniques and performance are reported (Myers 1951, Rollefson 1958, Burnet 1959, and Patten and Gillaspie 1966). To a large extent this wide variation in equipment and technique is a result of the great variability of water conditions, fish species and sampling needs in freshwater lakes and large rivers coupled with the fact that almost any electrofishing system will allow capture of some fish under conditions suitable to the particular system. In contrast, the less varied demands of electrofishing in small streams has resulted in more uniform and thus more highly developed methods (Cuinat 1967, Novotny and Priegel 1971).

The objectives of this study were to survey the equipment and techniques in use, to clarify the impact of the electrical variables influencing performance, to develop guidelines for constructing and operating fixed-electrode electrofishing boats, to build and test new types of such boats, and to pinpoint areas where additional developmental research should be carried out to provide future improvements in electrofishing methods.

Typical ac electrofishing boat used in Wisconsin for many years.

STUDY METHODS

Because of the wide-ranging objectives the approach used in carrying out the study involved a number of separate but interrelated activities, including: (1) literature searches on electrofishing systems and the response of fish to electrical stimulation; (2) field tests and observations of existing electrofishing boats; (3) theoretical and experimental evaluation of electrode systems; (4) design, construction and field testing of an experimental boat capable of operating with alternating current, direct current or pulsed direct current; and (5) surveys of the performance of existing, modified and new (experimental) boats over a wide range of operating conditions. (See Appendix I for sample of survey form.)

The results of these various activities can be generally organized into two categories, which form the basic format of this report: basic concepts and design guidelines, and experimental and operational systems.

PART I: BASIC CONCEPTS AND DESIGN GUIDELINES

SUMMARY OF PROBLEM AREAS

Basically, the function of an electrofishing system is to produce a sufficient electrical stimulus in fish near the electrodes to permit easy capture by netting. In an alternating current (ac) system the electrical stimulus simply immobilizes fish (electronarcosis or electrotetanus) requiring the net handlers to dip fish from considerable depths or distances from the boat. Often fish are immobilized at depths beyond reach of the dipper and are not susceptible to capture at all. In a direct current (dc) or pulsed direct current system, fish near the anode exhibit forced swimming (electrotaxis) toward the anode and are hence more easily netted. It is quite well established that fish are much more susceptible to ac than to dc and hence the radius of action of an ac electrofishing system operating at a particular voltage is much greater than a dc system at the same voltage. Pulsed dc is more effective than dc and to some extent combines the desirable forced swimming response of dc with the larger radius of action associated with ac.

Work done on electric shock response in humans (Dalziel and Lee 1968) has shown that electric current is the best measure of the strength of the sensible shock effect. Similar results regarding electrofishing effects are indicated by the work of Cuinat (1967) and by our own work in both the present study and the earlier work on stream shocking (Novotny and Priegel 1971). These results imply that the primary function of the electrofishing system is to establish an electric current in the water near the fish. A portion of this current (depending upon the ratio of fish and water conductivity) will pass through the fish and if of sufficient magnitude will elicit the desired response. The important point is that the current is the variable of concern. Electrode voltage, spacing, size, etc., are important parameters only to the extent that they influence the current.

Based on this concept, for any electrofishing system there exists some minimum value of current per electrode which will affect fish out to some specified distance from the electrode. This minimum current will depend upon electrode shape, nature of current (ac, dc, pulsed), desired range of action, fish species, water temperature, water conductivity and probably many less obvious factors. Of these factors only electrode shape and type of current are under control of the designer. All other factors are external variables which must be compensated for by variations in the operation of the boat. Based upon the surveys, field tests and literature review carried out during this study, the following specific problem areas were identified:

Range Limitation. The distance at which fish are affected can be too small to produce useful sampling results. This is often caused by incorrect electrode arrangements and insufficient current (and power).

Water Conductivity. Low water conductivity makes it very difficult to attain sufficient currents to produce useful electrofishing responses. Lennon and Parker (1958) who found extreme conductivities in Appalachian mountain streams, attacked this problem by adding salt to the water to improve electrofishing. Extremely high water conductivities call for currents too large to be supplied by portable equipment without special electrical control methods. For very high conductivity, dc is ineffective (Vincent 1971) and pulsed dc or ac may be more effective. Other factors that are important are voltage and electrode size.

Water Clarity and Vegetation. Turbid water and excessive vegetation restrict visibility and reduce the value of the immobilizing capabilities of the ac electrofishing. Pulsed dc and dc offer potential solutions to this problem.

Water Depth. Fish which are immobilized at depths exceeding 0.9-1.2 m (3-4 ft) are very difficult to capture by ordinary netting procedures. Pulsed dc and dc should help to overcome this problem.

Bottom Materials. High conductivity bottom materials tend to "short circuit" the current out of the water into the bottom material reducing the electrofishing effectiveness and sometimes overloading the power source. Little can be done to remedy this situation except to use short electrodes (near the surface) to avoid direct contact between electrodes and the bottom.

Water Temperature. The conductivity of water and water temperatures are more or less a straight line relationship; that is, as the temperature of the water increases, the conductivity of the water increases at an equivalent rate (Sigler 1969). Theoretically, success of electrofishing should increase with temperature, but workers in the field have noted differently. Smith and Elson (1950) believed that salmon parr exhibited the best response below 25 C (77 F) and suckers at less than 20 C (68 F). Webster, Forney, Gibbs, Severns and Van Woert (1955) had greater success in shocking brown trout at 7.8 C (46 F) than at 16.7 C (62 F) when both ac and dc were used. The response of brook trout to dc current is low in cold water, but increases with the temperature to 10 C (50 F). As the temperature increases further, the response decreases (Elson 1942). Most salmonids are more easily captured by electrofishing when the water temperatures are low, 0-10 C (32-50 F) (Vincent 1971).

Fish Mortality. Mortalities caused by ac electrofishing probably are higher than those caused by dc or pulsed dc (Taylor et al. 1957) and the gross physical damage from ac can be severe (Hauck 1949). Harmful effects from pulsed dc are usually a result of excessive exposure or intense electrical fields (Pugh 1962). It can be easily demonstrated that fish can be killed with electricity in their natural environment, as well as under laboratory conditions (Pratt 1954; Godfrey 1956).

With electrofishing boats, mortality is usually associated with regions of excessively high current density close to the electrodes. Potential solutions involve electrode designs which avoid such regions of high current density by using larger electrodes and lower voltages. No injury to fish has been observed with dc or pulsed dc during the study.

Fish Size. Individual variation is notable among fish even though they are of the same species and have similar lengths. The laboratory experiment of Haskell et al. (1954) on brown trout demonstrated this variability.

The larger the individual of a species, the more sensitive it is to a given electric shock (McMillan 1928; McLain and Nielsen 1953; Taylor et al 1957). Fish absorb power as a function of body surface area and particularly length (Holzer 1931). Also, the greater resistance of smaller salmonids (Nakatani 1954) and possibly small fish of other species as well, further reduces their response to shocks. All of these factors contribute to capturing a greater proportion of large fish than are actually present in the population.

Fish Species. Some species are quite difficult to capture by electrofishing. The most notable are northern pike and muskellunge. It appears likely that this is caused by the strong swimming ability and natural tendency to escape danger by rapid swimming possibly coupled with a high sensitivity to electric fields. Operating at higher boat speeds when seeking northern pike and muskellunge is a potential advantage.

Large differences in response have been observed between various fish species when pulsed dc is used. Some selectivity in electrofishing may be possible because of the differences. There may be optimal wave forms and pulse rates which will produce selective and efficient electrofishing for various species.

Equipment and Operating Problems. Numerous problems associated with equipment limitations and lack of operating guidelines exist. Examples include inadequate lighting systems, insufficient power, lack of voltage controls, lack of proper instrumentation, poor electrode design, etc. Solutions to these problems are suggested in later sections.

The problems identified above demonstrate the need for developing guidelines for electrofishing systems capable of adjusting for variations in external conditions. The general guidelines and principles which resulted from the work carried out during the study are presented in the next section.

GENERAL DESIGN

Although the design and operation of effective electrofishing boats is still to some extent an art because of lack of basic data on fish responses to various levels and types of electrical stimulation, there are a number of basic concepts which are useful in guiding the development of new boats. In this section the principles, techniques and equipment specifications which appear to be generally applicable are presented. The material presented here has been utilized during the course of the study and has therefore stood the test of field evaluation by operating personnel.

Components of an Electrofishing System

The components of a fixed electrode electrofishing system can be classified into four subsystems according to function. These are:

(1) Boat and mechanical—to effectively and conveniently carry the complete system,

(2) Electrical—to generate, control, and deliver the electrical energy to the electrodes,

(3) Safety—to provide proper safeguards for operating personnel, and

(4) Electrodes—to properly couple the electrical energy to the water.

These four subsystems are treated in detail in the following sections.

Boat and Mechanical Components

Selection of the boat, motor and other mechanical components is largely a matter of individual choice relating to convenience, availability, ease of maintenance, etc. We have found 16- to 18- foot square-ended aluminum boats satisfactory. An aluminum boat offers the advantage of simple reliable grounding of all electrical equipment through the physical attachment of the equipment to the boat. Addition of any metallic structural parts to a fiberglass or wood boat would require careful grounding practices to assure electrical safety whereas such structures are immediately grounded through structural members in an aluminum boat.

Electrical System

In addition to the main generator the electrical system of an electrofishing boat should include an auxiliary generator and battery, metering, disconnect switches and overload protection, voltage controls and possibly power conversion equipment, and a safe and reliable system of interconnecting the various components. A means of rapidly disconnecting the power in case of emergency must also be provided as part of the safety system. The discussions presented in this section are intended to serve as a guide in selecting components and designing an electrical system appropriate to the type of electrofishing service to be encountered.

Main Generator. A three-phase ac generator provides the greatest flexibility. In ac electrofishing all three phases can be effectively utilized by proper electrode design. If dc or pulsed dc electrofishing is desirable, a transformer rectifier system provides a voltage controlled dc source without need for large filters as would be required with a single phase generator. Compared to a dc generator, the ease of controlling voltage with transformers to match the generator to water conductivity conditions is a major advantage of an ac generator.

The frequency of the generator (cycles/second or Hz) does not appear to be a critical factor in ac electrofishing effectiveness, 60 Hz, 180 Hz, and 400 Hz having been used without significantly different effects. Since higher frequencies offer weight advantages in designing suitable transformers, the highest of the commercially available frequencies is preferred.

Power rating is determined by the maximum water conductivity to be fished, the size of electrode which can be supported by the boat and by weight limitations. In general, electrofishing range and hence effectiveness increases with increased power and it would therefore appear that selecting the largest generator meeting weight limitations is desirable *unless* only very low conductivity waters are to be fished. Power and voltage requirements for the boats developed and used during this study are given in Table 1.

Auxiliary Generator and Battery. Use of an automotive-type, 12 volt dc system for auxiliary power has proved very effective. This scheme offers auxiliary power at all times, independent of whether the main generator is operating, and automatic recharging whenever the main generator is operated. The entire system consisting of generator, voltage regulator, meters and battery can be integrated with the main generator to form a compact self-contained unit. The low voltage is very desirable for safety, the system is reliable and repair parts and accessories are readily available from automotive suppliers.

Meters. To permit proper utilization of the equipment, provision of a suitable set of meters is essential. For ac electrofishing, one voltmeter and a set of three ammeters is sufficient. When transformers are used, it is convenient to place the ammeters in the primary circuit so the operator has only one maximum current limitation to remember. In addition to a voltmeter in the primary circuit to monitor generator performance, a second voltmeter in the secondary is useful to indicate the actual output voltage.

For dc operation a voltmeter and an ammeter are essential. In the case of pulsed dc, two voltmeters are useful: one to read peak voltage and one for average voltage. Comparison of the two readings yields information on the duty cycle of the output pulses.

Disconnects and Overload Protection. As in any electrical system a disconnect switch and overload protection must be provided. In an electrofishing system the electrical load can vary considerably because of changes in water conductivity (caused, for example, by an inlet stream). Such changes can cause overload conditions with subsequent circuit interruption unless the system is comprised by operating well below rated load for the normal water conductivity. For this reason circuit breakers are much preferred over fuses for protection of the main power circuits. Protection for the auxiliary power circuits and for diodes and other components in power conversion equipment can be provided by fuses since the primary need is for protection against misuse or equipment failure.

Voltage Control. The use of transformers to control the output voltage and thus provide a proper match between electrode resistance and the generator characteristic is extremely valuable. This is particularly true when it is necessary to operate over a wide range of water conductivity. As a general guide to the voltage range needed for various water conductivities, the voltage levels found useful for ac electrofishing during the study are presented in Table 1. Since the voltage level required depends greatly on the size and type of electrode system, the data in this table

TABLE 1. Voltage Ranges for AC Electrofishing

Conductivity (micromhos/cm)	Voltage (V)	Power (kW)
10-20	460*	2.0**
20-40	460*	3.5**
40-60	460-390	4.5*
60-100	390-320	4.5*
100-160	320-230	4.5*
160-350	230-160	4.5*
350-700	160-100	4.5*

*Denotes limit imposed by equipment rating.
**Denotes limit imposed by maximum electrode size.

should only be considered as a general guideline for electrofishing boats similar in size and type to those used in this study.

The power values given in Table 1 are included to indicate the levels employed in the study. Note that except for very low conductivities, the power was limited by equipment ratings and not by electrofishing considerations.

The transformers used during the study had fixed range settings as opposed to being continuously variable. This poses no limitation since the main engine-generator could be controlled over a speed range which allowed intermediate voltages when necessary. This arrangement has a considerable weight advantage over a continuously variable transformer since the windings can be designed to be operated at nearly maximum utilization on all range settings.

Interconnection System. Considerable benefit can be gained by combining as much of the electrical system as possible into a single package built around the main engine-generator. This avoids the need for mounting many separate components on the boat itself and results in simpler and more reliable construction. The system developed during the study combined the main generator, auxiliary generator and regulator, disconnect switch and circuit protection, metering and the safety disconnect system. This package is described in detail in a later section.

It is extremely important to pay careful attention to the selection of electrical hardware for use under the demanding conditions of electrofishing boats. Use of marine grade components wherever possible will prove invaluable in eliminating malfunction due to corrosion. Many of the most frustrating problems encountered during the field testing portion of the study were the result of component failures in the interconnection system. To avoid such problems, items such as power connectors and switches must be carefully chosen.

Safety Systems

The importance of safety considerations in electrofishing cannot be overemphasized. During the study, the question of safety was given great attention from both the design and operational point of view. A complete description of the electrical safety disconnect system is presented in a later section and a discussion of electrical safety and the safety regulations developed during the study are included in Appendix II. In general, the following items should be carefully considered in establishing design and operational guidelines for safe operation.

(1) Equipment must be selected and designed to avoid potentially hazardous situations. As specific examples, power connectors having metallic parts which could become energized through insulation failures and net handles which could form an electrical connection between the water and an operator must be avoided.

(2) A low voltage system should be used for all electrical functions except the actual electrofishing function.

(3) Proper grounding practices to assure that all metallic parts in the boat are joined electrically are absolutely essential.

(4) A rapid disconnect system is essential. In addition, to insure that each operator is at his assigned station, a set of weight actuated switches can be employed. Additional protection can be achieved by using a latching system requiring the crew chief to actuate a start button after observing that each crew member is in his proper position.

(5) Crews must be aware of the hazards associated with electrofishing equipment and be properly trained in safety and rescue procedures.

Electrode Systems

The electrode systems employed in most electrofishing boats vary considerably from boat to boat. This causes difficulty in interpreting survey data since the various systems are not easily compared in terms of readily measured variables. To provide a basis of comparison of various systems and to develop design procedures for effective electrofishing electrodes, a considerable portion of the study was devoted to electrode phenomena. This work involved a combination of theoretical, experimental and operational activity.

Electrode Requirements. The requirements of an effective electrofishing electrode system include:

(1) Establishment of an effective electric current distribution in the water to be sampled.

(2) Avoidance of local regions of unnecessarily large current densities which waste power and are potentially harmful to fish.

(3) Adjustability to meet changes in water conductivity.

(4) Ability to negotiate weeds and obstructions.

(5) Ease of assembly and disassembly.

(6) Avoidance of unnecessary physical disturbance to water to permit easy visual observation of fish.

Most electrode designs appear to have been greatly influenced by the last three factors without sufficient consideration being given to the basic question of producing an efficient and effective electrofishing current distribution.

Basic Electrode Phenomena. As the current supplied to an electrode passes into the water it spreads in all directions and creates the electrofishing field. The current and voltage associated with the electrode become *distributed* through the water and the nature of this distribution is critical to effective electrofishing. The electrical parameters used to describe the distribution are the current density (A/cm^2) and the voltage gradient (V/cm). These quantities are measures of the strength of the current and voltage difference at a point in the distribution and are related to each other by the electrical conductivity of the water (micromhos/cm) according to the relation:

$$\text{current density} = \text{voltage gradient} \times \text{conductivity}.$$

Note that for a given conductivity, current density and voltage gradient are directly proportional and that increased conductivity results in increased current for a fixed voltage gradient. While current density is easy to interpret, voltage gradient is somewhat less obvious. For purposes of this discussion it can be interpreted as the voltage difference between two closely spaced points divided by the distance between the two points. Summing up the voltage gradient along any path between two electrodes yields the voltage difference between the two electrodes.

There are many references which suggest that current is the variable most directly related to electrical effects on fish. For this reason, the current density in the water is probably the best measure of electrofishing effects and the discussion will focus on how the current density distribution varies for different electrodes. Because fish usually have a different conductivity than water, the current density in a fish is different than that which would exist at the location if the fish were absent. This is an important effect which will be considered later, but it is still appropriate to consider the current density in water alone as a basic measure of electrofishing effectiveness. This discussion of electrode phenomenon is therefore based on the assumption that there exist definite values of current density in fish which will evoke the various desirable (and undesirable) responses associated with electrofishing. There is some minimum current density at which fish perceive the electric field (perception level), a higher level at which the desirable effect of electrotaxis for dc or electrotetanus for ac occurs (effective level) and a still higher level at which the undesirable effects of electrotetanus for dc or lethal effects for ac occur (danger level). These terms will be used to describe the effective fishing field of electrodes.

As the current spreads into the water around any electrode, the current density must correspondingly drop off steadily as the distance from the electrode increases. Every electrode therefore has a near zone of high current density which may be above the danger level. Surrounding this nearest zone is a region in which the current density is in the effective range. The current density gradually drops off until it is no longer large enough to cause the desirable reactions, and this marks the end of what might be called the effective zone. Beyond this distance the current density continues to drop until it is no longer even above the perception level. Clearly an effective electrode is one which has a very small (or preferably no) danger zone, a maximum effective zone and the smallest possible perception zone.

The way in which the current and voltage are distributed in the water near an electrode (even without fish present) is a complex question. The distribution is completely determined by the size, shape and spacing of the electrodes and it is the complex shape of most practical electrodes which makes the problem difficult. Fortunately, there are two simple shapes, the sphere and the cylinder, which essentially form bounds between which most practical electrodes exist and which permit a somewhat simplified description of actual electrofishing distributions. By examining the behavior of these two simple electrodes and recognizing that most practical electrodes fall somewhere between, it is possible to obtain a basic understanding of electrode behavior.

Figure 1 summarizes the important properties of the current and voltage distributions of spherical and cylindrical electrodes. These properties are easy to obtain because of the symmetry of the distributions resulting from the simple shape of the electrode. Thus, for spherical electrodes spaced more than several radial distances apart, the current spreads essentially uniformly in all directions and the current density drops off in proportion to the square of the distance from the center of the sphere. For cylindrical electrodes, the current density is uniform along the length of the cylinder and hence falls off more slowly in proportion to the first power of distance. As a consequence of these differences, the voltage distribution and hence the resistance of the two shapes are quite different, as shown in Figure 1.

Figure 2 illustrates the important electrofishing aspects of spherical electrodes. The upper portion of the figure is a sketch of the current and voltage distribution in the water surrounding the electrodes. The lines joining the two electrodes are "current lines" drawn in such a way that the total current between adjacent lines is the same. Note that the lines are very close together near the electrodes, indicating

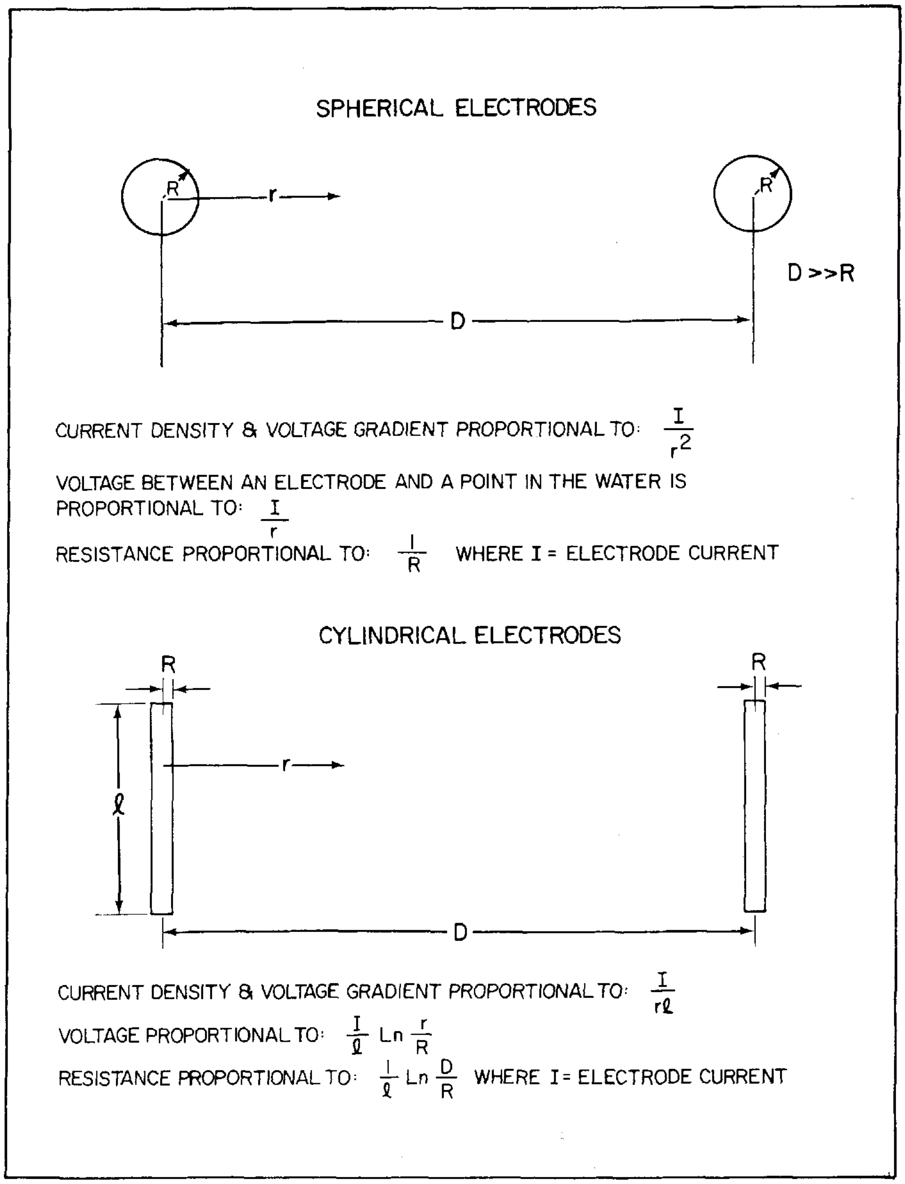


FIGURE 1. *Properties of spherical and cylindrical electrodes*

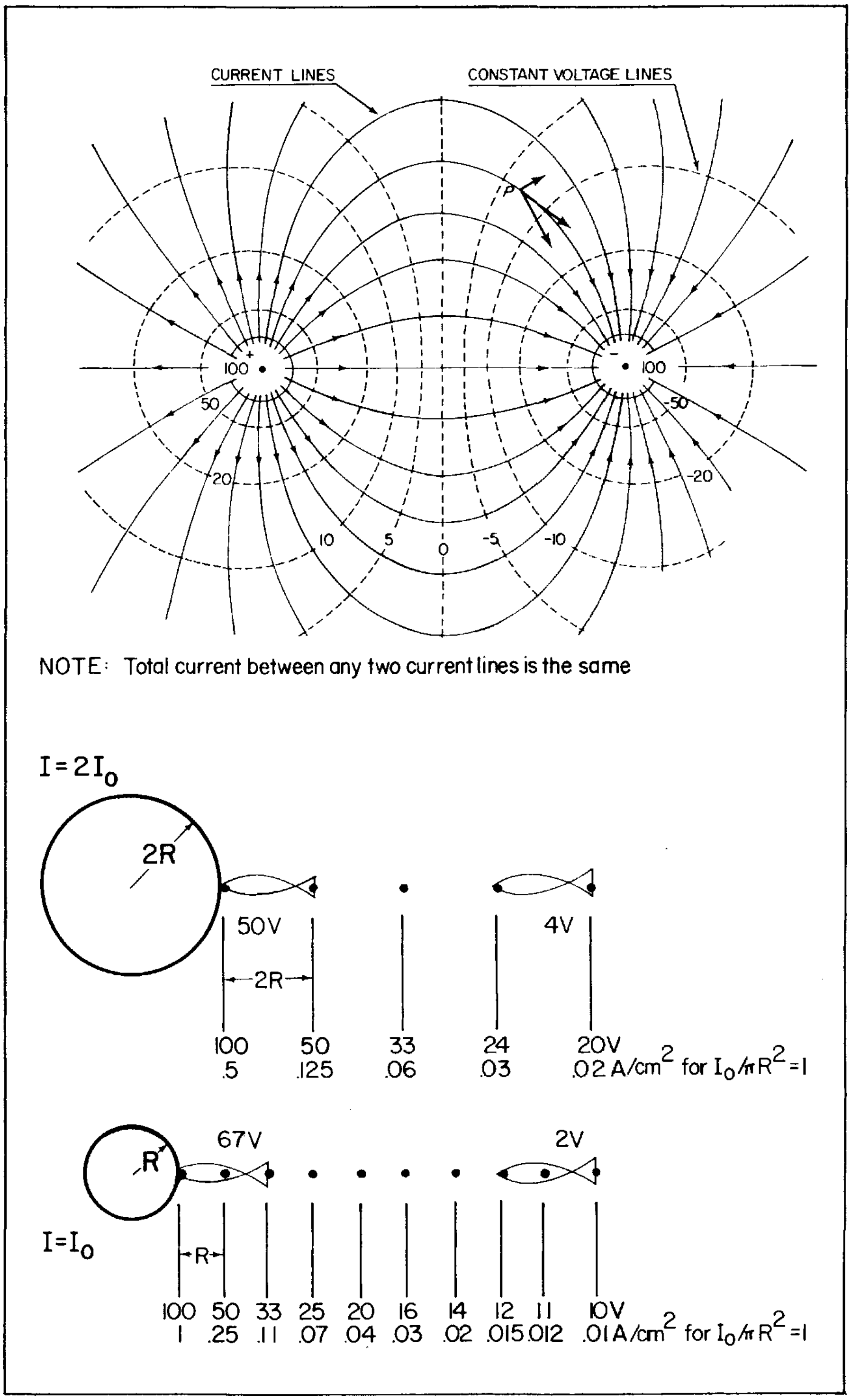


FIGURE 2. *Field pattern, voltage and current distributions for spherical electrodes*

high current density. The dashed lines surrounding the electrodes are lines of constant voltage, illustrating how the total voltage applied to the two electrodes is distributed in the water. Notice that most of the applied voltage is used up in the space immediately surrounding the electrode itself with succeedingly small portions used in regions further removed from the electrode surface. In water at large distances from the electrodes, the current density is very low, there is little voltage gradient and therefore fish will be relatively unaffected. For these reasons, electrode spacing is a relatively unimportant parameter for spherical electrodes. Each electrode essentially acts independently and is surrounded by its own spherical shell or zone of effective current density.

The lower portion illustrates the importance of electrode size. Two electrodes are compared in the figure, one twice as large as the other. The total voltage applied to the two electrode systems is the same (200 V across two identical electrodes). Note that the larger electrode produces twice as large a current density at every point external to the electrode and thus has potentially a much greater effective range. If there is a fish in the field, note that at the same distance the larger electrode produces twice the voltage.

This desirable effect of increasing the current density and voltage at points external to the electrode is gained at the expense of increased electrode current caused by a reduction in electrode resistance. The same effect could be caused by increasing the voltage applied to the electrodes. However, the larger electrode has a second major advantage as illustrated by comparing the maximum current densities at the electrode surface in Figure 2. The larger electrode actually has only one half as large a current density at the electrode surface; though surface area of the electrode is four times larger, the current is only doubled. The larger electrode thus offers two major improvements: a larger effective zone (greater range) and a reduced danger zone (lower maximum current density). To achieve these benefits requires an increase in current and power, but operation at the same total voltage. In contrast, increasing the voltage without increasing the electrode size increases both the danger zone and the effective zone and requires a much greater increase in power since *both* voltage and current are increased. The advantages of increasing the size of the electrodes are such that it is always advantageous to use the largest electrodes possible within the limitations imposed by physical constraints and the electrical limits imposed by the generator and electrical control system.

Although similar in general characteristics, the behavior of cylindrical electrodes is different in degree and in terms of the relative importance of the various dimensional parameters needed to describe their geometry. Unlike spherical electrodes, the spacing between cylindrical electrodes does have important effects even when the spacing is large compared to the radius of the electrode. As shown in Figure 1 (see also Appendix III) the important parameter of a long thin cylindrical electrode is the ratio of electrode separation D to the electrode radius R. The resistance between a pair of these electrodes is proportional to the natural logarithm of this ratio. Because this is a relatively slowly varying function, the performance of cylindrical electrodes is only slightly affected by rather large changes in D or R. An extremely important result is that doubling R or halving D has the same net result (i.e. reducing separation from 3 m (10 ft) to 1.5 m (5 ft) will give the same result as changing from a 25 mm (1-inch) to a 50 mm (2-inch) diameter electrode. Because of this rather small variation in electrode performance with respect to electrode dimensions, the benefits gained by increasing the size of cylindrical electrodes are not as pronounced as for spherical electrodes. Thus while it is still true that a larger electrode radius produces a greater current density at external points and a reduced maximum density at the electrode surface, the improvement is much smaller than for corresponding changes in spherical electrodes. Table 2 illustrates the magnitude of these changes for purposes of comparison.

All of these results for cylindrical electrodes assume the length of the electrode is much greater than its radius. The effect of increasing the length of such an electrode is to extend the region which is energized without changing the distribution in the radial direction. The total current into the electrode will also increase in proportion to its length (if the voltage is held constant).

If the length of a cylindrical electrode is reduced until it is nearly equal to the diameter, the resultant electrode would closely approximate a spherical electrode. Between this extreme and a long cylindrical electrode is a continuum of intermediate configurations which are difficult to describe in simple terms but which can be bounded in behavior by the two basic configurations.

Figure 3 presents a comparison of spherical and cylindrical electrodes in terms of the current density distributions. The figure compares a pair of cylindrical electrodes with a pair of spherical electrodes chosen such that each pair has the same resistance and hence each has the same total current if supplied with the same voltage. The normalized current density for each electrode is shown as a function of horizontal distance from the center of the electrode. Note that the cylindrical electrode has a slightly higher maximum current density (8% larger) but that the spherical electrode has a larger current density for all points out to a distance of about 1.2 m (4 feet). Beyond this distance the cylindrical electrode current density is higher. The ratio of the two current densities is also shown as a dashed line.

The relative advantages of a spherical electrode over a cylindrical electrode are clearly illustrated in this figure. The spherical electrode produces lower current densities in the "danger zone", higher current densities in the mid-region or "effective zone" and lower current densities in the far region or "perception zone". These effects are a result of the more uniform spreading of current around a spherical electrode and lead to generally superior performance for spherical electrodes. Unfortunately, spherical electrodes have many disadvantages associated with providing the desirable mechanical features of easy assembly and ability to negotiate obstructions in the water. For these reasons, some of the most successful practical electrode systems utilize arrays of cylindrical electrodes interconnected to approximate spherical electrodes. Such arrays obtain the desirable electrical properties of spherical shapes while maintaining the advantageous mechanical properties of cylindrical electrodes.

Summary of Electrode Characteristics. The basic electrode phenomena presented in the preceding section form a basis for the rational design of effective electrode systems. The following summary is presented to emphasize the critical parameters in electrode design.

For any electrode system:

(1) Each electrode is surrounded by a region of steadily decreasing current

TABLE 2. Effect of Changes in Electrode Size and Spacing at Constant Voltage

Nature of Change	Percent Change in Maximum Current Density at Electrode		Percent Change in Current Density at External Point		Percent Change in Distance Out to Constant Current Density	
	Spherical*	Cylin.**	Spherical	Cylin.	Spherical	Cylin.
Double radius	−50%	−42%	+100%	+16%	+41%	+16%
Triple radius	−67%	−57%	+200%	+28%	+73%	+28%
Quadruple radius	−75%	−65%	+300%	+38%	+100%	+38%
Half separation	No Change	+16%	No Change	+16%	No Change	+16%
One third separation	No Change	+28%	No Change	+28%	No Change	+28%
One fourth separation	No Change	+38%	No Change	+38%	No Change	+38%

*Results for spherical electrodes assume separation many times larger than radius.
**Results for cylindrical electrodes assume initial ratio of D/R equal to 150, i.e. 3 meter spacing with 4cm diameter.

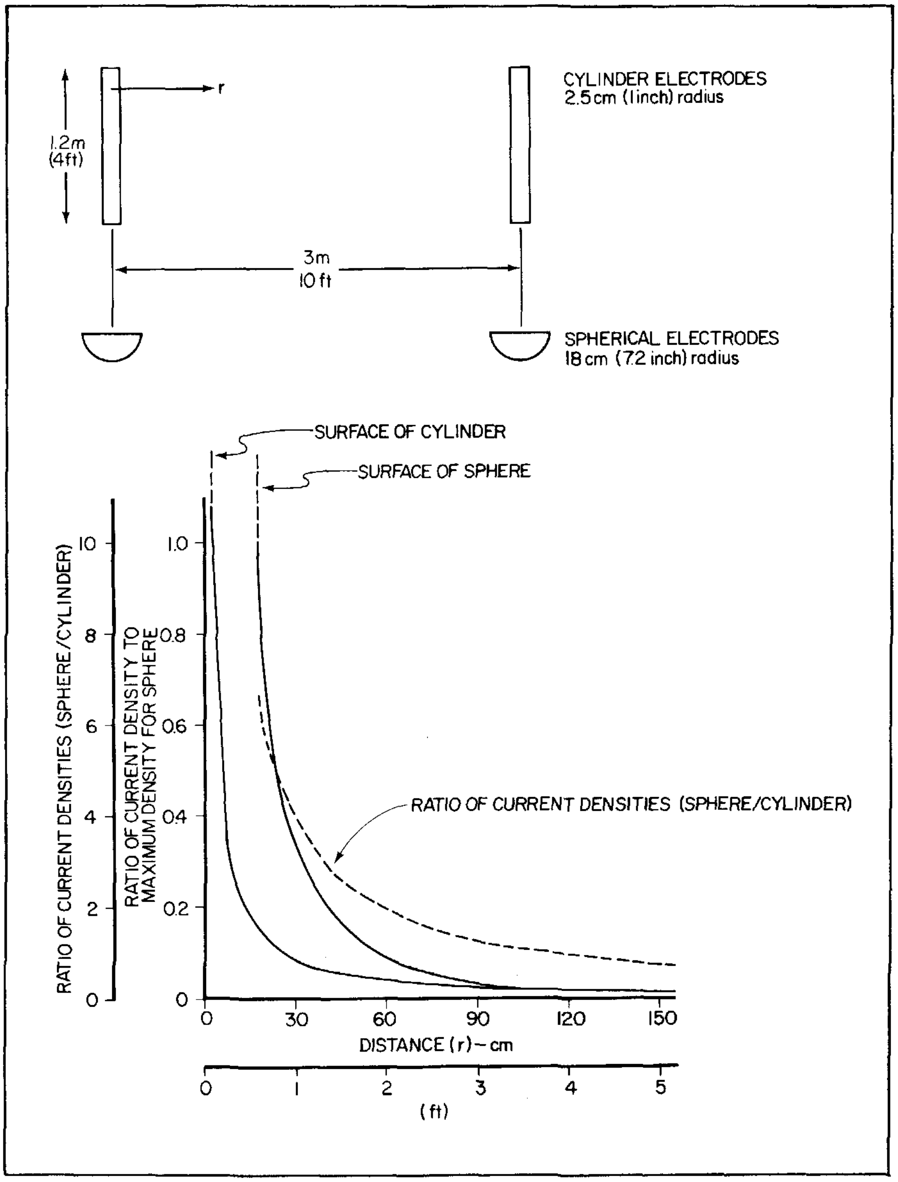


FIGURE 3. *Comparison of current distribution of cylindrical and spherical electrodes*

density which normally includes a "danger zone" close to the electrode, an "effective zone" at moderate distances, and a "perception zone" at large distances.

(2) Large electrodes (cross section dimension) have three desirable properties:

(a) lower resistance hence more current at a given voltage

(b) a larger "effective zone" because of the increased current density at moderate distances

(c) a smaller "danger zone" because of increased surface area and resultant lower maximum current density

(3) Electrode separation is a relatively unimportant parameter whenever the separation is large compared to the cross section dimension of the electrodes.

The relative importance of electrode dimensions depends upon the specific electrode. Spherical and thin cylindrical electrodes offer boundary cases which are useful in estimating actual electrode performance. An electrode in which all dimensions are of the same order of magnitude will behave similar to a spherical electrode (rings, square plates) whereas electrodes having dimensions which are orders of magnitude apart will behave similar to a cylindrical electrode (long thin cylinders, long thin plates).

For spherical electrodes:

(1) The resistance is dependent on electrode radius and varies in inverse proportion to this dimension.

(2) For separations large compared to the radius, each electrode operates independently of all others.

(3) Increased electrode radius causes a large increase in the "effective zone" and a large decrease in the "danger zone".

For cylindrical electrodes:

(1) The resistance depends upon the ratio of separation D to radius R and upon the length. The variation is very slight in terms of changes in the ratio of D/R and large with respect to changes in length (in inverse proportion).

(2) Increased electrode radius causes a moderate increase in "effective zone" and a moderate decrease in "danger zone".

(3) Decreased separation causes a moderate increase in both effective and danger zones.

(4) Increased length simply extends the field farther into the water.

Spherical electrodes have generally superior electrical properties but have many mechanical disadvantages. Thus electrode arrays which achieve the benefits of spherical electrodes while utilizing cylindrical elements are often the most effective.

Effects of Water Conductivity. There are two major effects associated with changes in water conductivity; the direct effect upon the total current taken by the electrode system, and a less direct effect upon the division of current between the current distributed in the water and fish in the region affected by the electrodes. The most significant problem occurs as the conductivity decreases with a corresponding decrease in electrode current. At some point the current densities in the water become so low that the "effective zone" is reduced to unacceptably small proportions. The only solution is to raise the current densities by raising the applied voltage or by increasing the size of the electrodes.

Fortunately the two effects noted above are at least partially counteracting. As conductivity decreases a fish becomes a relatively better conductor and tends to concentrate a larger portion of the available current in its body. For this reason it is not necessary to keep the current constant to maintain effectiveness as the conductivity decreases. This is extremely important since to maintain constant current over a large range of conductivity would require very large changes in voltage and electrode size. Earlier work reported by Cuinat (1967) and by the Novotny and Priegel (1971) on stream shocking with dc indicate that for a ten-fold decrease in conductivity the total electrode current can be allowed to drop to one-third of the original value without serious loss of effectiveness. Figure 4, reproduced from the 1971 report by the authors, illustrates the nature of the allowable reduction in total current as conductivity decreases. This figure, which is based on survey data, is included to illustrate the trend of the relationship and is not intended to apply directly to electrofishing boats where generally larger 'effective zones" are necessary. The currents needed to establish these larger "effective zones" would be expected to be considerably larger than those shown on Figure 4.

There is one additional conductivity related factor which should be noted. When the conductivity is low (below 100 micromhos/cm), fish are generally much more conductive than the water. In this situation when a fish actually touches or comes very close to the electrode, the fish's body becomes an effective extension of the electrode and is therefore exposed to high values of current. This creates a condition in which harmful levels of current are likely to occur with possible lethal results for fish. In effect, the "danger zone" is expanded, particularly for large fish. This undesirable situation may be partially rectified by using large electrodes to minimize the "danger zone". A larger electrode also minimizes the effect of touching the electrode because as its size is increased, the body of the fish becomes a relatively smaller electrode extension with relatively smaller concentration of current in it.

While very low conductivities are a major problem for the reasons outlined above, extremely high conductivities are also troublesome because it becomes necessary to supply large currents to the electrodes. With the equipment used during the study, conductivities over 500 micromhos/cm caused problems of overloading the main generator unless electrode size was reduced to quite small sizes. One potential solution to this problem lies in utilizing step-down transformers to permit supplying very large currents at reduced voltage. Up to the present time insufficient field trials have been carried out to give definitive guidelines as to the effectiveness of this procedure.

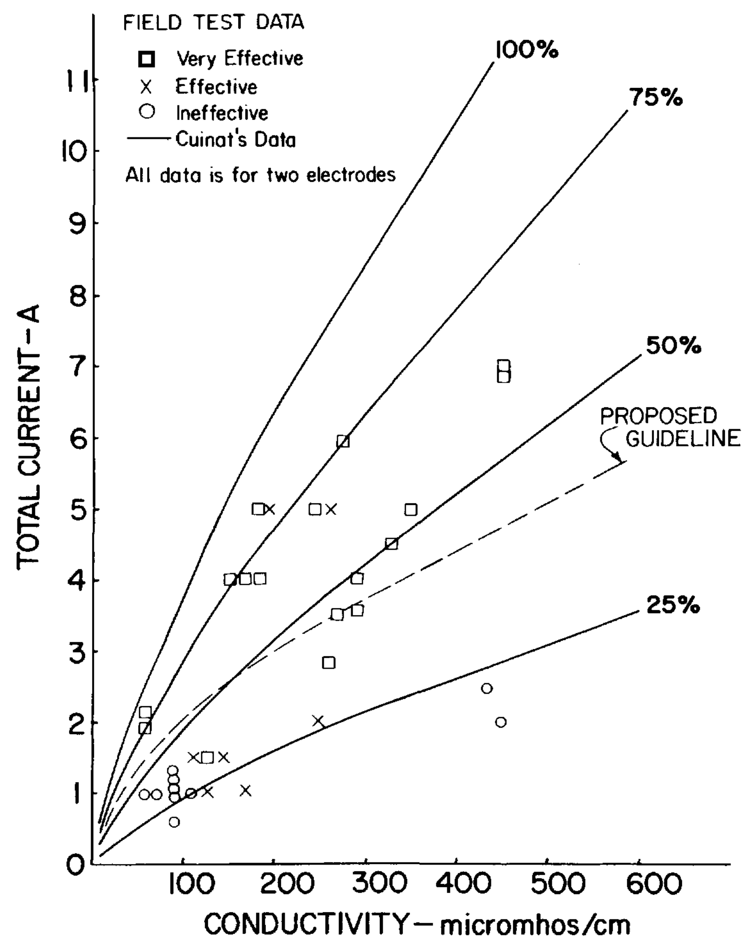


FIGURE 4. *Required current for effective stream shocking with direct current using two anodes*

Alternating Current Electrode Design Considerations. While it is true that large electrodes producing somewhat spherical current distributions are desirable in any electrofishing system, there are some important differences between ac and dc electrode systems. These differences are due to their producing different reactions in fish.

In an ac system the primary reaction is electrotetanus or simple immobilization of fish. Since the current is of alternating polarity, all electrodes of a particular system are equally effective and thus an ac electrode system should be designed to utilize all electrodes. In a three-phase system this provides one "effective zone" around each of the electrodes in the array. Often the three electrodes are essentially identical, but this is not necessary as long as the total current into each electrode is approximately the same. The need for nearly equal currents is dictated by the three-phase generator, which is designed to supply a balanced (equal current) load. Moderate unbalance (up to 30% perhaps) is acceptable but the full capability of the generator is not utilized under these conditions. In some instances generator problems can occur because of additional losses in the rotor windings as a direct result of severe unbalance. In general, the electrode system should be matched to the power source to operate at about 80%

of full rated current. Voltage control with transformers or electrode size adjustments to accommodate varying water conductivity should be provided.

The relative disadvantages of cylindrical electrodes are not as important with ac as with dc. This is again a result of the simple immobilizing reaction produced with ac. Thus, the essentially cylindrical current distribution of cylindrical electrodes producing an effective zone along the entire length of the electrode can be used even if the electrode reaches down to considerable depth into the water. As long as the immobilized fish are accessible to the net handlers, the downward penetration of the current distribution is useful. With dc, where the primary reaction is to attract fish to the surface, this downward penetration of an essentially uniform field is a disadvantage since fish attracted to the lower end of the electrode are not easily captured in weedy or turbid water. In general, however, arrays of cylindrical electrodes grouped to produce the effect of a larger, more spherical, electrode are more effective than single cylindrical electrodes. The specific arrays found to be reasonably effective during the study are described in a later section.

Direct Current Electrode Design Considerations. In a dc electrofishing system the desired fish reaction is the more complex electrotaxis or attraction to the anode. Since only the anode is effective, a dc electrode system should always be designed with the largest possible cathode and the anode sized to match the generator output. This arrangement minimizes the electric power associated with the cathode, which is wasted since it does not contribute to the desired electrofishing effect. Since the cathode current distribution is unimportant any convenient shape of electrode can be used. What is important is size and spacing between the separate elements if the cathode consists of a number of separate but electrically connected electrodes. Since individual elements which are closely spaced tend to interfere in the sense that they must utilize the same space to distribute the cathode current, much lower cathode resistance is obtained by keeping individual elements well spaced. This is the same phenomenon that occurs in large flat electrodes in which much of the central area can be omitted (leaving only the material along the perimeter) without greatly increasing the resistance or reducing the total current. Arrays of well-spaced cylindrical electrodes fulfill requirements very well.

One purpose of a dc electrofishing system is attracting fish to the surface when water clarity or vegetation growth makes capture of fish at any significant depth difficult. As a result the anode must be carefully chosen to produce the maximum current densities close to the surface. Essentially this makes spherical electrodes mandatory (or requires cylindrical electrodes to be mounted horizontally). Since a ring-shaped electrode is close to a spherical shape and can be placed essentially at the water surface, it is an effective anode shape. To make the electrode reasonably able to negotiate obstructions, a ring-shaped array of short cylindrical electrodes can be used. This type of array was developed and used in the dc systems employed in the study and is fully described in a later section.

OPERATING GUIDELINES

The comments in this section are intended to summarize the numerous operating guidelines developed during this study.

General Comments

(1) A conductivity meter to measure the water conductivity at the time electrofishing operations are to commence on a given body of water is essential. Knowledge of the water conductivity will allow the operator to adjust the voltage source and change electrode size to conform with the conductivity to insure maximum current densities during operation.

(2) Metering devices are essential so that the operator knows that sufficient currents are being provided.

(3) Operation at highest allowable current produces maximum effectiveness whenever possible. Adjust for about 80 percent of this value to allow for normal conductivity variations.

(4) Large electrodes and low voltage operation is superior to operation at higher voltages. Use higher voltages only when low water conductivity makes it necessary.

(5) The safety switching system can be used as a control to turn the power on and off. This can be effective in approaching areas of possible high fish concentration without power on and then energizing at appropriate time. The net handlers can exercise this control.

(6) Knowledge of the lake topography and the habits and habitat of the fish species sought along with some planning before the initial field work can improve the success of electrofishing.

(7) It is generally more feasible to fish at night, especially for those species that move towards the shallows at night.

(8) Make sure that all electrical systems (power, safety and auxiliary lights) are in good working condition, especially the safety system, before operations begin.

Alternating Current Operation

(1) Fish are not attracted by ac, but this type of current has the largest range of action, especially in clear, shallow water with a sand or gravel substrate.

(2) Occasionally, better performance is obtained at reduced output if fish are being stunned too far from the electrodes.

(3) It is necessary at times to operate at high boat speeds especially when seeking northern pike and muskellunge.

Direct Current Operation

(1) Fish will be attracted to the anodes without stunning. This can be advantageous when water clarity is poor, vegetative growth is dense, or algae prevents reasonable visibility.

(2) The range of dc is minimal. Low-pulse-rate pulsed dc is usually better than dc.

(3) It is desirable to operate at very low boat speeds to allow the fish to swim up to the anode and remain there until netted. When excessive boat speeds are utilized fish will be attracted to the anode but won't hold for any extended period as they quickly become exhausted, sinking or drifting back under the boat.

Pulsed Direct Current Operation

(1) Low pulse rates (5-15 pps) are similar to dc except they have greater effective range.

(2) Higher pulse rates (40-80-120) have greater range but fish will be stunned as they approach the anodes.

(3) Pulsed dc offers the same advantages as dc when operating in turbid water or dense vegetation.

(4) As with dc, slow boat speeds are mandatory to fish effectively.

(5) Pulse duty cycle appears to have only secondary effects. Settings at 25 and 50 percent appear to give similar results and hence 25 percent is preferable since it conserves power. The 10

percent setting appears to be less effective.

(6) Some species selectivity is possible with pulsed dc. Although only qualitative observations have been made, the following may be useful. Trout, carp, bullheads and largemouth and smallmouth bass respond well to higher pulse rates and will approach quite close to the anodes before being stunned. Walleye, yellow perch, bluegills and white and yellow bass are more easily stunned and lower pulse rates are required to bring them close to the anodes. There appears to be an optimal pulse rate for each species; however, quantitative data are lacking.

PART II: EXPERIMENTAL AND OPERATIONAL SYSTEMS

The experimental and operational systems developed and tested during the study are described in the following sections. Wherever possible specific operating experience is presented to substantiate the concepts outlined in Part I and to make possible direct application of the methods and equipment by other users. Supporting material not essential to the presentation but required for application of the methods is contained in the Appendixes.

EXPERIMENTAL AC–PULSED DC ELECTROFISHING BOAT

Introduction

One of the early decisions in the study was to develop and test an electrofishing system utilizing pulsed direct current. The purpose of the experiment was to evaluate the potential of pulsed dc as a means of solving the problems associated with electrofishing in turbid water and the possibilities of extending the depth of water to which electrofishing could be applied. As secondary objectives, the boat was to be utilized as a means of evaluating electrical and mechanical design innovations and safety systems. The successful results obtained with the original experimental boat led to production of five operational boats for special applications in which pulsed dc permitted successful electrofishing in areas where ac electrofishing was not normally adequate. To extend the usefulness of these pulsed dc boats the design was modified such that ac electrofishing was also possible under control of a simple mode selection switch on the operator's controls. The resulting combination ac-pulsed dc boat has proved to be a versatile highly effective electrofishing system capable of adjusting to a wide range of conditions. Only the final operational configuration is described in this report with an occasional reference to variations which were experimentally evaluated and discarded during the development.

Mechanical Configuration

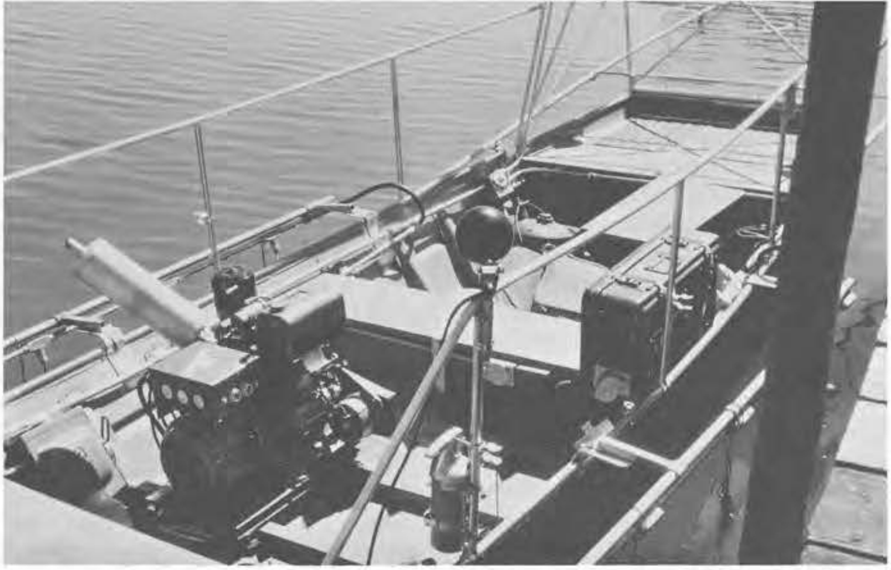
A standard 4.8-meter (16-foot) aluminum boat (Monark Model 1648) was used for the original design. Subsequent development resulted in switching to a 5.5-meter (18-foot) boat (Monark Model 1848) to provide additional working space and a greater margin of safety in rough water. Figures 5 and 6 show the basic configuration of the boat and the locations adopted for the various major components of the system.

The safety railing surrounding the front deck was constructed to facilitate the collecting operation and will accommodate two operators. This railing system also serves as a support for the main lighting system, bow running lights and the safety on-off controls. The railing was extended along each side of the boat all the way to the stern. Entry-ways just behind the front deck permit easy loading but are closed off by a sliding rail during operation. The full railing affords protection against the hazard of falling overboard into the electric field near the boat.

Floor mat switches are permanently installed on the front deck and require each operator to be in position before the system can be energized. Non-skid surfaces on these mats are essential. The seat mat switch at the rear operator's position is also permanently installed on the rear seat surface.

The booms are adjustable for height and spacing by means of pin-locked adjustments. During transit the booms are slid back into the boat and held in place at the bow by the boom support collars. When metal booms are used, an electrical ground wire terminated with a battery clamp is provided to assure a positive electrical ground for each boom.

All electrical circuits are enclosed in metal conduit with separate conduit systems for the main power (high voltage) circuits and the auxiliary power and safety (low voltage) circuits. The conduit systems are electrically tied to the boat hull by the mounting hardware as are all other conducting objects anywhere in the boat. Watertight junction boxes are used throughout the electrical system. All points where connecting wires leave the conduit system are equipped with cord connectors to provide strain relief and a weather seal. The plugs



The safety railing extended along each side of the boat to the stern.

Floor mat switches are permanently installed on on the front deck. Safety railing surrounding the front deck to protect operators and support main lighting system, bow running lights and the safety on-off controls. The boom support structure for adjusting height and spacing is fastened to the bow.

Engine-generator unit with control box mounted on generator. Note 12-volt automotive alternator in lower right corner.

and connectors for the electrical system are marine grade with voltage and current ratings in excess of the actual system design values. The manual safety switches are momentary contact push button switches weather sealed by rubber covers which transmit the actuating force.

The main operating lights are sealed beam lamps with individual switches. Auxiliary power is provided at several outlets, providing considerable flexibility in the location of auxiliary equipment and components. Fire extinguishers, life jackets, hand tools, fuses and other small parts for emergency repairs are part of the normal equipment.

Because the nets used to capture fish must be dipped into the water near the electrodes where the electric fields are large, it is extremely important that the net handles be constructed of materials with good electrical insulating properties. Conducting materials (metals) or organic materials which absorb water and become conductors must be avoided. Although fiberglass covered metal handles have been used, they can cause accidents if the fiberglass covering is damaged, allowing contact between the operator and the metal handle. This completes a circuit from the water through the operator to the boat and can result in severe electrical shock. The best material identified in the study is epoxiglas, the insulating material for tools used by electric utilities for work on live electric circuits. (Appendix IV).

Electrical System

Figure 7 is a functional diagram of the complete electrical system of the boat. The descriptions that follow are keyed to the functional divisions shown on this diagram. Circuit diagrams are included in Appendix V.

Engine-Generator and Generator Control Unit. The engine-generator unit provides main power and battery charging power. In addition, a number of additional electrical components are mounted in a control box on the generator to provide a self-contained, dual voltage, electrofishing power supply which can be controlled from buttons on the control box or from external foot or hand actuated low voltage switches. This unit can be used alone for ordinary ac electrofishing or combined with other units as shown on Figure 7 to provide greater flexibility.

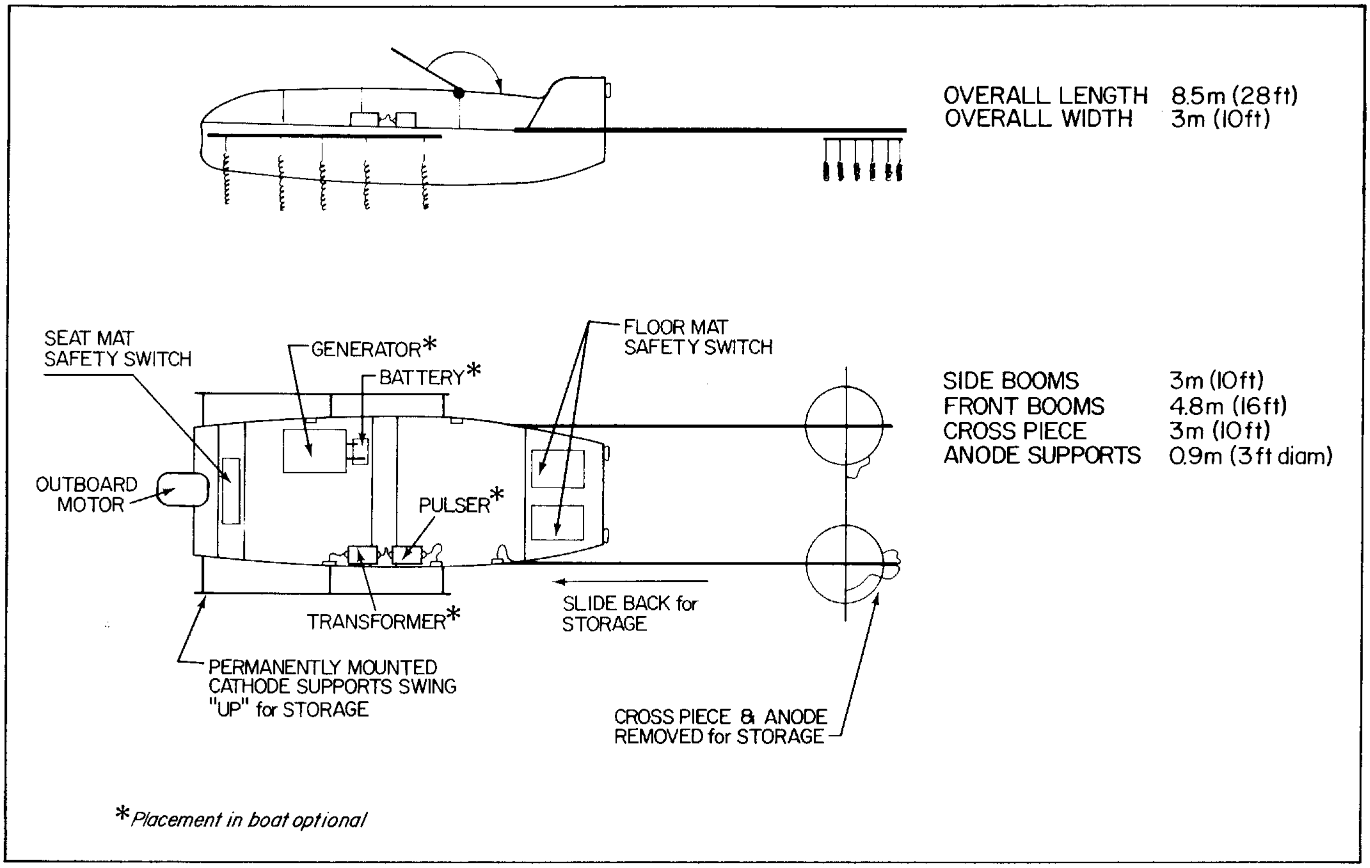


FIGURE 5. *Electrode configuration of experimental ac-pulsed dc electrofishing boat*

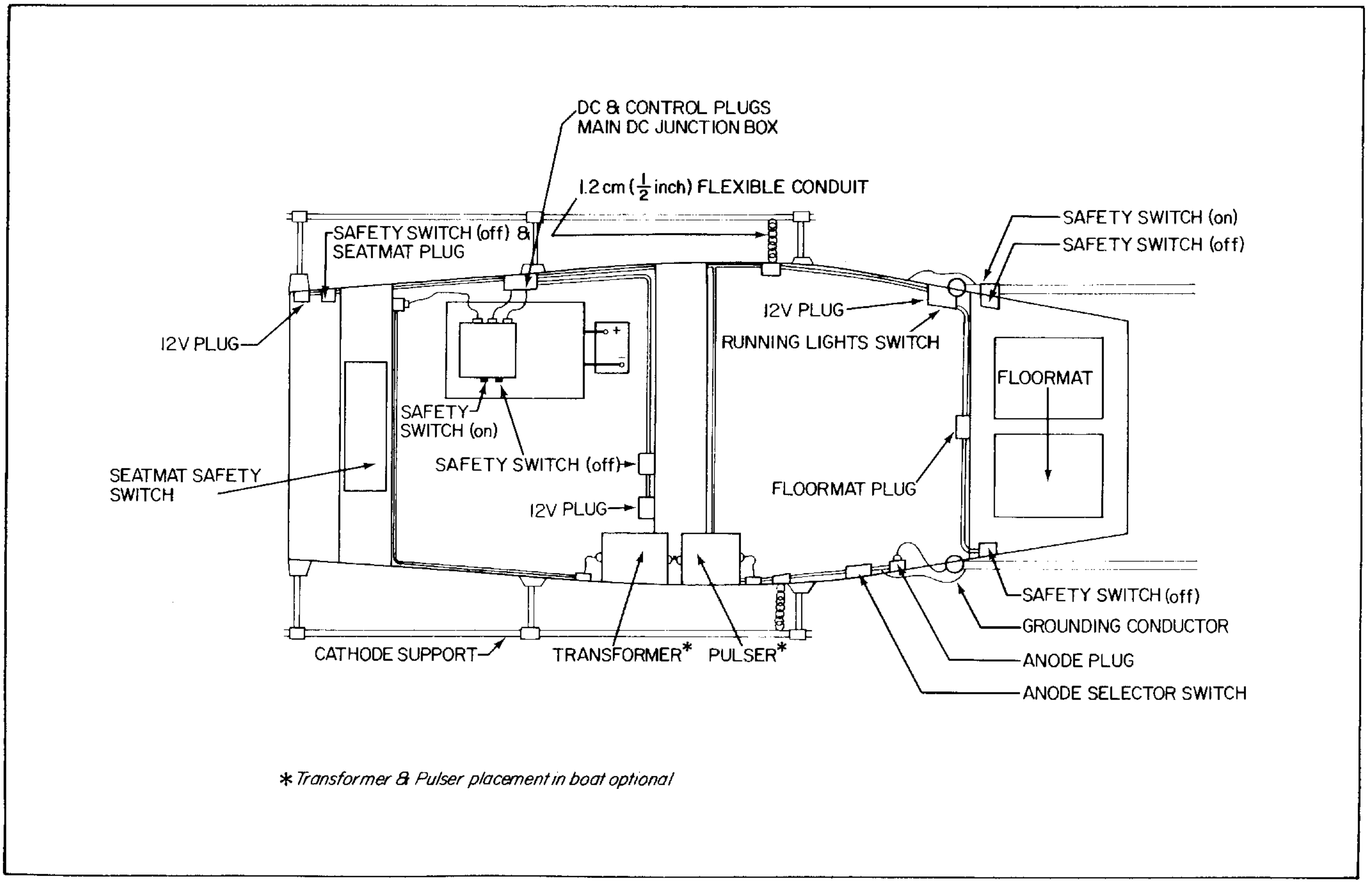
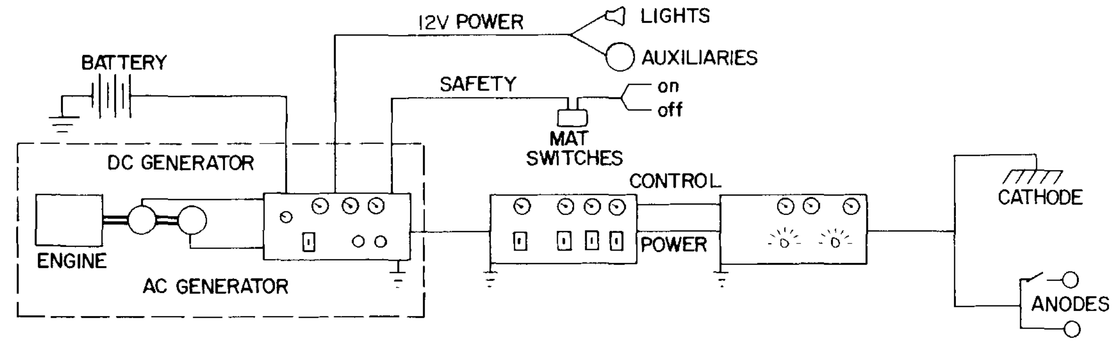


FIGURE 6. *Major components location—experimental ac-pulsed dc electrofishing boat*



	ENGINE	GENERATOR CONTROL UNIT	TRANSFORMER UNIT	PULSER UNIT	ELECTRODES
CONTROLS	1) Engine Speed 2) Choke	1) Engine on-off 2) Safety on-off 3) AC Breaker	1) Voltage Switches	1) Mode & Pulse Rate 2) Duty Cycle	1) Anode Switch 2) Exposure 3) Number of Droppers
METERS		1) AC Voltage (0-230) 2) AC Amperes (0-15) 3) Battery Amperes (60-0-60)	1) AC Voltage (0-500) 2) AC Amperes (3) (0-25)	1) DC Voltage Peak (0-500) 2) DC Voltage avg. (0-500) 3) DC Amperes avg. (0-25)	
PROTECTION		1) AC Breaker 2) 60 A DC Fuse 3) 2 A Safety Circuit Fuse		1) Pulser Fuse	1) Boom Ground Wires

FIGURE 7. *ac-pulsed dc electrical system functional diagram*

The components which comprise the unit and the ratings of the components are as follows:

(1) Engine-12 hp with electric starter.

(2) Main Generator–4.5 kW, 230 V, 180 Hz three-phase self-excited generator.

(3) Auxiliary Generator–55 A, 12 V automotive-type alternator and voltage regulator.

(4) Controls

(a) Engine throttle to provide speed (and hence voltage) control

(b) Engine choke

(c) Engine on-off switch (key switch on later model)

(d) Safety circuit on-off buttons controlling a three-pole relay with latching contact (12 V coil)

(e) Main power disconnect switch (circuit breaker)

(5) Metering

(a) Main generator voltage 0–300 V

(b) Main generator current 0–15 A

(c) Battery charging current 60–0–60 A

(6) Protective Devices

(a) 15 A three-phase ac circuit breaker

(b) 60 A fuse for 12 V power circuits

(c) 2 A fuse for 12 V control circuits

(7) Connectors

(a) Three-pole connector for external safety switches

(b) Four-pole connector for main generator power

(c) Two single-pole battery connectors

(d) Two single-pole connectors for 12 V power

The entire unit weighs approximately 113 kg (250 lb) including the gas tank and muffler. The battery is a standard 12 V automotive battery fitted with a separate battery case and located just forward of the engine-generator unit. A complete circuit diagram is given in Appendix V.

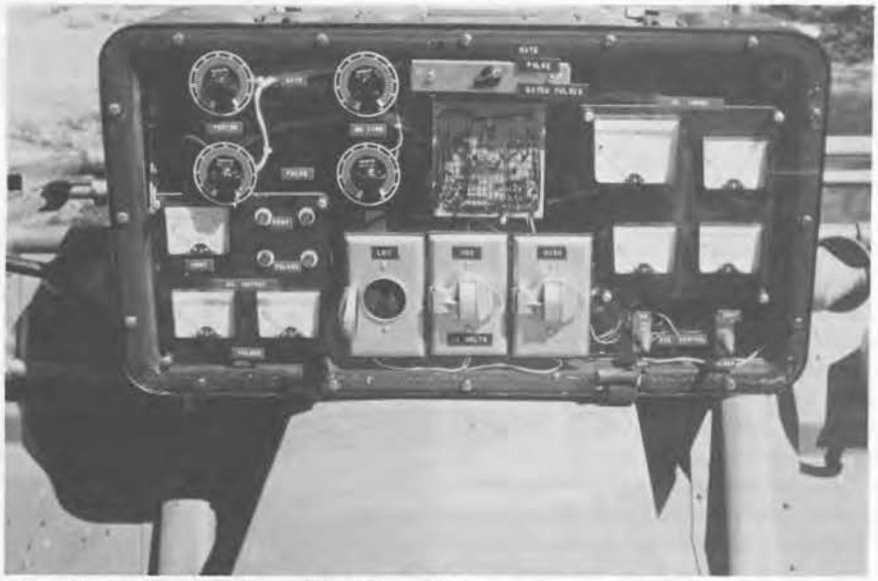
The 12 V system and its operation are identical to that in an automobile. Only occasional monitoring of battery water level and observation of the battery ammeter to verify proper operation are necessary. Depending upon the size and quality of the battery, auxiliary equipment can be operated for reasonably extended periods without operating the main generator. When the main generator is operating, approximately 600 W are available at 12 V.

Safety switching is provided by the three-pole ac relay connected to provide self-latching through a holding circuit. The mat switches and safety off buttons are connected in series in the holding circuit such that if any switch is momentarily opened the relay opens disconnecting the main power. The on buttons, one on the generator control box and one remotely located at the bow, are connected to complete the latching circuit. Thus, to initiate operation each operator must be at his assigned station (closing all mat switches) and the operator must press one of the on buttons. The circuit remains energized until any one of the safety mats or off buttons is momentarily opened.

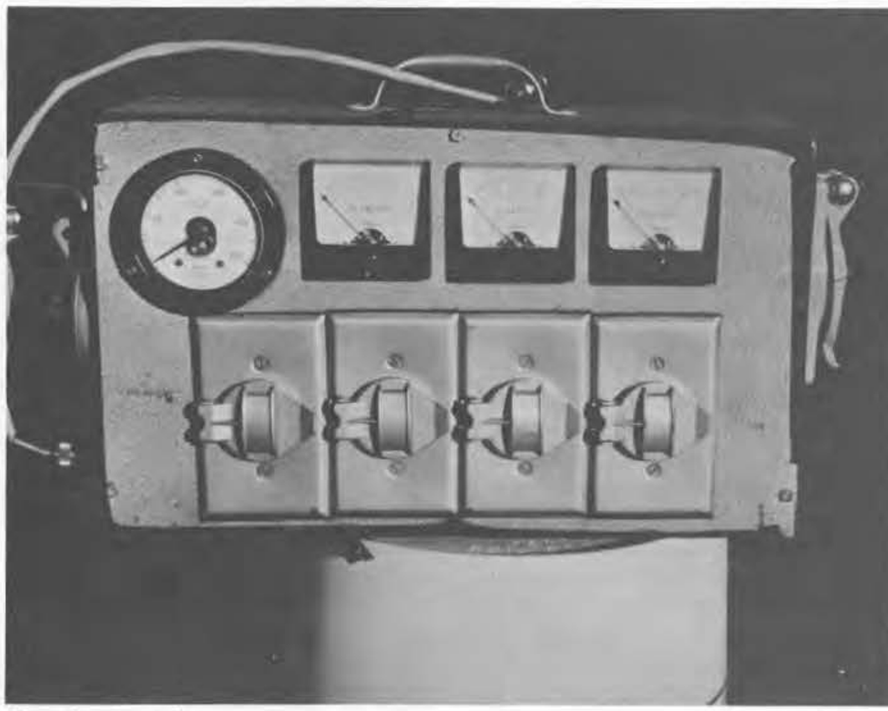
Transformer Unit. To increase the flexibility of the overall system the transformer has been designed as a separate unit which can be used with or without the pulser. For dc or pulsed dc operation the transformer supplies a variable voltage to the pulser and for ac operation the transformer output is connected directly to the electrode system either through the pulser under control of the mode switch or by simply omitting the pulser entirely.

Table 3 gives the voltage and current ratings and the transformer ratios available on the unit. Voltage settings are selected by operating one of a set of four selector switches. If two or more of the selectors are set to the on position, the unit automatically operates on the lower voltage setting. A single voltmeter is provided to indicate the actual output (secondary) voltage. Three ammeters are connected in the primary of the transformer to serve as a means of monitoring the load conditions of the system. With this arrangement the operator need only be concerned with a single current limit of 11.7 A no matter which voltage setting is employed. The actual output current (if desired) is obtained by multiplying the measured current by the appropriate current ratio from Table 3.

The design of the transformer was carried out to minimize the weight of the unit. Only two transformer cores are used (in open-delta connection) and the windings are designed to be utilized at essentially full capacity on all voltage settings. An additional low power low voltage winding was also provided to serve as the power supply for the electronic circuits in the pulser unit. These circuits are brought out through a separate connector to supply the pulser. The transformer



Experimental unit that contained transformer and pulser.



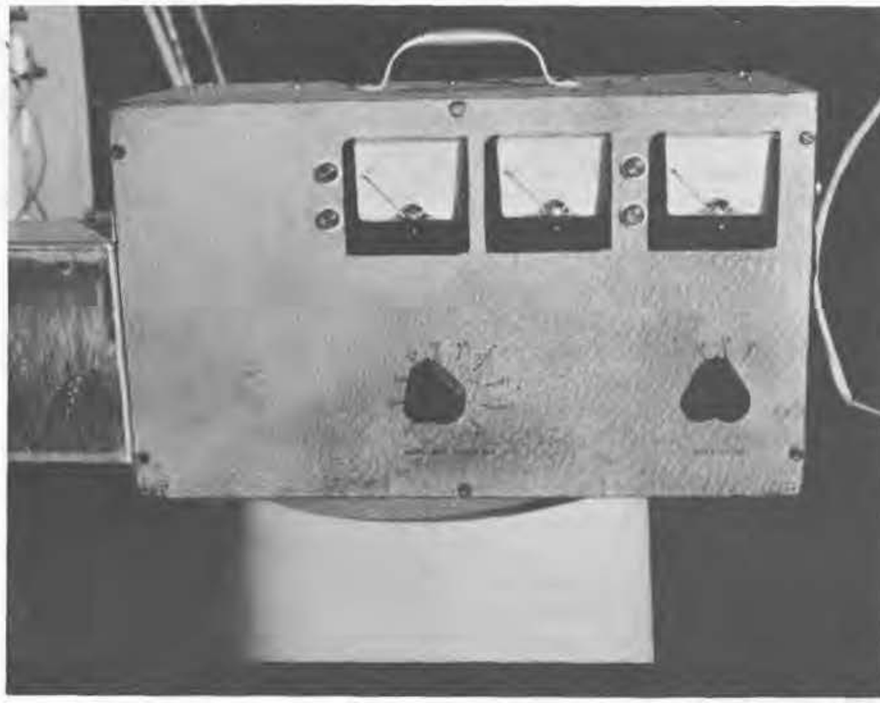
Transformer unit.

TABLE 3. Transformer Ratios and Ratings

Setting	Unity	Low	Medium	High
Output voltage for 230 V input	230.0	287.0	345.0	460.0
Output current for 11.7 A input	11.7	9.4	7.8	5.85
Voltage ratio	1	1.25	1.50	2.0
Current ratio	1	0.8	0.667	0.5

input is a four-pole connector which mates with the generator output connector. A similar four-pole connector provides the transformer output which connects to the pulser or directly to the electrode system. Additional information on the transformer design is contained in Bernstein and Miller (1973) (Appendix VI).

Pulser. The pulser is a solid state switching system which incorporates a three-phase rectifier, a bistable power switch, and a set of timing and control circuits to drive the bistable switch at the desired switching rates. A three-pole relay is used to bypass the rectifier and power switch when an ac output is desired. The unit is controlled by two rotary switches; one controlling the duty cycle of the output pulses and the second controlling the mode or pulse rate. Three duty cycles can be selected during pulsed operation with the on-time of the pulse being 10, 25 or 50 percent of the total pulse time. The mode and pulse rate switch permits selecting dc or ac operation or pulsed operation at 5, 15, 40, 80 or 120 pulses per second. An off position is provided on both controls.



Pulser

Three meters are provided to monitor the performance of the pulser. A dc ammeter is connected in the output of the power switch to indicate the average value of the output current. This is adequate for all but the lowest pulse rate where the meter can follow the instantaneous current. At this low pulse rate the average of the meter swing or the reading on dc corrected for the duty cycle must be used as a measure of the current. This is not a serious limitation since low pulse rates are seldom needed. Two voltmeters are provided; one connected at the output of the power switch to indicate the average output voltage, and a second connected at the rectifier output to indicate the peak voltage. Comparison of the readings of these two meters during pulsed operation provides a measurement of the duty cycle and is a convenient means of determining if the pulser is operating correctly.

The pulser is internally protected against short circuits by a special fast-acting fuse. The interrupting level of this fuse is chosen high enough (25 A) to avoid interruption under the moderate overloads caused by increase in water or bottom material conductivity or increase in electrode exposure. The semiconductor components of the pulser were chosen to accept such overloads without damage. With an input ac voltage of 230 V, the output of the pulser is 300 V at 15 A dc based on the 4.5 kW rating of the generator. At higher voltages the output current is reduced to remain within the rating of the generator. A complete description of the pulser design and circuitry is contained in Appendix VI. The operating instructions developed for the unit are given in Appendix VII.

Electrode System

Since the boat was intended primarily for operation with pulsed dc the electrode system was designed specifically for this operating mode. For ac operation the electrode configuration is far from optimum in that only two electrodes are effectively used and the ac currents are somewhat unbalanced. However, the configuration has proved adequate and the advantages of having both ac and pulsed dc available have proved to be significant.

Cathode Array. To minimize the voltage and power associated with the cathode a very large array is necessary as noted earlier in discussing dc electrodes. To achieve this large size without severely compromising the handling qualities of the boat, the cathode was designed as a set of ten 1.2–meter (4-foot) lengths of 2.5-centimeter (1-inch) diameter flexible conduit. These electrodes are mounted five on each side of the boat, supported by 3-meter (10-foot) length of conduit.

Power is brought out to the electrodes in a 1.2-centimeter (½-inch) aluminum conduit with a length of flexible conduit to provide for folding the entire array for storage and transit. The wires supplying each electrode leave the conduit system through a cord connector for relief of strain and a seal against water. The mechanical load is carried by a chain and insulator fastening each electrode to the supporting conduit. To reduce the electric field near the water surface, the top 20.2 cm (8 inches) of each electrode are covered by a length of heat shrinkable insulating tubing.

Anode Array. To achieve the essentially spherical field suitable for dc electrofishing the anode array consists of two 0.9-meter (3-foot) aluminum rings with a large number of "dropper" electrodes suspended from the rings. A conventional boom arrangement supports the two rings approximately 0.3 m (1 ft) above the water and between 2.4 and 3.6 m (8 and 12 ft) ahead of the bow of the boat. The rings are normally between 0.9 and 2.1 m (3 and 7 ft) apart.

Each of the rings serves as a separate anode, providing both mechanical support and an electrical connection for the dropper electrodes that actually carry the current into the water. A switch in the boat permits energizing just one or both of the rings. The rings

Cathode array–set of ten 1.2 m (4-foot) lengths of 2.5 cm (one-inch) diameter flexible conduit (5 on each side of boat).

Cathode array support and power supply system.

Anode array–two 36-inch [91 cm] aluminum rings with a large number of "dropper" electrodes (Fig. 8).

are doubly insulated from the booms, which are grounded to the boat hull for safety. Power is carried out to the rings by a pair of wires in one of the booms with the cross-piece serving as an electrical connector for the ring on the opposite side.

The dropper electrodes are 1.4-centimeter (6-inch) lengths of stainless steel tubing supported by a copper wire that is clipped to one of the rings (Fig. 8). Care must be used in attaching the wire to the stainless steel tube since this junction will corrode rapidly if allowed to come in contact with the water when the power is on. An insulating sleeve is fitted over the tube to provide control over the amount of surface exposed to the water.

For operation with three-phase ac each anode ring is used as a separate electrode and the cathode is used as the third electrode. This results in an unbalanced load on the generator, but if the largest current is kept within the generator rating, satisfactory performance is obtained.

Electrical Characteristics. The electrode system was designed to permit adjustments to accommodate varying water conductivities. Three different adjustments are possible; operating with one or both anodes, varying the number of dropper electrodes, and varying the exposure on the dropper electrodes.

Operating with one or both anodes is useful for initially adjusting the electrode system in water of unknown conductivity and also permits operation of only one anode in very high conductivity water. Because the two anodes are relatively close together the current with both anodes operating is not twice the current with one anode. The actual ratio depends somewhat on the exposure of the dropper electrodes and is in the range of 1.75 (small exposure) to 1.65 (large exposure). One of the original concepts of the design was to permit adjusting to full output on one anode with dc operation and then to use both anodes under pulsed operation where the load on the generator is reduced by the off periods of the pulsed output. This would take advantage of the power reduction with pulsed operation to increase the current during the on period and thus increase the effective zone of the system. Unfortunately, the capabilities of the power switch are such that operation at these high current levels is marginal and this operating concept was abandoned on these units. Systems under development will utilize the concept.

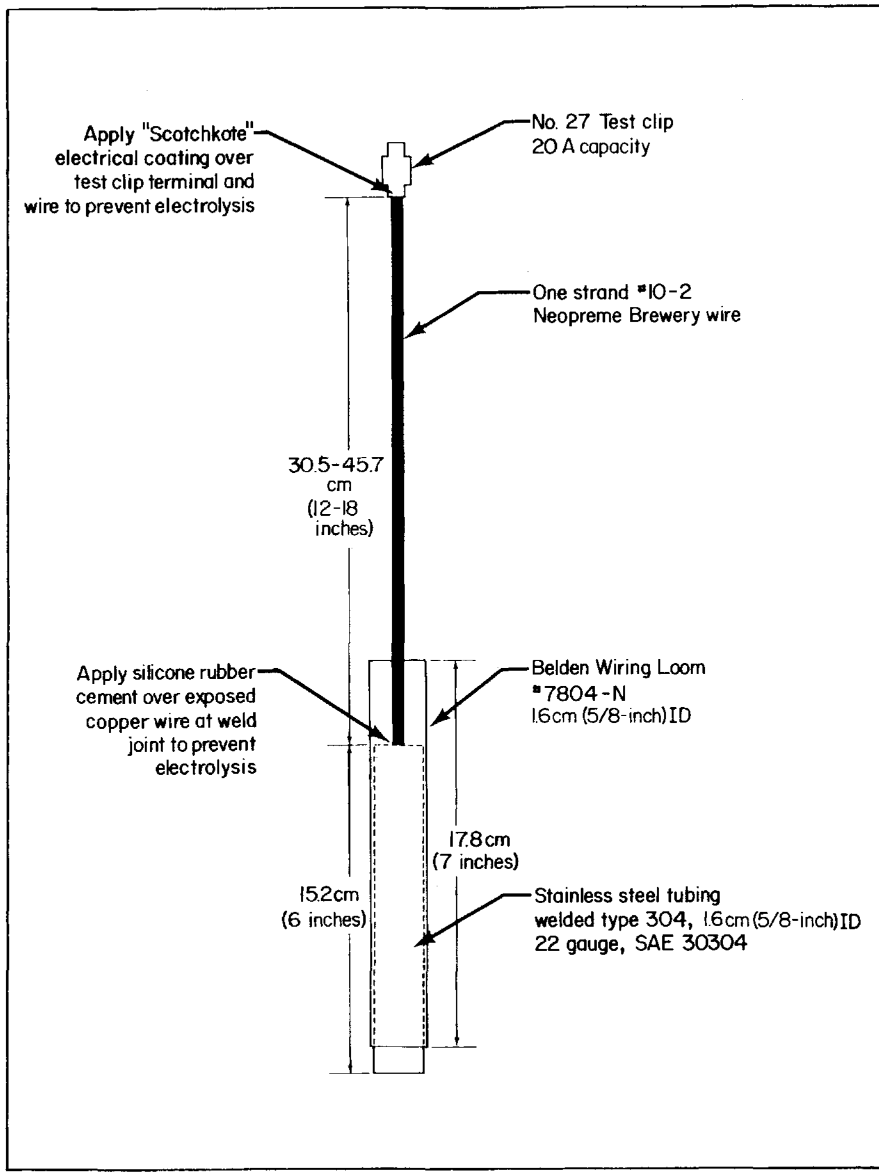


FIGURE 8. *Detail of "dropper" electrodes*

Varying the number of dropper electrodes was not intended as a primary adjustment procedure since it produces significant effects only if the number of dropper electrodes is changed radically. In general, as the number of dropper electrodes is reduced the current density around each remaining one is increased, resulting in excessive power loss in some regions and a possible hazard to fish. For this reason the number is always kept above ten (on each anode) and is most often twelve or more. The only condition under which dropper electrodes are removed is in very high conductivity water (above 500 micromhos/cm) where it is the only alternative to not operating at all.

The primary adjustment mechanism is varying the exposure of the dropper electrodes by moving the sliding sleeve of insulating material. Figure 9 illustrates the effect of this adjustment. Note that a range of electrode resistance of approximately three to one is available with the 1.4-centimeter (6-inch) dropper electrodes employed. Figure 9 also shows approximate cathode resistance as measured under actual operating conditions. Even with full 1.4-centimeter (6-inch) exposure the cathode resistance is only about 12 percent of the total resistance. Thus, at worst, about 88 percent of the system power is delivered to the anodes where it is useful in dc electrofishing.

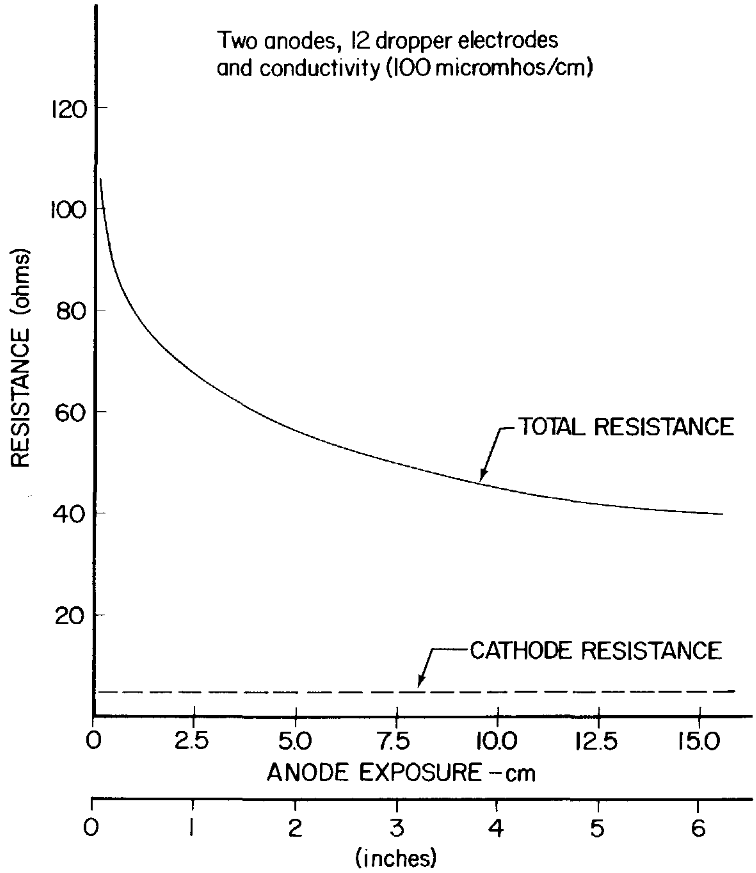


FIGURE 9. *Electrode system resistance*

The adjustment range provided by varying electrode exposure permits operation at nominal output (300 V, 12 A dc) over a conductivity range from approximately 150 to 400 micromhos/cm. Below 150 micromhos/cm the voltage must be increased and nominal output can be extended to approximately 70 micromhos/cm at 450 V dc. Below this conductivity the system as presently designed does not deliver nominal power output because of limitations on voltage. Larger anode rings or longer dropper electrodes could be employed to extend this range. Above 400 micromhos/cm it is necessary to remove dropper electrodes or operate with a single anode. The operating instructions reproduced in Appendix VII contain a table of suggested anode adjustments to achieve nominal output. The entries in the table are conservative to allow for inaccuracies in conductivity measurement without causing overload conditions.

For ac operation the conductivity range for nominal output is somewhat larger because of the availability of higher voltages (normally limited by pulser components) and because the requirements on electrode configuration are less demanding. Thus the low conductivity limit is extended by the higher voltage available and for high conductivity it is feasible to remove dropper electrodes without causing unreasonable current density distributions. Utilization of a step down transformer would also be of value in extending the high conductivity limit. The degree of current unbalance caused by the unsymmetrical electrode configuration varies with anode exposure from having one current about 50 percent larger at small exposure to about 25 percent at full exposure.

Electrofishing Performance

The first experimental boat was completed in the fall of 1970 and a very limited amount of actual electrofishing was carried out late in the season. These early tests were very encouraging and a major experimental program was planned for 1971 including evaluation of performance over a range of conductivity, fish species, and type of lake as well as experimentation with various changes in the equipment itself. Late in 1971 we decided to build five operational boats which would essentially be only slightly modified versions of the original experimental boat. Unfortunately, construction delays and electronic problems with the modified pulsers delayed completion of these boats so that only a limited amount of pulsed dc operation was actually attained in 1972. Hence, most of the results reported below have been obtained on the original experimental boat.

In general we found that fish respond to low pulse rate pulsed dc in the same way they respond to dc except that in the former the range of action is greater. Good response to low to moderate pulse rates (10-40 pps) has been obtained with fish coming to the anodes from depths of 3 m (10 ft) or more under favorable conditions. This type of response is very useful in turbid water or in areas of excessive vegetation since fish will come all the way to the anode where they are visible and easily captured. Other situations in which this mode is valuable include electrofishing in rivers where the water current tends to sweep stunned fish away from the boat or in lakes in which rocks or other cover make it impossible to see fish that are stunned in their places of refuge.

As the pulse rate is increased fish are affected at even greater distances but tend to become immobilized (stunned) as they draw near to the anodes. The distance at which 100 pps pulsed dc affects fish has been estimated at approximately twice the corresponding distance for dc. Some species (largemouth bass, northern pike, trout, bullheads) seem to have

Anode array illustrating fish response to intermediate pulse rates.

greater tolerance and respond readily to high pulse rates, coming very close to the anodes without being stunned. Other species (walleye, bluegill, yellow bass, white bass) seem more susceptible and are stunned at significant distances (1.2 m (4 ft) or more) unless the pulse rate is kept low.

The greatest effective range (for the same anode current) is obtained with ac. Since the fish are simply stunned wherever they happen to be located when they come under the influence of the effective zone, many fish are too deep to be seen or too far away to be captured readily. However, because of the larger range, ac is very useful in many situations and the inclusion of an option to switch to ac without any change in electrode configuration is very useful.

When dc or pulsed dc is selected during electric fishing, greater results are obtained when the boat operator moves the boat along at a reduced speed. At reduced speeds the fish, especially the smaller ones, will hold at the anodes and near the surface for a longer period of time, making capture easier. If the boat is moving at too great a speed, the fish will be attracted to the anodes but will not hold for any length of time as they quickly become exhausted and sink back as the boat is propelled over them. Fishing at these low speeds for northern pike and muskellunge is not recommended as these species apparently detect the electric field at great distances and quickly retreat from the shallows to deeper water. Increased speeds are necessary to intercept these two species as they dart from the shallows. In shallow waters, ac is usually more effective in capturing northern pike and muskellunge as the effective zone is larger (especially if the substrate is sand) and chances of immobilizing them are increased. A northern pike dashing rapidly from shallow water to dc anodes can easily pass right through the electrical zone.

Smaller fish are usually more difficult to capture with ac because they are harder to see after being paralyzed. With dc and pulsed dc greater numbers of smaller fish can be captured since they are not as easily paralyzed and as they swim towards the anodes, they swim out of the protected areas in vegetation and are readily seen. Again, the boat must be moving at low speeds to realize these benefits.

Some fish species not often seen in ac boom shocking are readily taken with pulsed dc (bullheads especially in deep water, more than normal numbers of largemouth bass, lawyers). The pulse rate tends to allow some selectivity in fish capture in that some species are so easily stunned at high pulse rates, walleyes in particular, that capture is unlikely in deep water. Some species are so tolerant of electric effects that they can be brought up from significant depths by high pulse rates (bullheads) without being stunned until they draw very near the anodes. Grass pickerel were attracted out of aquatic vegetation submerged 1.8 m (6 ft) and brought to the surface where capture was easy. In contrast, lake sturgeon were readily attracted from deep water to the anodes but are such powerful swimmers that they passed through the electric field making capture impossible. Operating with ac, lake sturgeon were readily taken because they were stunned some distance from the boat.

Additional Experiments

A number of experiments were unsuccessful or impractical and were discarded as operational concepts. The most significant of these are reported below along with comments on possible future application of the techniques.

Several modified forms for the anode array were evaluated, including a linear array mounted below each boom, an additional cylindrical electrode suspended at the middle of each anode ring, and two anodes operating essentially adjacent to each other. The linear array was definitely inferior in performance despite its increased current capability, apparently caused by the essentially cylindrical current distribution, which is poorer in the dc case where attraction to the anode is desired. A long cylindrical electrode was added at the center of each anode ring to increase the anode size for operation in very low conductivity water. The method is not particularly useful since a very long electrode is needed to produce a significant change and the fish are often attracted to the lower end of the electrode where capture is difficult. For ac operation, or for operation in very clear water where attraction to the anode is less important, the concept is of some use. The two anode rings were operated very close together to simulate a single large anode and the increase of depth at which fish could be affected evaluated. The desired result was achieved but the increase in downward range was small and the loss in sideward range was large. The concept is of limited use because of the inconvenience of modifying the anode arrangement.

Since it is obvious that large numbers of fish perceive the low levels of current density well out ahead of the boat and escape before coming into the effective zone, the possibility of automatically switching the power on and off at a very low rate was evaluated. In principle, this would allow the boat to approach fish without warning. The concept was found impractical since the off period has to be long and fish easily escape during this time, especially with dc or pulsed dc. It is much more effective to switch the power on and off manually.

An attempt was made to combine the desirable attracting capability of low pulse rates with the immobilizing capability (near the anodes) of high pulse rates by providing a switch for the net handler, permitting the varying of pulse rates in response to differing conditions. Thus if a large number of active fish were attracted to the anode, a short period at a high pulse rate could be used to immobilize the fish and facilitate capture. The concept has some value and the boats we presently have are equipped to operate in this mode; the major difficulties lie in the rapidity with which events take place and in learning to use the technique.

A number of other concepts were evaluated and found to have little value, including operating with various on-off switching rates of the main pulse rate, switching off half of the cathode array to obtain better balance of currents during ac operation, and several minor variations in electrode configuration. Evaluation of such modifications and innovations is continuing.

Operating Guidelines

As with any type of electrofishing equipment, the skill and knowledge of the operators are major factors determining overall effectiveness. In the course of evaluating the performance of dc and pulsed dc operation, a number of differences in operating technique as compared to ac electrofishing were found to be necessary. The most significant difference is the necessity of moving the boat much more slowly than is common in ac electrofishing to allow time for fish to respond. This is particularly important when fish are attracted from deeper water.

Since the operator has several options available (changes in pulse rate or operation with ac) it is necessary to become familiar with the characteristics of each operating mode and select the proper one for the particular application. In general, ac operation is preferable in shallow clear water where visibility is no problem and it is not necessary to attract fish out of their refuge areas. These situations occur most often at night when fish are in shallow water and foraging and are hence not in refuge areas. Pulsed dc operation is most useful in deep or turbid water or where fish must be attracted out of refuges to make them visible. In general, low pulse rates must be used where attraction all the way to the anode is required. Higher rates give greater range but result in fish being stunned at some distance from the anode.

Some species selectivity is possible because of this phenomenon, since at high pulse rates only certain species will approach close to the anodes. Although only qualitative observations have been made, the following data will be useful. Trout, largemouth bass, carp and bullheads respond well to higher pulse rates and will approach quite close to the anodes before being stunned. Walleyes, white bass, yellow perch and bluegills are more easily stunned and lower pulse rates are required to bring them close to the anodes.

There appears to be an optimal pulse rate for each species, but at this time quantitative data are lacking. In general, the following pulse ranges have been found useful: trout, largemouth bass and carp (40-120); bullheads (80-120); walleyes (5-40) and white bass, yellow perch and bluegills (15-40).

In certain situations special techniques have proved useful in increasing effectiveness. Rivers should be electrofished by moving as slowly as possible downstream. Drop-offs and "holes" should be worked over slowly by circling the area several times. Dense vegetation can be sampled by placing only the anodes over the vegetation to attract fish to the surface. Often approaching with the power off and energizing only after attaining the desired position is very effective. Operating with one anode off to concentrate fish under one anode when working with only one net handler is sometimes effective.

Summary of Electrofishing Results

The field tests with the experimental boat and the limited experience with the five operational boats have demonstrated that pulsed dc electrofishing holds promise as a significantly improved technique for electrically sampling fish populations in lakes and rivers. In particular, the work has demonstrated the following specific points regarding pulsed dc electrofishing:

(1) Comparing the distance at which fish are affected (size of effective zone) for equal peak anode current, pulsed dc is intermediate between dc and ac. The effective zone for high pulse rates (100 pps) is estimated to be twice as large as for dc.

(2) Pulsed dc electrofishing is a solution to the problem of electrofishing in turbid water or in areas where excessive vegetation makes ac electrofishing ineffective. Attracting fish to the surface near the anode requires a properly designed anode and operation at suitable (low) pulse rates.

(3) The depth to which effective electrofishing is possible can be extended by using pulsed dc. In general, higher pulse rates (100 pps) are needed since the effective zone is larger with high pulse rates.

(4) If it is necessary to attract fish all the way to the anode, the pulse rate must be low (less than 40 pps with the simple rectangular pulses used in this study) to avoid stunning fish as they approach the anode.

(5) Some species selectivity is possible with pulsed dc. High pulse rates stun certain species readily, producing low numbers of these species close to the anode and relatively larger numbers at some distance from the anode.

(6) With the experimental equipment, the option to operate with ac is a significant advantage since the size of the effective zone is largest with ac.

(7) Once familiar with the characteristics of pulsed dc and ac electrofishing, operators can take advantage of the flexibility of having both systems available to meet the varied demands of sampling in lakes and rivers.

Future Developments and Required Research

The electrofishing boat described here was developed to evaluate the potential of pulsed dc for use in electrofishing lakes and large rivers. The initial results were sufficiently good to construct five operational boats for use in those situations where pulsed dc offers significant advantages. In the course of the work, a number of areas where additional research and developmental activity could produce significant improvements have been identified. Work is progressing in those areas which seem to hold greatest promise of improved electrical sampling methods.

One of the most promising areas has to do with full utilization of the available electrical power during pulsed dc operation. Clearly, as the duty cycle of the pulsed output decreases the average electrical power decreases because of the longer off period. The peak current during the on period can therefore be increased without overloading the main generator. The present pulser is limited in this regard by its capability to handle the larger currents. This is primarily an electrical design problem although the correct electrical specification depends upon how short a duty cycle is possible before the desired electrotaxis response in fish is adversely affected. Results on the experimental boat indicate that a duty cycle as low as 10 percent may be acceptable.

Operation at higher pulse rates than the maximum available on the experimental boat (120 pps) also holds some promise. A laboratory study of this question is planned. There are indications in the literature (Halsband 1967 and Northrop 1967) that a fast rise, slow decay pulse may be more effective and help to prevent stunning fish as they approach the anode. If this effect is obtainable, the possibility exists of dramatically extending the range and effectiveness of pulsed dc operation. Since a controlled waveform pulser with the power capability needed is a difficult and expensive electrical design problem, these questions are being investigated in the laboratory to develop specifications for a prototype experimental pulser. The possibilities for species selective electrofishing are included in these experiments. The present experimental boat is limited to a conductivity range between about 70 and 400 micromhos/cm by a combination of electrode size limitations and electrical limitations in the pulser. Some improvements in electrode size and configuration are possible to extend the lower limit. One or more units will be modified for specific use in low conductivity water.

There are a number of interesting questions regarding switched operation of the power in ac electrofishing. Since electrical devices now exist for rapid switching of ac power, a number of questions regarding low frequency on-off operation of ac should be investigated. If some power saving can be realized by such switching, the effective zone for ac could be expanded without requiring a larger main generator.

Finally, operating experience with the operational boats will yield extremely valuable information regarding correct use of the equipment. Based on such experience, development of more explicit operating guidelines will be possible with corresponding increases in the effectiveness of this sampling method.

ALTERNATING CURRENT ELECTROFISHING BOATS

Introduction

Many of the concepts and electrical design changes developed in connection with the experimental pulsed dc boat are applicable to ac boats. During 1971 and 1972 the study of pulsed dc electrofishing was expanded to include improvements to existing ac electrofishing systems with the specific problem of sampling very low conductivity water being identified for special attention. The work on ac electrofishing has been confined primarily to transferring the concepts developed in the work on pulsed dc to ac systems with emphasis on ac electrode design and development of a special transformer for use in ac electrofishing. Guidelines for operating ac electrofishing boats over a wide range of water conductivity were also developed based on actual field tests of prototype boats.

Mechanical Configuration

The ac electrofishing boats utilized in the study use a standard 1.8-meter (16-ft) aluminum boat (Monark Model 1648). Figure 10 illustrates the basic configuration and the locations of the major components of the system. Considerable variation in component location, boom support structure, and auxiliary equipment exists since boats are most often locally constructed and are modified to suit the individual needs of the local situation.

The safety disconnect system and safety switches (including mat switches), electrical interconnection system, lighting and auxiliary power system, and special consideration for the insulating qualities of the net handles are the same as described for the pulsed dc boats.

Electrical System

The electrical system of the ac boats is essentially the same as for the pulsed dc boats except that the pulser is omitted and the connections to the electrode system are modified to properly supply the ac electrodes. Wiring diagrams are included for the modified power circuit in Appendix V.

Engine-Generator & Generator Control Unit. With the exception of minor modifications in later units the engine-generator and generator control unit are identical to that described for the pulsed dc boat. The later units have a key start-switch instead of start-stop buttons for the engine and some units will be equipped with lights for night operations.

Transformer Unit. Since the ac boats are not restrained by the current limits inherent in the pulser, the transformer was redesigned to better match the generator power rating to the conductivity range over which the boats must operate. To cover the widest possible conductivity range the transformer is capable of either increasing the voltage for low conductivities or decreasing the voltage for high conductivities. Table 4 gives the voltage and current ratings and transformer ratios available on these "raise-lower" transformers. Except for the addition of lower ranges and the modification in transformer ratios the transformers are the same as those used on the pulsed dc boats. All transformers have the ammeters connected in the primary circuit so the operator need only be concerned with the single current limit of 11.7 A imposed by the generator rating. The actual output (electrode) current must be obtained by multiplying the measured current by the appropriate current ratio from Table 4.

Electrode System

Electrofishing with ac is primarily restricted to shallow clear waters. Since fish are normally only found in abundance in such areas of a lake after dark, the best success with ac electrofishing is obtained by night operation with appropriate lighting arrangements to permit visual observation and collection of stunned fish. While underwater lights are feasible, most boats utilize normal above-water flood lighting to illuminate a large area surrounding the electrodes. It is also characteristic of ac electrofishing to operate the boat at the maximum speed permitted by the ability of the net handlers to observe and capture fish stunned by the electric current.

The combination of night operation and high boat speed call for an electrode system which maximizes visibility of stunned fish and is capable of readily negotiating obstructions in the water. An electrode which produces a

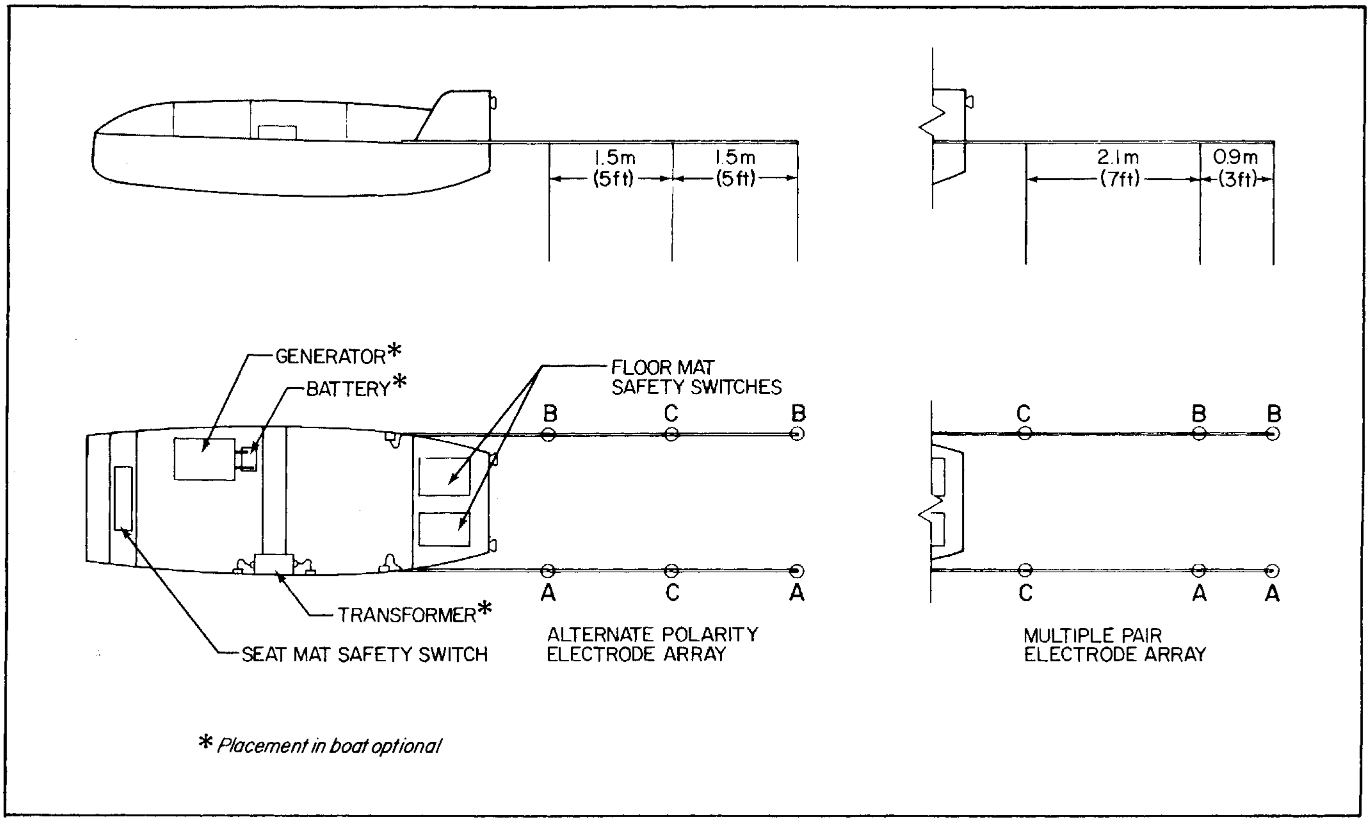


FIGURE 10. *Configuration of the electrodes and the location of the major components of the ac electrofishing boat*

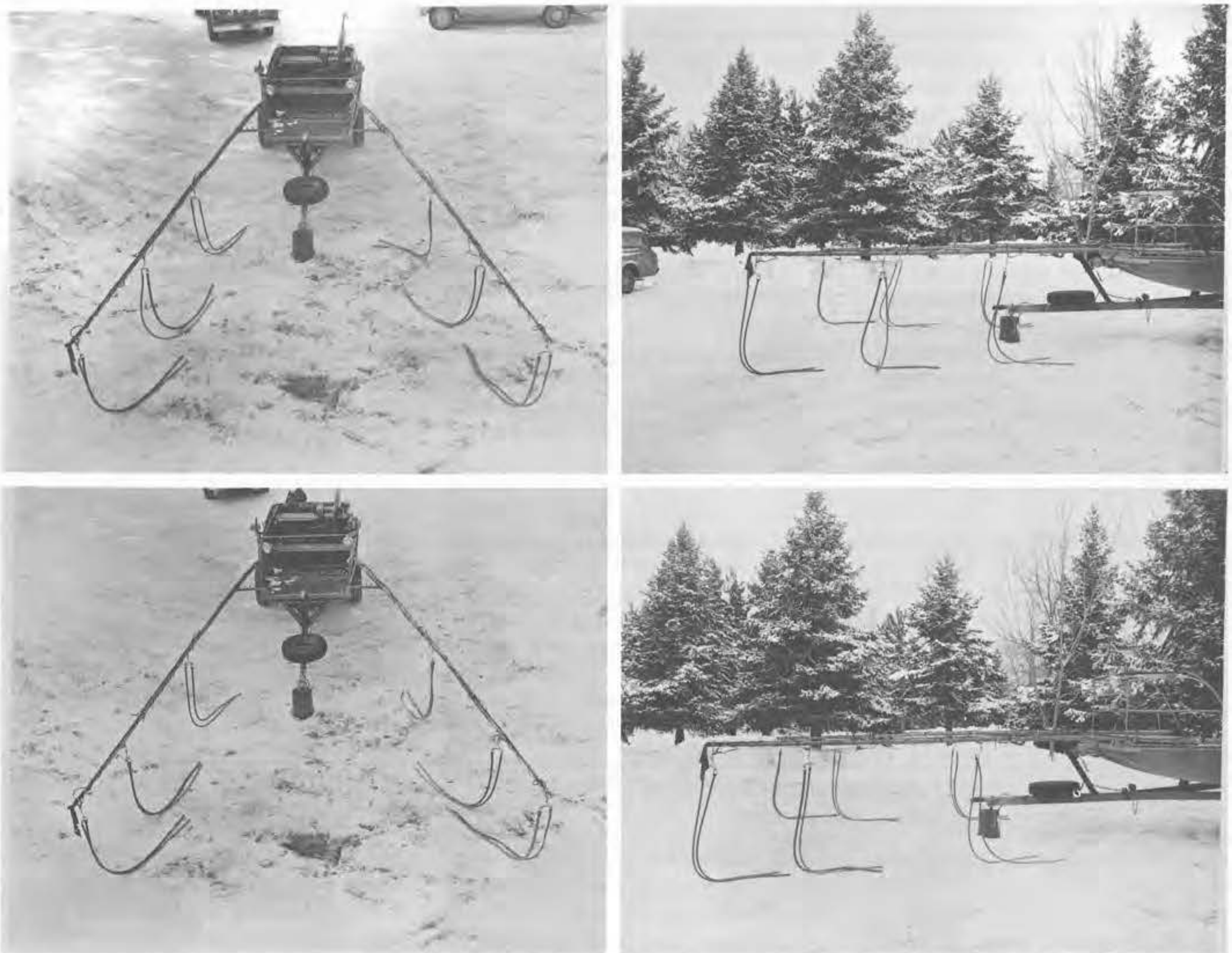
significant surface water turbulence is a great disadvantage since it causes much of the incident light to be reflected off the water surface and greatly interferes with visibility into the water. Compared to the requirements of a dc electrode in which the primary need is to keep the maximum current density region near the water surface to attract fish to the surface, an ac electrode is much less critical in terms of current distribution and much more critical in terms of the physical factors of low turbulence and ease of negotiating obstructions (because of higher boat speed). These considerations tend to favor the use of cylindrical electrodes in ac electrofishing.

The major disadvantage of a cylindrical electrode is the relatively poor current distribution and the associated difficulty of making the electrode large enough to avoid excessively high current density regions. Simply lengthening a cylindrical electrode does not alter the current distribution but only extends the same distribution to a larger region. Arrays of cylindrical electrodes properly arranged to minimize high current density regions and at the same time minimizing water turbulence have been found to be a good solution. Such arrays make possible the increased electrode size necessary for effective electrofishing without the need to use large diameter electrodes.

Cylindrical Electrode Arrays. The arrays developed during the study utilize two basic concepts to produce the desired electrode system characteristics: paired electrodes and in-line arrays. A paired electrode is simply two thin cylindrical electrodes supported by a separator which places the two electrodes 4 to 6 diameters apart. The pair functions as a unit and can be combined with other similar units to form a more complex array. The mounting to the boom includes a swivel to permit the pair to rotate to minimize turbulence. A paired cylindrical electrode produces the effect of a larger diameter electrode without the added weight and drag of a larger diameter electrode. An in-line array is simply an arrangement in which all

TABLE 4. Transformer Ratios and Ratings for "Raise-Lower" Transformers

Setting	Lower Low	Lower Medium	Lower High	Raise Low	Raise Medium	Raise High
Output voltage for 230 V input	92.0	161.0	230.0	322.0	391.0	460.0
Output current for 11.7 A input	29.2	16.7	11.7	8.35	6.9	5.85
Voltage ratio	0.4	0.7	1.0	1.4	1.7	2.0
Current ratio	2.5	1.43	1.0	0.715	0.59	0.5



Alternate polarity electrode array (Top).
Multiple pair electrode array (Bottom).

electrodes are mounted directly under the boom in a straight line. This has an obvious advantage in reducing turbulence as well as making mounting a relatively simple matter.

The two arrays utilized in the study are illustrated in Figure 10. The left array (hereafter called alternative polarity) was developed by Leon Johnson* based on extensive field tests of various arrangements designed to increase the size of the overall electrode system. The right array (hereafter called multiple pair) is a modification of the first arrangement designed to expand the lateral dimension of the effective zone where a wider fishing zone is required. At present it appears that both configurations are useful depending upon the conditions and species being sought. Each array uses the same basic electrode element; a paired electrode consisting of two 1.8-meters (6-ft) lengths of 2.5-centimeters (1-inch) diameter flexible conduit separated approximately 10 cm (4 inches). Normally six elements are utilized as shown in Figure 10, but in very high conductivity water it is possible to operate with only three elements, removing one from each of the terminals of the generator. Occasionally a single cylindrical electrode is used in place of a pair but this is much less effective and often produces hazardous regions close to the electrode.

The boom support structure is adjustable for boom height (above water) and boom separation. Normally the booms are adjusted to operate about one foot above the water. This adjustment is necessary to compensate for changes in load and load distribution in the boat. Boom separation adjustments are used partly for convenience in working along shorelines or weedbeds and partly to compensate for changes in water conductivity. The separation is variable from a minimum of 1.8 m (6 ft) to a maximum of 4 m (13 ft) (measured at tip of booms). In general, wider separations yield a wider lateral dimension for the effective zone. However, in low conductivity water the width of the effective zone of each electrode can become small enough to create a region near the center of the booms in which fish are relatively unaffected. In these cases the separation must be reduced.

Electrical Characteristics. Each of

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*Wisconsin Dept. of Natural Resources, Bureau of Research, Spooner, Wisconsin

TABLE 5. Electrical Characteristics of Cylindrical Electrode Arrays, 230 V, 100 micromhos/cm, 1.5m (5 ft) Electrode Immersion

Number of Electrode Pairs	Boom Separation m (ft)	Type of Array	Boat Speed	Currents Phase a	Phase b	Phase c
6	1.8 (6)	Alternate	Stopped	6.7	6.1	6.0
6	3.9 (13)	Alternate	Stopped	6.4	5.8	5.7
6	3.9 (13)	Alternate	Normal	5.6	5.1	5.0
6	1.8 (6)	Multiple	Stopped	5.9	5.2	5.2
3	1.8 (6)	Either	Stopped	3.6	3.3	3.3
3	3.9 (13)	Either	Stopped	3.3	3.0	3.1
3	3.9 (13)	Either	Normal	2.9	2.6	2.7

TABLE 6. Voltage and Electrode Selection

Conductivity Range (micromhos/cm)	Voltage (V)	Electrodes
10–50	460	6
50–70	390	6
70–100	320	6
100–200	230	6
200–400	160	6
400–1200	90	6
1200–2000	90	3

the arrays illustrated in Figure 10 produces an essentially balanced electrical load. The alternate polarity array has a lower resistance because the individual elements connected to each phase are farther apart and hence do not interact with each other to as great an extent as for the multiple array. However, even with the 3-meter (10-ft) separation between elements of the same phase, there is a significant interaction and the current density distribution is much improved over that which is obtained in a three element array. Table 5 presents typical electrical performance of the two arrays.

The interaction effect noted above can be observed by comparing the current for the three electrode array and the six electrode alternate polarity array. Without interaction the six electrode array would have twice the current of the three electrode array, while the actual comparison is 6.0 to 3.3 or about 180 percent. The larger interaction effect of the multiple array is shown by the corresponding comparison of 5.2 to 3.3 or about 158 percent. These interaction effects are generally desirable since they reflect a reduction in the maximum current density and hence a reduced danger zone close in to each electrode element.

Table 5 illustrates two other important characteristics of the arrays. Boom separation is clearly a relatively unimportant parameter in terms of total current delivered to the electrodes. This is characteristic of cylindrical electrodes. The importance of boom separation lies not in the total current but in controlling the extent to which the effective zones of the separate electrode elements overlap. Too wide a separation will create non-overlapping effective zones in the center area between the booms. The multiple array has some advantage in this respect since the effective zone around each of the multiple electrodes is larger and hence wider boom separations are possible.

The second characteristic is the effect of boat speed on the total current. Higher speeds should result in lower currents since the electrode elements are deflected upward by the drag in the water. If the electrode elements were to ride along the surface only half in the water, the current could be reduced by approximately 50 percent. Measurements of the actual reduction in current are much less as given in Table 5. The reduction is seldom more than 15 percent and is not a serious problem with the electrode elements used.

Electrofishing Performance

Most of the field evaluation carried out on ac boats has been concerned with performance in low conductivity water and has used the alternate polarity electrode system. The results are summarized in Figure 11. The straight lines in this figure represent typical operating conditions for the alternate polarity array at the various voltages available. Each line ends when the transformer primary current is 10 A, representing an acceptable nominal load for the generator (rated at 11.7 A). Thus, operation significantly beyond the end of any of the lines will lead to overloading the generator. The scatter of the field test points off the operating lines is a result of small differences between boats, variations in the length of electrode actually exposed in the water, and the imbalance in currents caused by variations in electrode size and placement (the average value of the three current readings is plotted).

The evaluation of performance by an operator is a subjective judgment which further complicates interpretation of the data in Figure 11. However, the data clearly show the advantage of operation at higher voltage when the conductivity is below 80 micromhos/cm. Note that for conductivities below 40 all evaluations are "ineffective" except those at 390 and 460 V. The lowest conductivity tested was 14 micromhos/cm where reasonable effectiveness was obtained at 460 V and the effectiveness was extremely poor at 230 V.

Since effectiveness is increased with increased current, operation at the largest possible current within the rating of the generator should be sought under all operating conditions. The operating lines on Figure 11 can be used to determine the best voltage for various conductivity ranges. Figure 12 is an expanded graph showing the full range of the boat and transformer used in the tests. Note that the transformer settings available provide operation from a minimum conductivity of 10-15 micromhos/cm up to about 1200 micromhos/cm with the six electrode array. By removing three electrodes the upper limit can be extended to over 2000 micromhos/cm. Table 6 indicates the proper choice of voltage level and number of electrodes for various conductivity ranges. The table, obtained from Figures 11 and 12, is intended only as an approximate guideline; the best approach is to use the six electrode array and operate at the voltage which most nearly utilizes the full 11.7 A rating of the generator. Electrodes should be removed only if generator overloading is a problem at the lowest voltage setting of the transformer.

The multiple pair array has received only limited field use but initial results are very encouraging. As anticipated the array has a much larger lateral effective zone with initial estimates indicating about 35 percent increase in the overall width of the effective zone at the same anode current. Since the multiple pair array has a higher resistance it must be operated at higher voltage to attain the same current as for the alternate pair array. It is therefore well suited to intermediate and higher conductivities where full output current is readily attainable. The multiple pair array produces a lower maximum current density and hence a smaller hazardous zone than the alternate array and should therefore reduce the chances of injuring fish.

The two arrays produce somewhat different current distributions, each offering some advantages. The alternate array tends to produce an elongated and relatively narrow effective zone along the entire length of each boom. Normally the effective zones associated with each boom overlap in the center region between booms but if boom separation is too large there is often a zone of insufficient current density in the center region. The multiple pair array tends to produce a wide effective zone of relatively short

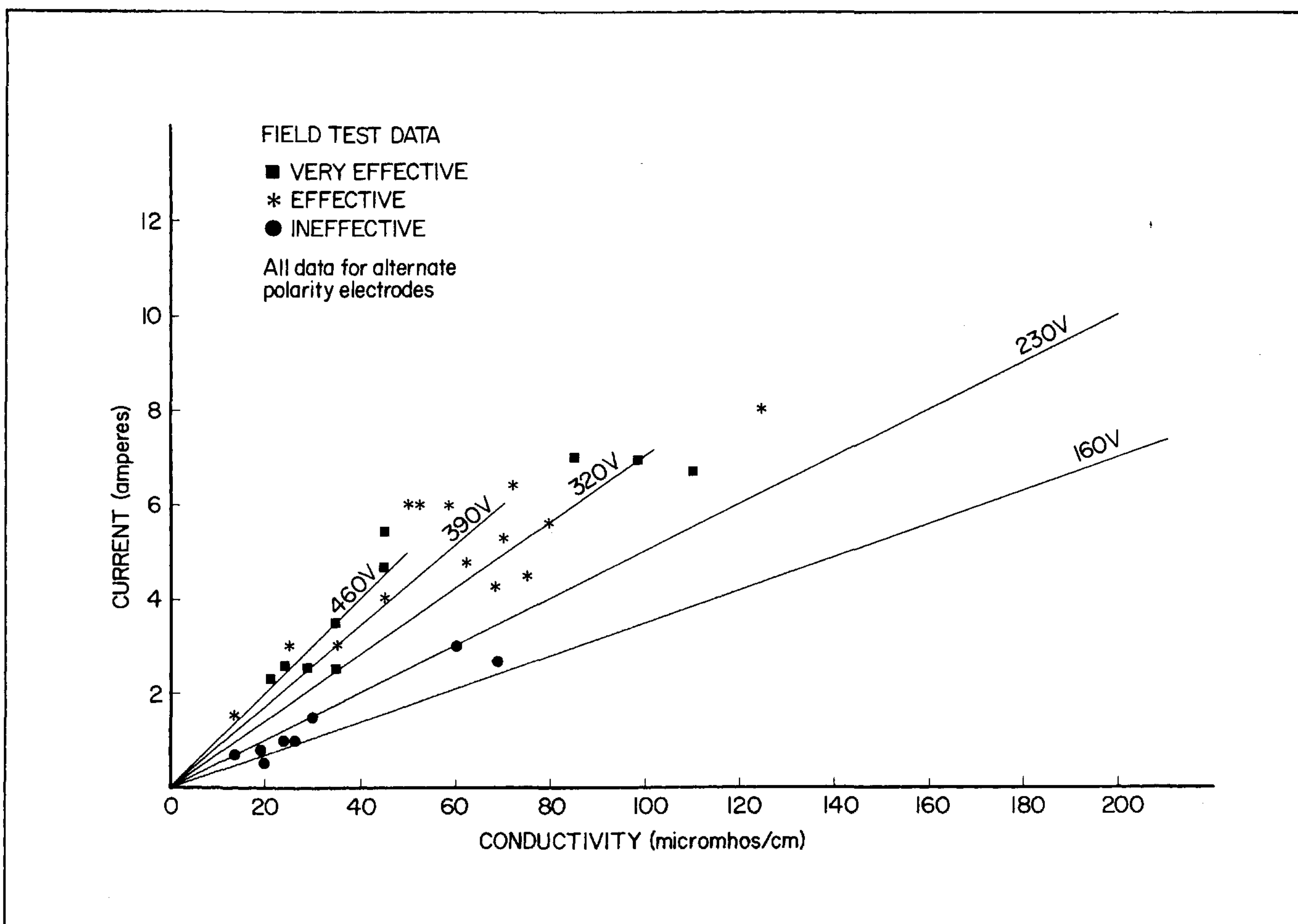

FIGURE 11. *Electrofishing performance of ac electrofishing boats.*

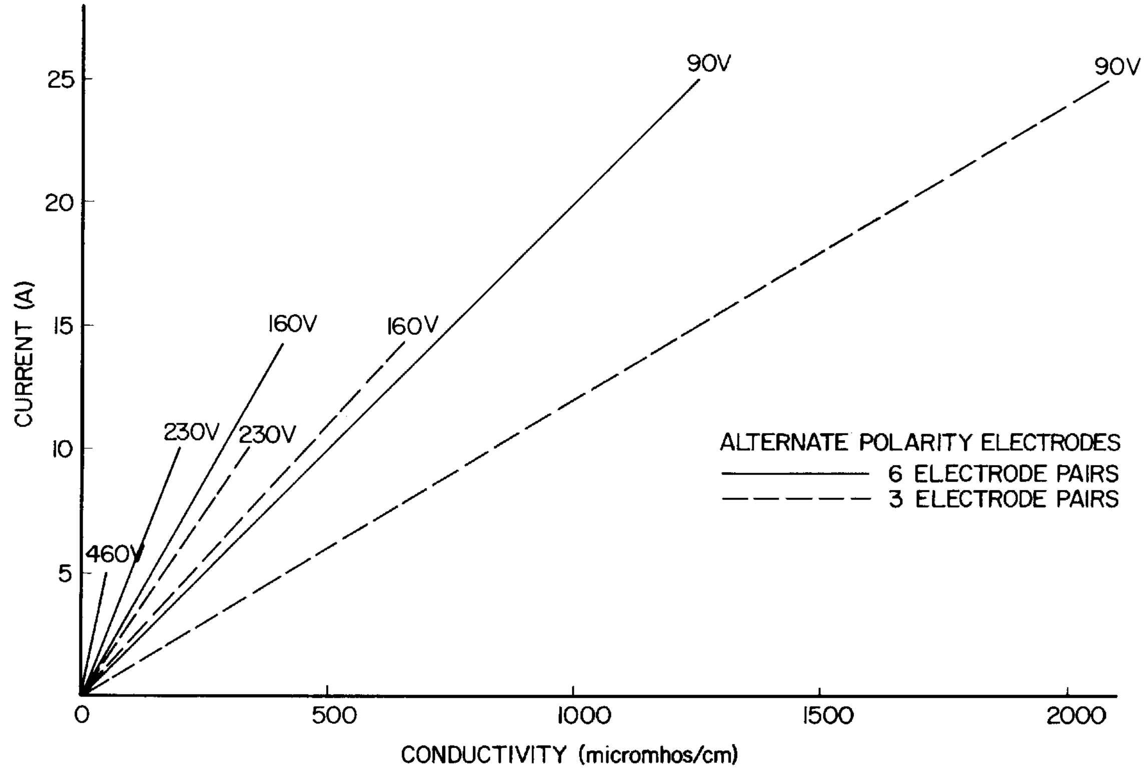

FIGURE 12. *Operating range of ac electrofishing boat*

length centered about the forward electrode pairs. As noted previously, the width of the effective zone is considerably larger but is achieved by reducing the length of the effective zone. Under the varying conditions of lake electrofishing, each of the field patterns has value. For example, in electrofishing along shorelines for northern pike and muskellunge, fish are often captured as they attempt to swim past the boat toward deep water. The longer effective zone of the alternate polarity array is then a distinct advantage. For most other species the wider effective zone of the multiple pair array provides a larger sampling zone and is hence often advantageous.

Since the two arrays can readily be accommodated on the same boom structure by providing two additional connection points, present designs provide for using either array. Additional field testing will be necessary to determine if both arrays are sufficiently useful to be retained in the future. Further development of the multiple pair array is also possible by utilizing three pairs for each forward electrode. However, the present arrays already represent close to the maximum feasible boom loading without severely complicating the boom support structure and ultimately the handling qualities of the boat.

Summary of Electrofishing Results

The work carried out on improving the effectiveness and extending the conductivity range of ac electrofishing boats has produced the following specific results:

(1) Transformers can be used to advantage in extending the conductivity range of ac electrofishing boats. Successful operation down to conductivities of 10-15 micromhos/cm at 460 V has been demonstrated. Extending the range to high conductivities appears feasible but has not been adequately evaluated.

(2) The value of large electrodes in increasing effectiveness and reducing injuries to fish has been demonstrated. Paired cylindrical electrodes mounted in line along the booms have advantages in minimizing water turbulence (hence maximizing visibility) and producing reasonable current density distributions. Operation with the largest possible electrodes at lowest possible voltage is desirable.

(3) Alternate polarity and multiple pair electrodes have been demonstrated to be usable configurations. At present it appears that alternate polarity electrodes are advantageous in very low conductivity water and where a relatively long narrow effective zone is desirable—for example, when fish are to be captured as they attempt to escape past the boat to deep water. Multiple pair electrodes produce a wider effective zone with smaller hazardous zones and offer potential for minimizing injury to fish and increasing the lateral size of the sampling zone.

Future Developments and Required Research

The primary goal of the work on ac electrofishing boats was to develop methods of sampling very low conductivity water. Application of the transformer developed for the experimental pulsed dc boat coupled with enlarged electrode systems has provided means of extending the low conductivity range of ac electrofishing. On the basis of this work several areas for future developmental activity have been identified.

The utilization of a transformer to increase the output voltage in low conductivity water suggests use of a step-down transformer to decrease the voltage and increase the available current in high conductivity water. The later models of the transformers built during the study have this capability, as illustrated in Figure 12. However, no field evaluations have been carried out above a conductivity of 450 micromhos/cm. Field testing coupled with possible electrode modifications to effectively sample high conductivity water are necessary. Further development of the multiple pair electrode configuration to improve the current density distribution and minimize hazards to fish should also be undertaken.

Application of low frequency on-off switching of the ac power similar to techniques used in electric fish screens (Chmielewski 1967) should be investigated. If the power required for effective ac electrofishing can be reduced by such switching techniques, the savings can be realized in smaller, lower-cost generators or by increasing the size of the effective zone using the same generator. Since electronic switching components in the power ranges needed are now (or very soon) available, such techniques may represent feasible technical innovations in the near future.

APPENDIXES I: Survey Forms Used in Study

Date: ____________

AC LAKE SHOCKER SURVEY FORM

Operators: ____________ Lake: ____________

____

____________ County: ____________

Conductivity Reading: ____________ micromhos/cm at ____________ ^{o}F

Make of generator: ____________

Electrical performance:

1. Current: ______ A.C. ____________ D.C. ____________
2. Open circuit (electrodes disconnected): ____________ volts

   (DC or Phase A) (Phase B) (Phase C)
3. Electrodes operating: ________ volts ________ amps ______ amps ______ amps
4. Electrode configuration - give sketch and approximate dimensions including spacing, length and diameter of electrodes:
5. Describe any special electrical equipment (transformers, regulators, etc.)

Fishing Performance:

1. Describe lake conditions (water depth, water clarity, vegetation abundance, etc.) ______________________________

____

____

____

2. Describe fishing effectiveness (how well were fish affected, were any fish injured, how well did system function in deeper water, etc.) Give your qualitative judgment of overall effectiveness compared to other similar electric fishing.

____

____

____

____

____

3. Other comments: ______________________________

____

____

Pulsed DC Boom Shocker Operating Report

Operators ______________ Date ______________

______________ Time ______________

______________ Conductivity ______________ µʊ/cm

______________ Water Temp ______________ °F

Lake & Location ______________________________

Clarity (Approx. depth to which fish were easily visible) ______________

Average Depth of Water Being Worked ______________________________

Type of Bottom ______________________________

Electrode Exposure ______________ inches.

Number of Electrodes ______________ left ______________ right

DC Operation One anode ______________ volts ______________ amps

Two anodes ______________ volts ______________ amps

AC Operation ______________ volts ______________ amps ______________ amps ______________ amps

OPERATING RESULTS

Mode or Pulse rate	Duty Cycle	Comments - Overall effectiveness, estimated depth reached, species captured, species selectivity, variation of effectiveness in relation to bottom type or weeds, variation of effectiveness in relation to pulse rate or duty cycle, etc.

II: Electrical Safety and Electrofishing

INTRODUCTION

Electrofishing uses voltages and currents which can be lethal for the operator. Portable, electrical equipment used in a moist, outdoor environment is more prone to fail and cause shock hazards. An understanding of the problem by the operator and proper design of the equipment can do much to insure safe operation.

This report will discuss the electrical parameters associated with electrical safety and then describe some of the design details that aid in safe operation of electrofishing equipment.

PHYSIOLOGY AND ELECTRICAL SHOCK

Most of the data available on electrical shock parameters deal with 60 Hz currents and voltages. Some work has been done with direct and pulse currents but the results are still not conclusive. Results of animal experiments and some human experiments seem to indicate that 20 to 500 Hz currents are more dangerous than direct current or higher frequency currents.

It is generally agreed that it is the current which passes through a body that does the damage. The voltage in a circuit is only important insofar as it can produce current in the body. Large currents passing through or around a person can cause serious injury because of the heating and burning of tissue. This type of injury is more common at higher voltages used by power companies.

Death at lower voltages, such as 120 to 240 V found around homes, can usually be attributed to one of three causes:

a. Ventricular fibrillation
b. Respiratory arrest
c. Asphyxia

Ventricular Fibrillation

Ventricular fibrillation is an uncoordinated asynchronous contraction of the ventricular muscle fibers of the heart in contrast to their normal coordinated and rhythmic contraction. The heart seems to quiver rather than to beat. This condition is caused by an electrical shock where the path of current is through the chest, such as between two arms or between an arm and a leg. Once a person goes into ventricular fibrillation, the only way to stop the fibrillation is to use a defibrillator which applies a pulse shock to the chest to restore the heart rhythm. Closed chest heart massage and artificial respiration may help until the victim can be defibrillated.

Respiratory Arrest

Shocks with a current path through the respiratory center can cause respiratory arrest. The respiratory center is at the base of the skull slightly above a horizontal line from the back of the throat. Thus, shocks from the head to a limb could lead to respiratory arrest. Artificial respiration can help in this case.

Asphyxia

Asphyxia is caused by contraction of the chest muscles. When current is above a certain level, a person cannot let go of an electrically hot wire. Currents somewhat above this level may not be sufficient to cause ventricular fibrillation but may be sufficient to cause the contraction of the chest muscles and asphyxia since the victim cannot let go of the wire.

ELECTRICAL PARAMETERS

The electrical resistance between the limbs of an individual is highly variable. It depends on the contact conditions such as dry skin versus moist skin, the tough skin of a laborer versus a baby's tender skin, and so on. Tests indicate that a good approximation for the resistance between any two limbs is 500 ohms. This is the estimated resistance with good contact through the skin. Using this figure, a person across a 120 V line, touching the line with any two limbs, might have a current of approximately 0.24 A through his body since the current might be approximately 120/500 A. Across 240 V, the current might be on the order of 0.48 A.

The threshold for perception of 60 Hz is 0.0002 A. A current of 0.00036 A can be perceived by 50% of a group of men while 50% of a group of women can percieve 0.00024 A. This is an important parameter since a shock of such low level in itself is not dangerous but it might startle an individual so that he falls from a ladder, falls out of a boat, or has some other involuntary action which could be hazardous to him or an associate.

When a person grasps a wire at 60 Hz, one man in 200 cannot let go of the wire when the current is 0.009 A or less. At 5 Hz this one man in 200 cannot let go at 0.015 A or less while at 1 kHz the let-go current is 0.013 A. At 60 Hz, 50% of a group of men cannot let go 0.016 A while only one man in 200 can let go 0.022 A at 60 Hz. For women the let-go current is less such that one woman in 200 cannot let go 0.006 A at 60 Hz. This current level is important because the victim is held to the wire. His resistance may then decrease so that more harmful currents can pass through his body.

Asphyxia can be caused by 60 Hz currents of 0.04 to 0.06 A. The victim should be pulled off the line or better yet the line should be de-energized to allow the chest muscles to relax and permit breathing.

Respiratory arrest is not as common as asphyxia and ventricular fibrillation since people usually keep their heads out of electrical equipment. There is no figure readily available as to current level causing this condition but it is probably on the order of 0.1 A between the head and a limb. Artificial respiration will certainly help.

Ventricular fibrillation is the killer since the only real relief involves the use of a defibrillator available at a good hospital. From experiments with animals extrapolated to possible human application, the 60 Hz current range which will produce ventricular fibrillation in one out of 200 people is given by the expression

$$I = \frac{0.116 \text{ to } 0.185}{\sqrt{T}} \text{ A rms}$$

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*By T. Bernstein, Electrical Eng. Dept., Univ. of Wis., Madison.

where T is in seconds. This equation is valid for a range of T from 8.3 milliseconds to 5 seconds. Tests seem to indicate that from 5 to 20 or 30 seconds the threshold is essentially the same.

From this information it should be evident that 20 to 500 Hz currents as low as 0.0002 A can be dangerous. A current of 0.009 A might prevent a person from letting go of a conductor while a current of approximately 0.15 A for 1 second could cause ventricular fibrillation. Direct current values are higher by a factor of approximately 3.

DESIGN FEATURES FOR SAFE ELECTROFISHING EQUIPMENT

The dc and ac generators used in electrofishing provide more than enough voltage and current to electrocute a person. Safe design tries to insure that electrically energized conductors cannot be touched. This is done by carefully insulating all leads associated with the generator. Any switches which must be operated should be carefully insulated if voltages over 24 volts are used in the switching circuit. It is better to use low voltages for the switching circuits and have these circuits isolated by a relay from the higher voltage power circuits. All metal parts of the boat should be carefully bonded, electrically connected, to make sure that there will be no voltage between metal parts in the event of an insulation failure.

Safety switches are of value. There might be a switch on the seat used by the outboard motor operator so that if he falls in the water the power might be interrupted. Switches on the boom handle for a stream shocker or on the front deck of the lake shocker might be designed so that power is removed if the operator lets go of a handle or falls into the water.

Periodic tests should be performed on the system to insure the integrity of the insulation system. A simple continuity check would be quite useful to make sure that no part of the generator electrical output is in contact with the boat.

Many articles have been written on the subject of electrical safety. Three recent articles of interest containing many references are Lee (1966), Dalziel and Lee (1968) and Bernstein (1973).

III: Theoretical Determination of Electrode Resistance

Calculation of electrode resistance generally requires determination of the current density distribution and a subsequent integration to find the total voltage associated with the predetermined current distribution. For uniform conductivity regions the solutions depend only on geometric parameters and are independent of voltage and conductivity. Except for simple (symmetric) geometric shapes, solutions are difficult and require use of a computer. Fortunately, the problem of calculating the capacitance of a conductor array is mathematically identical to the calculation of electrode resistance and hence a large body of literature exists for various geometric shapes including most of those commonly encountered in electric fishing electrodes.

For spherical or cylindrical electrodes the symmetry of the current distribution permits a simple closed form solution. Since these simple electrode configurations are very useful in describing the basic patterns associated with electrofishing electrodes the solutions are presented here. These simple electrodes also form a useful means of establishing the form of the solutions for more complex electrodes. With these basic results available to clarify the problem, the resistance of a number of more practical electrode shapes is presented in graphical form.

NOTATION

The following symbols are used through the remainder of this appendix.

D—separation distance between cylindrical electrodes (cm)
E—voltage gradient (V/cm)
I—total current into electrode (A)
J—current density (A/cm^2)
K—principle dimension of electrode (cm)
l—length of cylindrical electrode (cm)
R—radius of cylindrical or spherical electrode (cm)
R_e—resistance of single electrode (ohms)
R_s—resistance of electrode system (ohms)
r—radial distance to arbitrary point (cm)
V—voltage (V)
σ—conductivity (micromhos/cm)
γ—dimensionless geometric ratio
$f(\gamma)$—dimensionless function describing resistance variation with electrode proportions

SPHERICAL ELECTRODES

For a spherical electrode far removed from the return electrode, it is possible to consider the field pattern and resistance of the electrode independent of the shape or size of the return electrode. To find the total resistance of the electrode system the resistances of the two (or more) electrodes are simply combined by the usual laws for combining resistance.

Since the current distribution of an isolated spherical electrode has spherical symmetry, the current density at any point is radial and has a value

$$J = \frac{I}{4\pi r^2} \qquad A/cm^2$$

The voltage gradient is given by

$$E = \frac{J}{\sigma} = \frac{I}{4\pi\sigma r^2} \qquad V/cm$$

and integration yields the voltage between an external point r_a and the surface of the sphere as

$$V_a = \int_R^{r_a} E dr =$$

$$\frac{I}{4\pi\sigma}\left[\frac{1}{R} - \frac{1}{r_a}\right] \text{volts}$$

As the point r_a is moved out to large values this voltage approaches

$$V = \frac{I}{4\pi\sigma R} \qquad \text{volts}$$

and the resistance of the spherical electrode thus becomes

$$R_e = \frac{V}{I} = \frac{1}{4\pi\sigma R}$$

CYLINDRICAL ELECTRODES

The field pattern around a single long cylindrical electrode (neglecting the distortion near the ends) is cylindrically symmetric. The current density at any point is radial and has a value

$$J = \frac{I}{2\pi r \ell} \qquad A/cm^2$$

The voltage gradient and voltage of an external point with respect to the surface of the electrode are

$$E = \frac{I}{2\pi\sigma r \ell} \qquad v/cm$$

$$V_a = \int_R^{r_a} E dr =$$

$$\frac{I}{2\pi\sigma\ell} \text{Ln} \frac{r_a}{R} \qquad \text{volts}$$

Since this voltage increases without bound as r_a increases, it is not possible to treat an isolated long cylinder as an isolated electrode. If, however, a pair of such electrodes separated by a distance D is considered, superposition of the individual fields and integration yields

$$V = \frac{I}{\pi\sigma\ell} \text{Ln} \frac{D}{R} \qquad \text{for } D >> R$$

The resistance of the two cylindrical electrodes is therefore

$$R_s = \frac{V}{I} = \frac{1}{\pi\sigma\ell} \text{Ln} \frac{D}{R}$$

OTHER ELECTRODES

For more complex electrode shapes the current density distributions must be found by more elaborate computational methods. However, the solution for the resistance can always be put into the form

$$R = \frac{1}{K\sigma} f(\gamma) \qquad \text{ohms}$$

where K and γ describe the size and shape respectively. Figure 13 gives the function $f(\gamma)$ for a number of common electrode shapes. The principle dimension K and the dimensionless geometric ratio γ are identified for each electrode in Table 7.

EFFECT OF SHALLOW WATER OPERATION

The resistance computed from Table 7 and Figure 13 yields results for electrodes far removed from boundaries (water surface or bottom). An electrode placed close to the water surface will have a larger resistance since a portion of the conducting medium has been removed. The influence of bottom materials depends upon the relative conductivity of the bottom materials and the water. In general corrections to the computed values can be made, but except for cases where the electrode is essentially operated at the surface (instead of at considerable depth) such corrections are not of value because of the great variability of operating conditions. When an electrode is operated essentially at the surface, the computed resistance should be doubled.

Examples

To clarify the procedure and assist in interpreting the geometric factors involved in the computation, a series of examples are presented below. All calculations are for a conductivity of 100 micromhos/cm.

1) 25 cm diameter spherical electrode

$K = 25$ cm $\qquad f(\gamma) = 0.159$

$$R_e = \frac{0.159}{25\text{x}10^{-4}} = 63.6 \text{ ohms}$$

2) 25 x 0.6 cm ring electrode (both dimensions diameters)

$K = 25 \qquad \gamma = \frac{0.6}{25} = 0.024 \qquad f(\gamma) = 0.29$

$$R_e = \frac{0.29}{25\text{x}10^{-4}} = 116 \text{ ohms}$$

3) 200cm x 50cm rectangular plate electrode

$K = 200\text{cm} \qquad \gamma = \frac{50}{200} = 0.25 \qquad f(\gamma) = 0.42$

$$R_e = \frac{0.42}{200\text{x}10^{-4}} = 21 \text{ ohms}$$

4) Ring of example 2 as anode with plate of example 3 as cathode mounted under boat.

Since cathode is essentially at surface, double calculated value. Total resistance of system would be

$$R_s = 116 + \frac{21}{2} = 126.5 \text{ ohms}$$

5) Electrode system consisting of two 100 cm by 3 cm cylindrical electrodes separated by 300 cm.

$K = 100$ cm $\qquad \gamma = \frac{300}{3} = 100 \qquad f(\gamma) = 1.47$

$$R_s = \frac{1.47}{100 \times 10^{-4}} = 147 \text{ ohms}$$

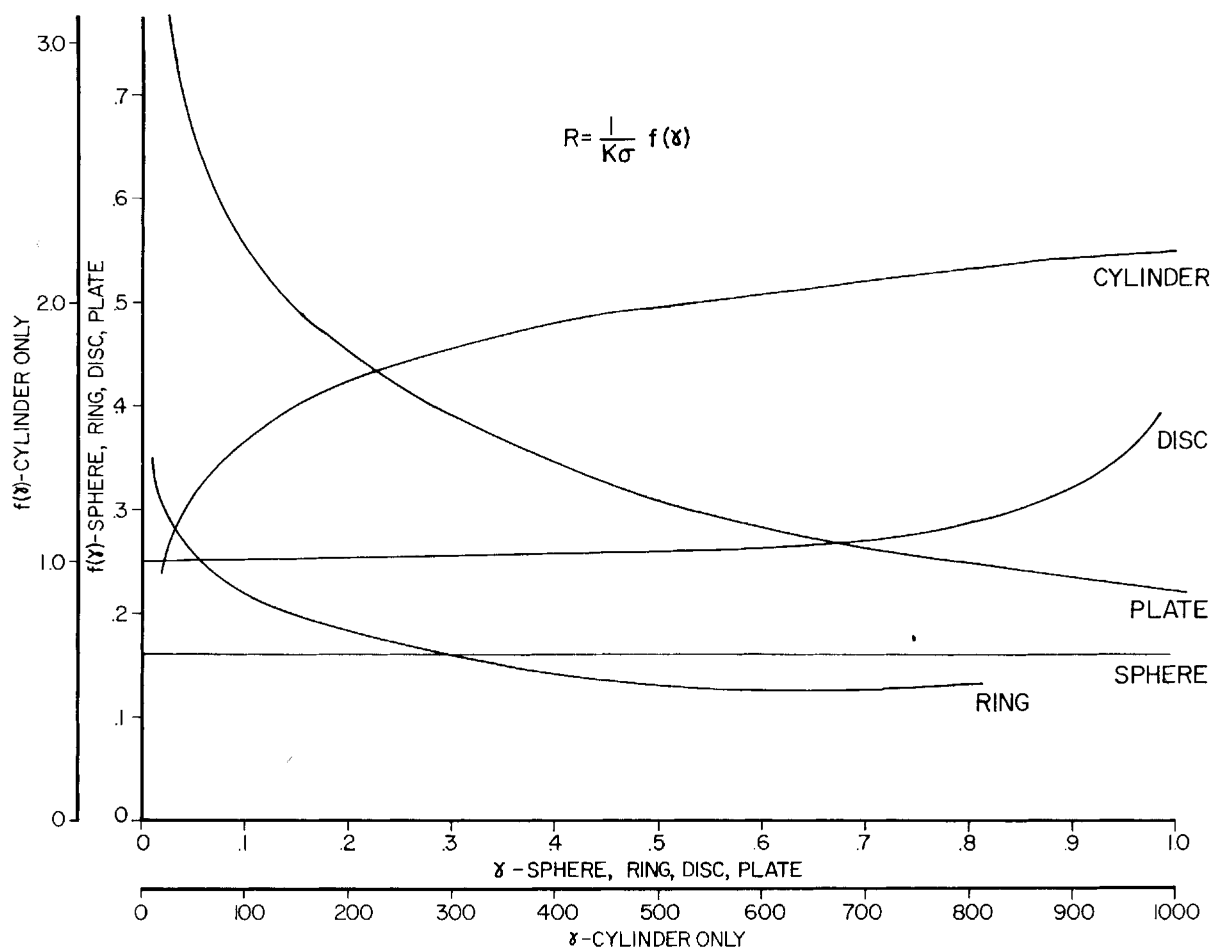

FIGURE 13. *Electrode resistance factors*

TABLE 7. Electrode Resistance Parameters

Electrode	Principle Dimension K	Geometric Ratio γ
Sphere	Diameter	Not Needed
Cylinder	Length	Separation Distance/Cylinder Radius
Ring	Ring Diameter	Thickness Diameter/Ring Diameter
Disc	Outer Diameter	Inner Diameter/ Outer Diameter
Rectangular Plate	Long Dimension	Short Dimension/Long Dimension

IV: List of Major Components Used in Experimental and Operational Boats

Engine-Generator

1. Model FS 180-1A
2. Rating: 4.5 kVA, 0.9 PF, 4 kW, 230 V, 3 phase, 180 Hz ac and 55 A, 12 V dc.
3. Source: T&J Manufacturing, Inc., Oshkosh, Wisconsin 54901.

Transformer and Pulser

(Bernstein and Miller, 1973)

1. Source: Instrumentation System Center, University of Wisconsin-Madison, Madison, Wisconsin 53706.

Safety Mats

1. Floor mats: Model 1423-12H or Model 1830-12H (need 2).
2. Seat mat: Model 824-26L (need 1).
3. Source: Recora Company, Inc., Powis Road, St. Charles, Illinois 60174.

Dip Net Handles

1. Chance epoxiglas poles, Model H4539-2, 2.8 cm (1¼ inch) diameter, 240 cm (7 ft, 11 inch) length, makes two handles.
2. Source: Graybar Electric Company, Inc., 1301 West Badger Road, Madison, Wisconsin 53701 or local source.

Safety Mat Plugs

1. BTO 6JF-8-2P-0 Burndy (need 1).
2. BTO 22P-8-25-0 Burndy (need 1).
3. Source: F.J.R. Midwest Inc., 9340 William St., Rosemont, Illinois 60018.

Safety Switches and Covers

1. Hubbell 1281-MO (need 1).
2. Hubbell 1281-MC (need 4).
3. Hubbell 1750 (need 5).
4. Source: Harvey Hubbell Incorporated, Bridgeport, Connecticut 06602 or local source.

Anode Cross Piece and Droppers

1. Stainless steel tubing welded type 304, 1.6 cm (5/8 inch) O.D., 22 gauge, SAE 30304.
2. Source: Central Steel and Wire Co., P.O. Box 5310A, Chicago, Illinois 60680.

Anode Ring

1. Aluminum, 1.2 cm (½-inch) O.D., 91 cm (36-inch) diameter ring.
2. Source: Dot Line Mfg. Co., Box 567, Silver Lake, Wisconsin 53170.

Plugs and Receptacles

1. Hubbell marine grade, all twist-lock type.
2. Source: Harvey Hubbell Incorporated, Bridgeport, Connecticut 06602 or local supplies.

Booms

1. 2.8 cm (1 1/8-inch) aluminum tubing wrapped with 7 wraps of fiberglass, 4.8 cm (16 ft) length.
2. Source: St. Croix Corporation, 9909 Southshore Drive, Minneapolis, Minnesota 55441.

Lamps (Night Fishing)

1. Sealed beam, General Electric No. 4478.
2. Source: local supplier.

Wire

1. Rated for 600 V, oil resistence.

Cord Connectors

1. Grouse-Hinds type, CGB, aluminum.
2. Source: local supplier.

V: Wiring Diagrams

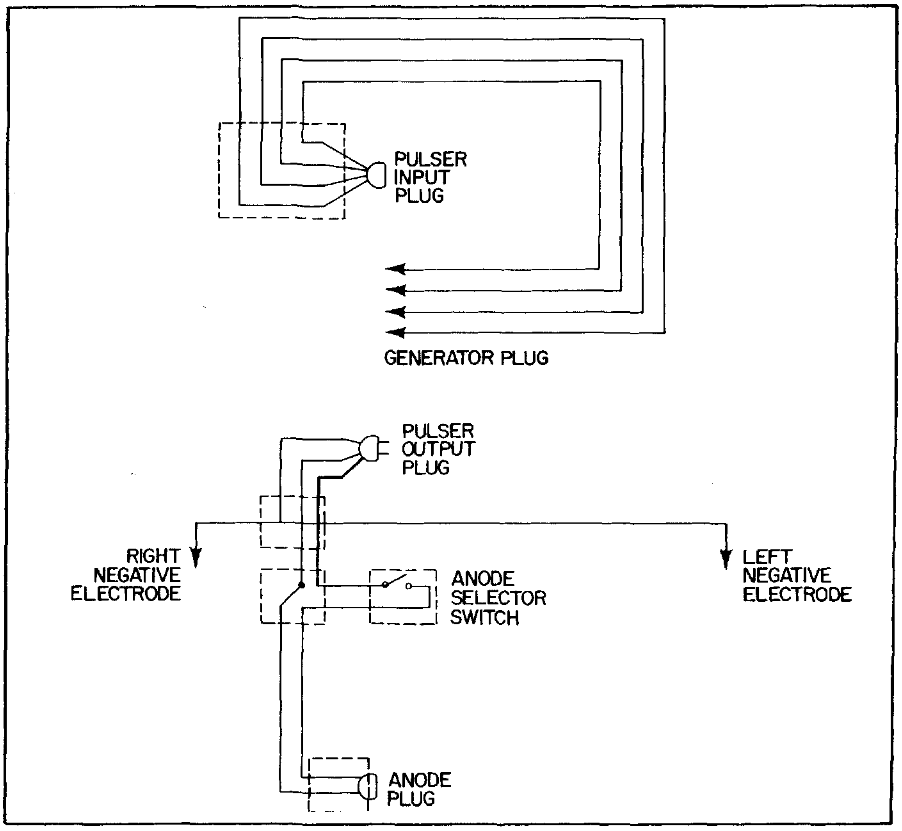

FIGURE 14. *Power circuits for ac-pulsed dc electrofishing boat*

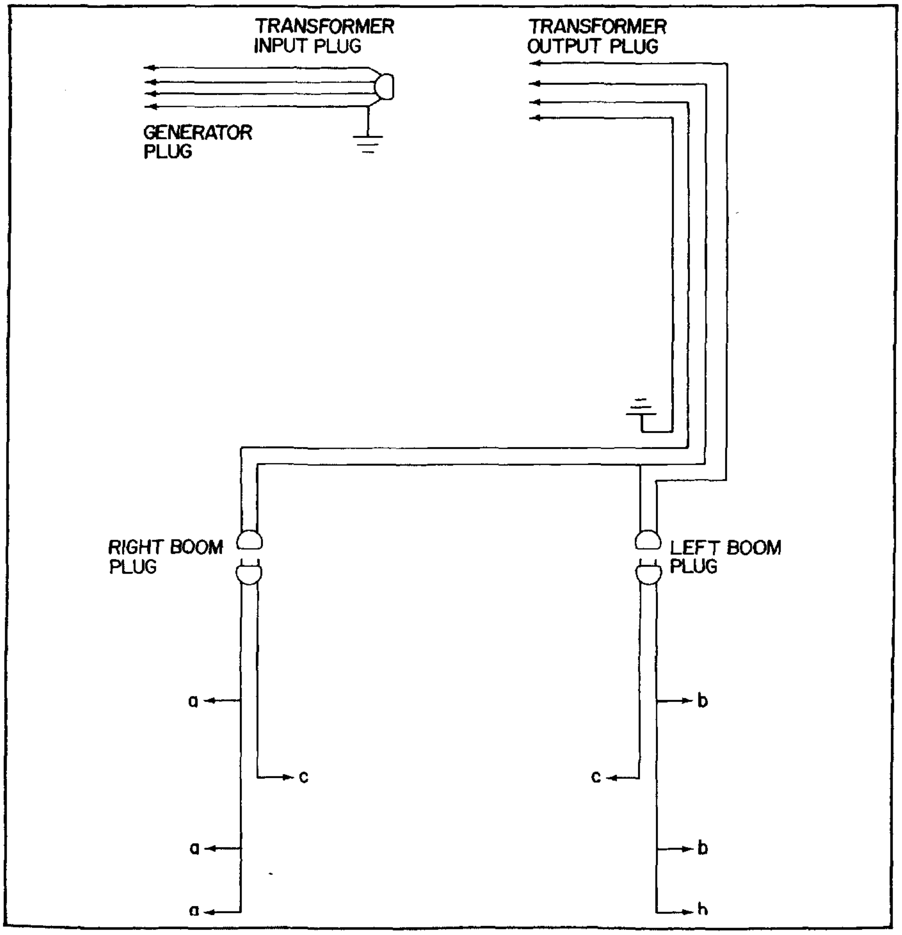

FIGURE 15. *Power circuits for ac electrofishing boat*

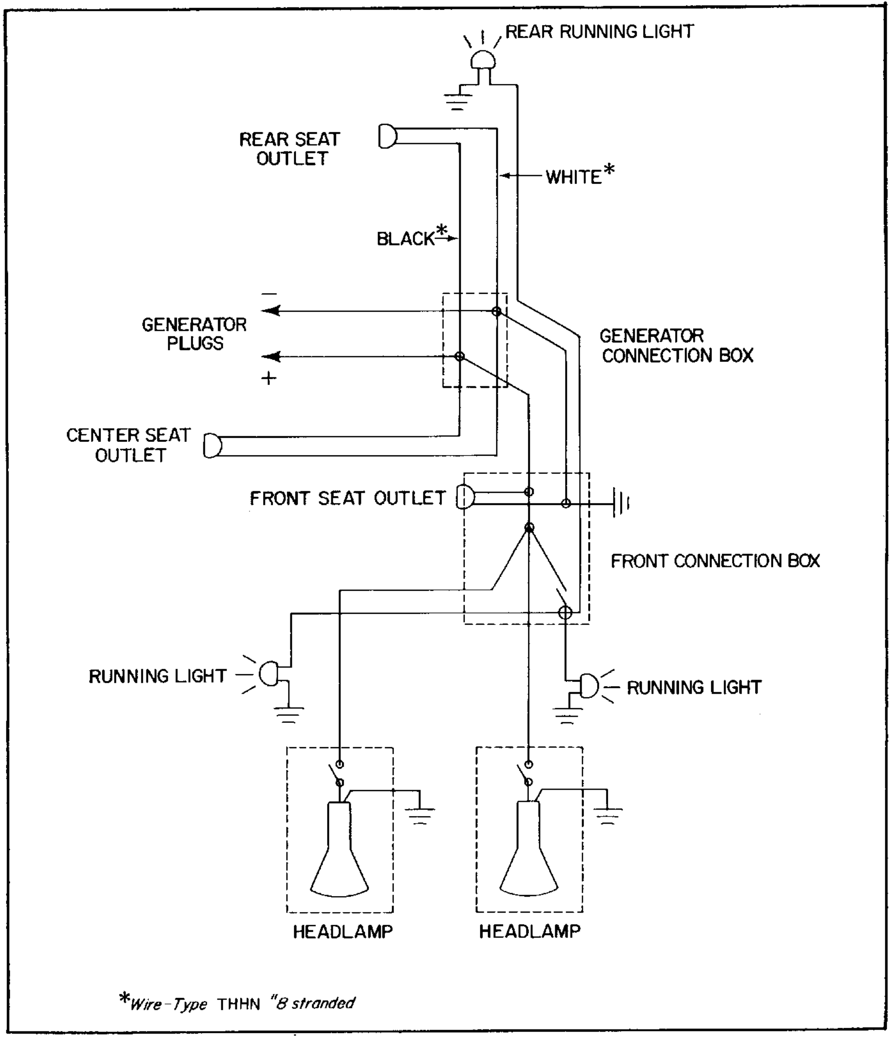

FIGURE 16. *Twelve-volt lighting and auxiliary circuit*

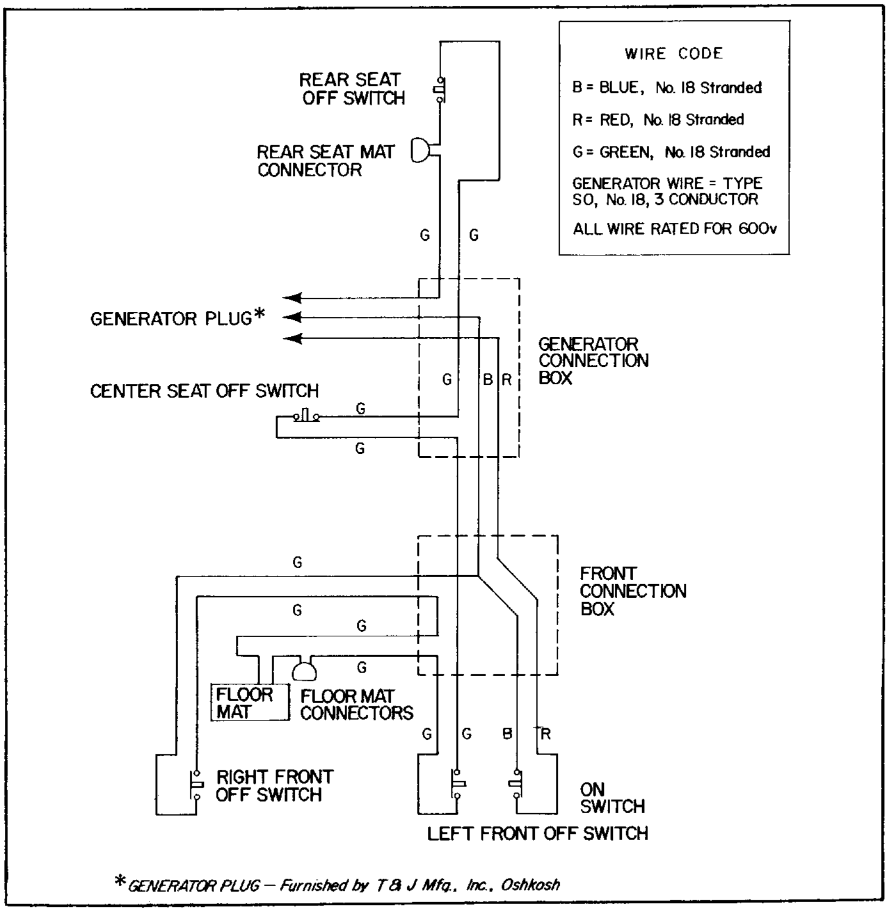

FIGURE 17. *Twelve-volt control circuit*

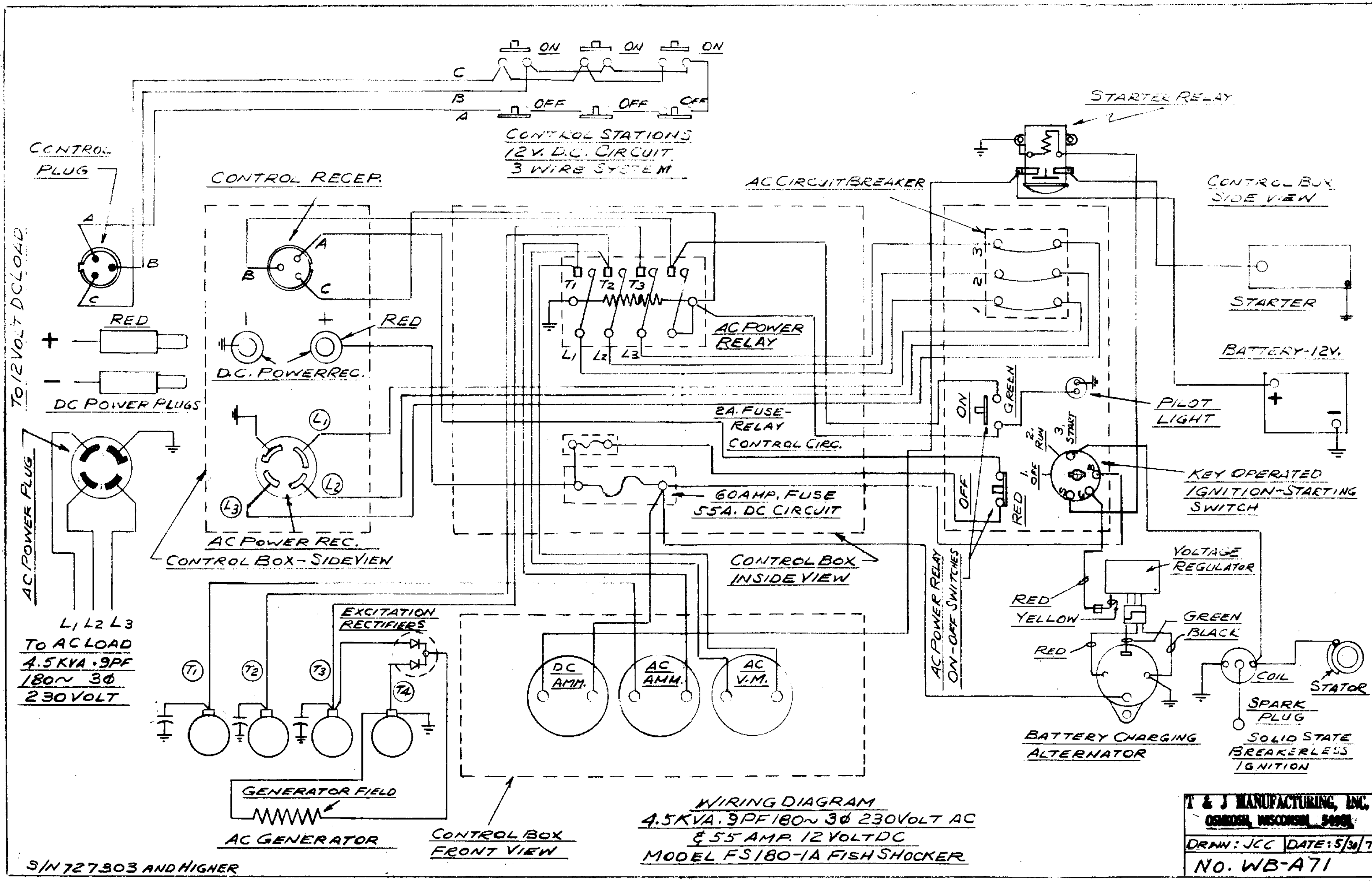

FIGURE 18. *Circuit diagram of Model FS-180-1A engine-generator*

VI: Design Considerations for an Electrofishing Power Supply*

Abstract

An electrofishing power supply was developed to deliver up to 4.5 kW to stun fish. The control makes it possible to use a 3 phase 230 V, 4.5 kVA, 0.9 PF, 180 Hz alternator and deliver an output to the elctrodes of up to 500 V and up to 15 amperes as ac, dc, or as a pulse train with a frequency from 5 to 120 Hz and with an "on time" from 10 to 50% of the period. Electrical safety was carefully considered in the design.

Introduction

Electrofishing makes use of electrical fields in the water to stun fish so they can be netted, examined, counted, and returned to the water as part of a fish census. It is important that the fish not be injured in the process. Alternating current in the water will stun the fish wherever the field is sufficiently strong while direct current fields will cause the fish to swim, involuntarily, to the positive electrode where they are stunned when they reach the strong field near the electrode[1,2]

The electrofishing power supply and control was developed for the Wisconsin Department of Natural Resources. The system is mounted in a 16 or 18 foot aluminum flat bottom boat with electrodes at the bow and sides of the boat. Operators at the bow retrieve stunned fish near the bow electrodes with nets having insulated handles. These fish are placed in holding tanks where they recover in a few minutes and can be returned to the water.

The basic power source is a 3-phase, 230 V, 4.5 kVA, 0.9 PF, 180 Hz alternator driven by a gasoline engine. An open delta transformer arrangement allows this voltage to be varied from 92 to 460 V. The 3-phase alternating current can be routed directly to the electrodes or can be rectified to provide a dc output. The direct current power at up to 500 V and up to 15 amperes is switched by means of a solid state SCR control. This direct current output to the electrodes can be either on continuously, off, or it can be delivered as a pulse train output with a frequency range of 5 to 120 Hz and an "on-time" of 10 to 50% of the period.

The great variability of the output is useful in investigating the fish-stunning ability of direct and alternating currents as well as combinations of both on various species of fish. The pulsed output makes it possible to use instantaneous power higher than the continuous duty rating of the alternator. The variation in voltage is used to obtain suitable current levels for a wide range of lake conductivities.

Electrical safety was one of the most important design parameters. The generators used in electrofishing provide more than enough voltage and current to electrocute a person.

System Operation

Figure 1 shows a system block diagram for the electrofishing power supply. The engine-driven alternator, 3-phase output is routed to the transformer panel through a contactor. This contactor opens the circuit in the event one of the safety interlock switches opens indicating an operator on the boat is out of position. The transformer output is switched by a relay in the power control panel such that in one relay position the transformer output is rectified to be used as dc or pulsed dc output while in the other position the transformer output is used without rectification. The pulse-timing circuit and SCR switching circuit control the dc output. The load relay selects whether the dc or sinusoidal ac output is routed to the electrodes and insures that switching from dc to ac does not take place under load.

The cathode shown in Figure 2 consists of 10 flexible electrodes, each 4 feet [1.2 m] long, mounted five on each side of the boat. The anode, Figure 3, is made up of two 36-inch [91 cm] diameter rings mounted approximately 12 inches [30.4 cm] above the water and approximately 8 feet [2.4 m] apart and 10 feet [3 m] ahead of the boat. The anode electrodes themselves consist of 6-inch [15.2 cm] lengths of 5/8-inch [1.6 cm] diameter stainless steel tubing suspended from the 36-inch [91 cm] diameter rings by 12 inches [30.4 cm] of copper wire. Each anode electrode has an insulating cover which can be moved to expose various lengths of tubing to the water to aid in the control of current in various conductivity lakes. A total of approximately

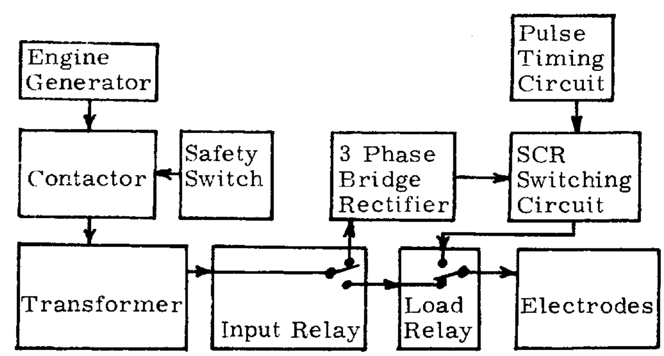

FIGURE 1. System Block Diagram

*By Theodore Bernstein, Electrical Eng. Dept., and Harry H. Miller, Instrumentation Center, Univ. of Wis. Reprinted from Proc. 1973 IEEE Southeast Conf. Cat. No. 73, CHO785-2, REG III.

30 of these droppers are normally used for the anode.[3]

Figure 4 shows an overall view of the boat. At the front is a deck for the fishermen protected by a guard rail. The automotive type headlights provide illumination for fish gathering. Behind the front deck is the fish holding tank. The transformer and power control panels are located near the center seat. The outboard motor operator's position is at the rear.

For dc operation, the positive output of the power control panel is connected to one or both of the anode rings while the negative output is connected to the cathode on each side of the boat. For ac operation, one phase wire is connected to one anode ring, the second phase wire to the second anode ring, and the third phase wire to the cathode electrodes.

Safety

The electrofishing power supply provides voltages and currents which could be hazardous for the operators.[4] All electrofishing power leads are routed in conduit separate from all other wiring. Low voltage 12 V dc is used for the switching circuits and lights. All metal parts of the boat are carefully bonded to make sure that there will be no voltage between metal parts in the event of an insulation failure.

The alternator output is controlled by a contactor that disconnects the output to the transformer panel when the 12 V, dc contactor coil is de-energized. Only one pushbutton switch, located adjacent to the left front operator, can energize the contactor coil. In order for this coil to be energized or to remain energized, it is necessary that three safety interlock switches be activated. These switches are located under the front deck floor mats at the left and at the right front operator position and under the seat cushion at the rear outboard motor operator position. The safety interlock switches insure the power will be interrupted if the operator leaves his seat or falls into the water.

Engine-Generator Power Source

The power source used for electrofishing is a Model FS180-1 engine-generator set manufactured by T & J Manufacturing Inc. It consists of a gasoline engine, 3-phase alternator, alternator-rectifier combination and associated basic engine, alternator, and alternator-rectifier controls.

The gasoline engine is a 12 hp, 4 cycle, single cylinder engine and is used to drive the alternator and the alternator-rectifier.

The alternator is a 3-phase, 180 Hz, 230 V unit rated at 4.5 kVA at 0.9 PF. The alternator is the power source for electrofishing. A 3-phase, 180 Hz, primary power system was selected so that the power source and any associated transformers would be smaller and lighter than comparable 60 Hz components.

The alternator-rectifier consists of an automotive type alternator and rectifier with a dc output of 12 V, 55 A. It is used to charge the starting battery and to provide safe, low voltage for control, lighting, and other auxiliary functions where the operator might contact the power supply.

The engine-generator control panel contains conventional components for engine starting and battery charging. In addition, the panel contains input power control connectors, output power connectors, ac and dc ammeters, ac voltmeter, and a power contactor which can disconnect the alternator output from the output connector.

Transformer Panel

The transformer panel, the lower panel in Figure 5, provides the transformers and control to convert the input 230 V, 180 Hz, 3-phase power to selected voltage levels. The two transformers in the panel are connected in open delta so that only two transformer cores are required for this 3-phase transformer configuration. This is a weight saving at these power levels and simplifies the coil switching for voltage selection. The three output voltage switches in conjunction with the High-Low voltage switch permits the selection of any of six, 3-phase output voltages.

The input leads are routed through three 25A ammeters that provide an indication of alternator load and load balance. When the High-Low voltage switch is in the High position, the transformer switching relays are de-energized and each of the transformers is connected in an auto-transformer configuration with output voltage taps at 322, 391, and 460 V as shown in Figure 6. When the High-Low voltage switch is in the Low position, the transformer switching relays are energized and the windings are paralleled on each transformer as shown in Figure 7 and output voltage taps of 92, 161, and 230 V are available.

Figure 8 shows the schematic wiring diagram for the transformer panel. The 50 turn winding on each transformer provides a nominal 33 V, isolated winding on each transformer. These 33 V windings are connected in open delta to provide 3-phase excitation for the 3-phase bridge circuit providing the isolated dc power supply for the control electronics. The single phase full wave rectifier bridge in the transformer panel is connected to a 33 V winding and provides power for the operation of the series connected transformer switching relays. Since most electrofishing is done in relatively low conductivity lakes in Wisconsin the transformer switching relays are energized for lower voltage output as this is the less common condition.

The three output switches in conjunction with the High-Low voltage switch select the 3-phase output voltage. With the High-Low voltage switch in the High position and with a 230 V input to the transformer panel, outputs of 322, 391, or 460 V (Nominal: 320, 390, 460 V) can be selected by actuating an appropriate switch. With the High-Low voltage switch in the Low position the outputs can be 92, 161, or 230 V (Nominal: 90, 160, 230 V). The switch interconnection is unique in that if two output switches are actuated inadvertently, only the lower voltage will appear at the output.

An ac voltmeter is connected across one of the phases at the output of the transformer panel to measure phase line to line voltage.

TRANSFORMER WINDING SPECIFICATIONS

Core Part Number: Arnold Engineering, 6T9259-Z4

Core Material: Z Silectron, 4 mil

Size (in.):	I.D.	O.D.	HT
Core	3.23	5.00	1.50
Cased Core	3.04	5.21	1.71

Gross Core Area: 8.47 cm^2

Stacking Factor: 0.9

Mean Path Length: 32.9 cm

Windings: 7 Windings

NOTE: Photographs of the boat and equipment (Figures 2, 3 and 4) are not included in this reprinting, since they may be found on page 19 and on the cover in this bulletin. Figure 5 has been omitted.

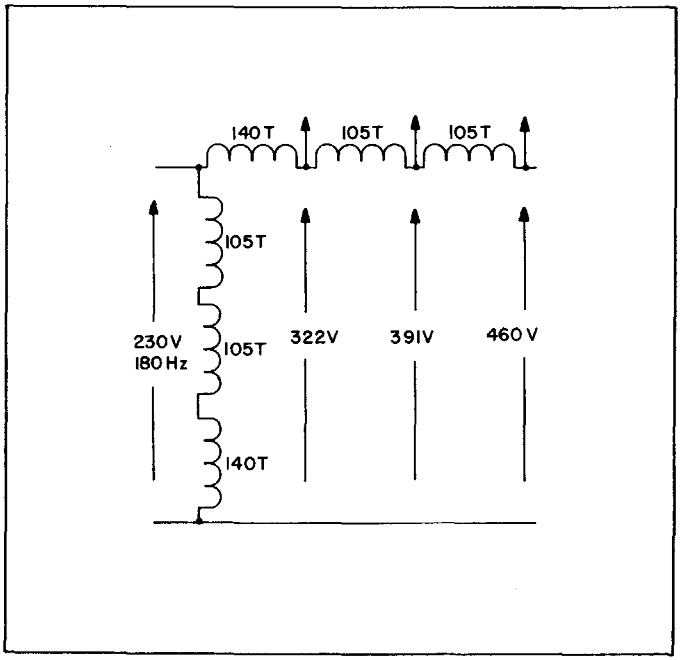

FIGURE 6. High Voltage Transformer Connection

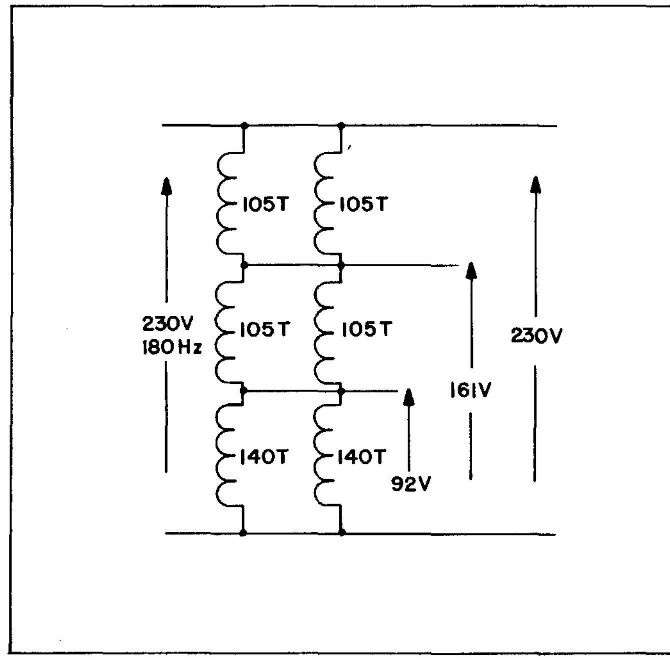

FIGURE 7. Low Voltage Transformer Connection

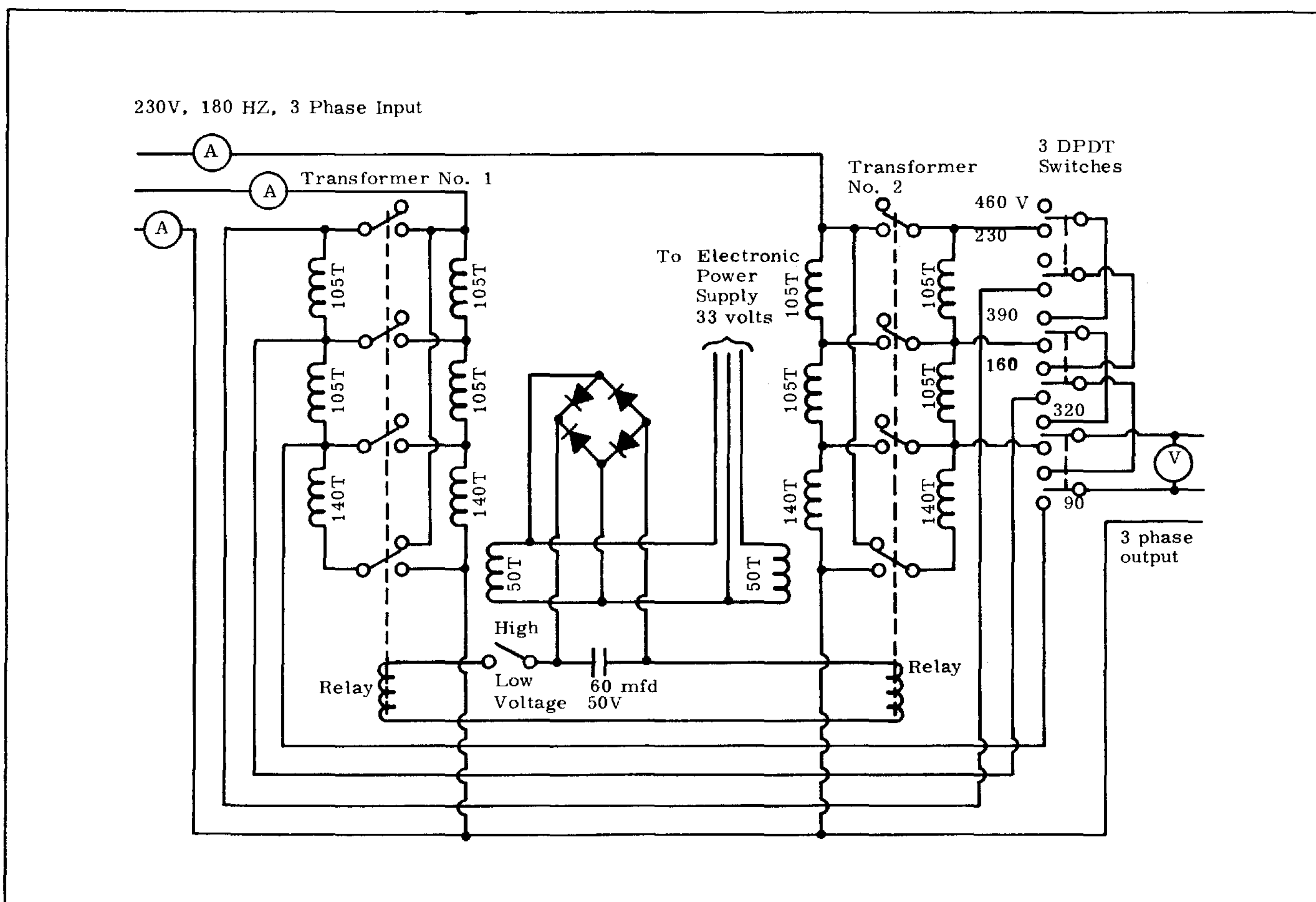

FIGURE 8. Transformer Panel
Components: 3 DPDT Switches, Hubbell 1382; Ammeters, 25A.AC; Voltmeter, 500 V AC; Relays, Potter and Brumfield, PM17DY, 24V; Bridge Rectifier, Varo VS248; Input Plug, Hubbell 74CM50 with Cover; Output Plug, Hubbell 74CM10 with 7420 Cover; Transformers, Arnold 6T9259-Z4 Cores.

2-AWG 12, 140 turns each
4-AWG 14, 105 turns each
1-AWG 16, 50 turns

Power Control Panel

The Power Control Panel, upper panel in Figure 5, contains relay and semiconductor power devices and control electronics which permit the ac output of the Transformer Panel to be routed directly to the electrodes or to be rectified and switched prior to being routed to the electrodes. A rotary selector switch on the front of the Power Control Panel permits the output to the electrodes to be turned off, to be sinusoidal ac routed directly from the Transformer Panel, or to be continuous dc or pulsed dc at frequencies of 5, 15, 40, 80 and 120 Hz. Another switch, the duty cycle switch, can select the "on times" of 10, 25, or 50% of any period for the selected frequency. The three meters on the front panel monitor the dc parameters with one 750 V dc meter for the voltage at the output of the 3-phase bridge, the second 750 V dc meter for the actual voltage routed to the electrodes after switching, and the 25 A dc meter for the dc current routed to the electrodes.

With the rotary selector switch in the OFF postition, Figure 9, the input 3-phase power is routed to the 3-phase bridge rectifier circuit. The 750 V dc meter will indicate the rectified voltage and the input neon lights will be on. Relay K1 will will be energized by the dc input voltage that provides base drive for transistor Q1. Relay K1 will be energized and connect the electrodes to the dc portion of the internal circuitry. SCR1 will be on because of the gate drive through resistors R1 and R2. Capacitor C1 will be charged to dc line voltage through SCR1, CR1, and the electrode circuit. SCR2 will be nonconducting since it has no gate drive and its gate to cathode is shunted by resistor R4. Since SCR2 is nonconducting there will be no output and meters M2 and M3 and lights L2 will indicate no output.

When the rotary selector switch is moved to the continuous DC position, gate drive is removed from SCR1 and is routed to SCR2. SCR2 will turn on routing the dc power to the output through CR1 and meter M3. At the instant SCR2 is gated on, capacitor C1 reverse biases SCR1 and turns it off. SCR1 will have its gate to cathode shunted by resistor R5. Rectifier CR1 prevents the 3-phase bridge output ripple voltage from appearing at the electrodes when SCR1 is conducting and SCR2 is off. Without rectifier CR1, there is an ac path from the output of the rectifier bridge through SCR1 and capacitor C1 to the electrodes. With CR1 in the circuit, dis-

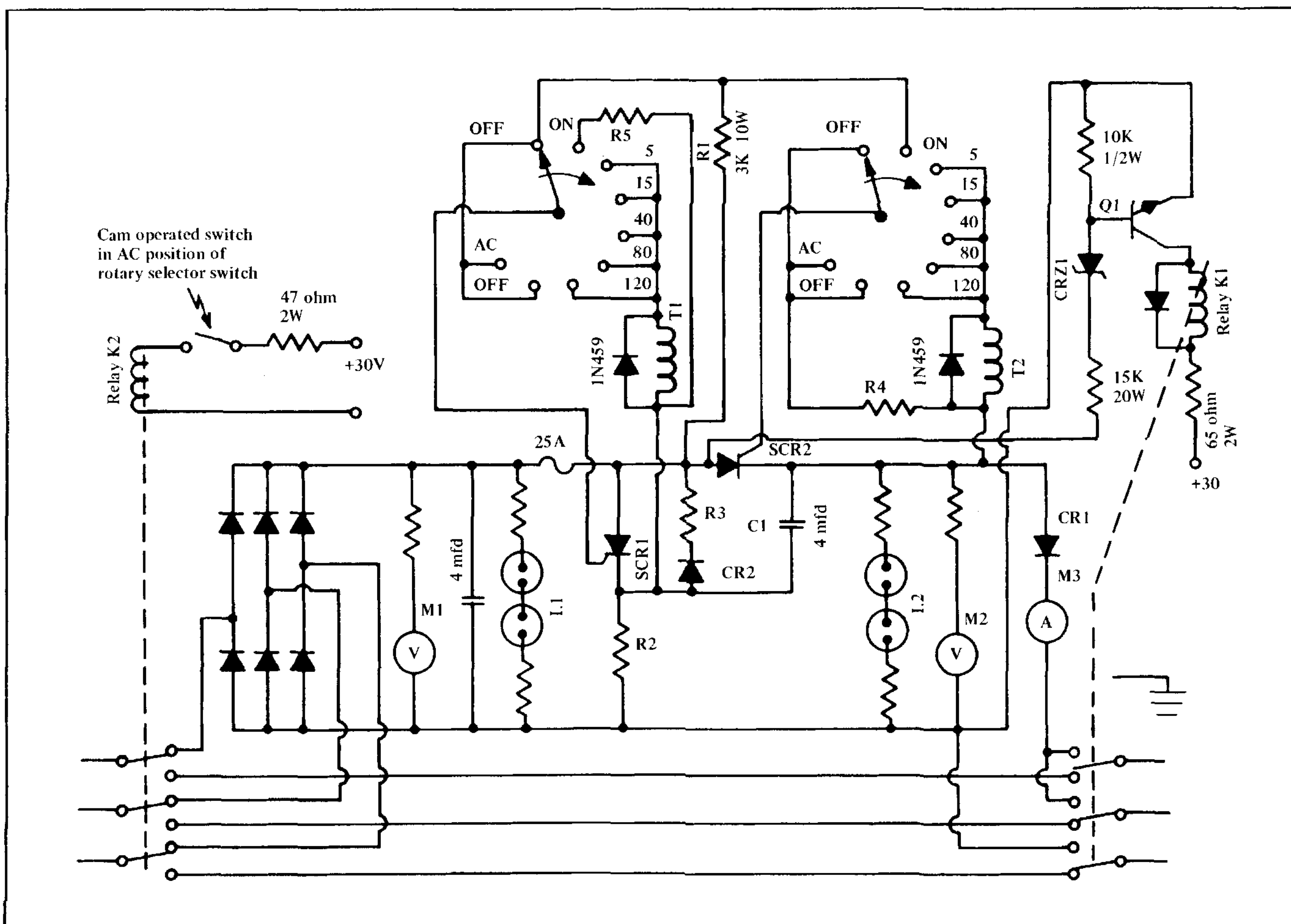

FIGURE 9. Power Control Panel
Components: Full Wave, 3 phase bridge, Tung-Sol B-20K, 1000V 35A; SCR-1-2N4444; SCR-2N1849B; Q1-TIP29A; R1-3K ohm, 10W; R2-1500 ohms, 200 W; R3-10 ohms, 25W; R4, R5-270 ohm, 1W; CR1-600V35A; CR2-600V, 5A; CRZ1-22V, 1W zener; L1, L2-230V neons, 2 in series; T1, T2-Sprague 11Z2000; Relays K1, K2-Potter Brumfield PM17DY 24V; Input Plug-Hubbell 74CM50 with Cover; Output Plug-Hubbell 74CM10 with 7420 Cover; Voltmeters 750V DC: Ammeter 25A DC.

charge of capacitor C1 through the electrode circuit is prevented and capacitor C1 is charged to peak ripple voltage to block the current path through the capacitor. Resistor R3 and rectifier CR2 aid in the rapid discharge of capacitor C1 so that it can be recharged with opposite polarity through SCR2 and R2 after SCR1 turns off. This is important when high frequency, low percentage "on time" is desired as will be described later. The output neon lights are now on and the output meters indicate the output voltage and current.

If the rotary selector switch is returned to the OFF position, SCR1 will be turned on and will provide a path for the voltage on capacitor C1 to turn off SCR2.

With the rotary selector switch in the 5, 15, 40, 80 or 120 Hz position, a switched dc output at the desired frequency is obtained. The percentage "on time" of 10, 25, or 50% can also be selected. In these positions, the SCR pulse transformer, T1, associated with SCR1 provides a pulse when it is desired to turn off the output while SCR2 is turned on by pulse transformer T2 when an output is desired. The pulses from the electronic circuit will turn on SCR1 and SCR2 alternately by action of pulse transformers T1 and T2 at a frequency and percent "on time" determined by the rotary selector switch. The output neon lights will flash on whenever there is an output pulse and the output dc voltmeter will oscillate as a function of the output voltage peak amplitude, frequency, and percent on time.

When the rotary selector switch is moved to AC, a cam-operated switch energizes relay K2 which connects the output of the Transformer Panel directly through the contacts of relay K1 to the electrodes. The control circuit for relay K1 insures that the relay will not switch under dc load since relay K1 will not de-energize until the dc voltage has fallen below 22 V as determined by zener diode CRZ1.

The capacitor commutated SCR dc switching circuit is relatively conventional. The high frequency, low percent "on time" condition made it necessary to make R2 a relatively low resistance, high wattage resistor, 1.5 kΩ, 200 W, so that the capacitor C1 could be charged to a sufficient voltage through R2 during the short on time to turn off SCR2 when SCR1 turns on. This same problem led to the use of CR2 and R3 to hasten the discharge of C1 during the short on time of SCR2.

Timing Circuit

A conventional free running multivibrator, shown in Figure 10, is used to set pulse frequency from 5 to 80 Hz. The multivibrator drives a one shot which sets the duty cycle. A 3-position rotary switch sets the duty cycle at 10%, 25% and 50% for each of the 4 frequencies, 5, 15, 40 and 80 Hz. The one shot drives a buffer amplifier. The output of the buffer is a positive pulse which goes through a wafer of the 8 position rotary switch.

The 120 Hz is generated by a fixed frequency multivibrator followed by a one shot which sets duty cycle by a wafer on the 3-position switch. Pulsed 120 Hz can be obtained at any switch frequency setting when the operator actuates a foot operated switch, S1, on the front deck. The switch energizes a relay to switch from the frequency setting of the rotary selector switch to the 120 Hz multivibrator. This permits the operator to obtain the greater stunning effect at any time.

The relay contacts are connected to an emitter follower. The positive pulse from the emitter follower is differentiated by the 0.01 μF capacitor and 1 kΩ resistor. The positive going pulse derived from the leading edge goes through a diode triggering the driver SCR which turns on SCR2 in the power circuit. The negative going pulse derived from the trailing edge is inverted and triggers the driver SCR which turns on SCR1 in the power circuit.

The driver SCR's trigger power SCR1 and SCR2 through pulse transformers T1 and T2. The transformers were necessary for isolation. The pulse to the gates of the power SCR's is about 30 V peak with an exponential delay to 10% in 40 microseconds.

Acknowledgment

This project was supported by the Wisconsin Department of Natural Resources. Gordon R. Priegel of the Department of Natural Resources and Dr. Donald W. Novotny of the Department of Electrical Engineering, University of Wisconsin-Madison, determined the requirements for the electrofishing system, designed the boat, and got to do the fishing.

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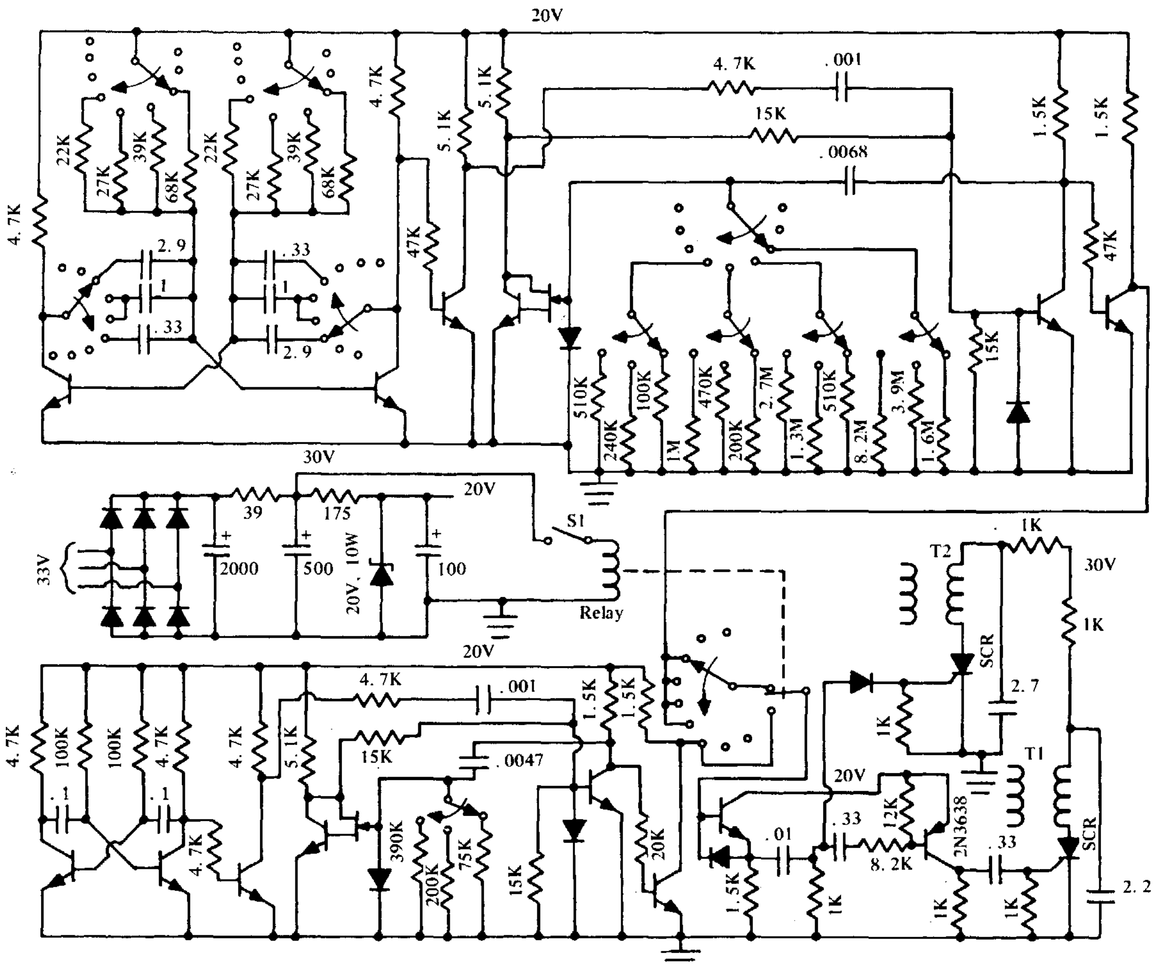

FIGURE 10. Timing Circuit
Components: Resistors, 1/2W, 10%; Transistors, 2N3641 Except as Noted; FET's, 2N5458; SCR's, 2N4184; Diodes, 1N459; Bridge Diodes, 100V, 2A; Capacitors in Timing Circuits, Paktron, WB Series, Mylar; Capacitor Values in MFD's; T1, T2-Sprague 11Z2000; Switch S1 Operated by Net Men; 9 Position Rotary Switch, OFF, ON, 5, 15, 40, 80, 120 Hz, OFF, AC: 3 Position Rotary Switch, 10, 25, 50%.

VII: Operating Instructions for ac-Pulsed dc Electrofishing Boats

1 Safety

Warning—Electrofishing equipment is hazardous. Although the ac-pulsed dc electrofishing boat has been designed with operator safety as a primary consideration, the necessity of observing all rules of water and electrical safety cannot be over-emphasized. In addition to the usual safety precautions:

(1) Be sure both boom grounding clamps are attached to suitable grounding points in boat.

(2) Learn the location of each off switch. Power to the electrodes can be interrupted by pressing any of the off switches or by unloading any of the mat switches.

(3) Do not place hands or conducting objects in the water near the boat. There are hazardous voltage gradients in the water near the boat as well as near the electrodes.

(4) Do not bypass or use dummy loads on mat switches.

(5) Stop the generator before changing fuses, removing or inserting plugs, or making any changes in the electrical system or electrodes. Remember, the generator does not have to be operating to have lights available.

(6) Although the 12-volt system does not pose a serious shock hazard, it is capable of large currents and associated arcing hazards. Do not treat these circuits and the battery carelessly.

(7) Do not operate the ac-pulsed dc electrofishing boat close to other boats or near a shoreline where people or animals are located.

2 Electrical Ratings and Switching

Caution—Failure to observe the three items below can cause damage to the equipment.

(1) The main power control relay is in the generator control box and is controlled by the safety switches. Always disconnect the generator from the pulser by pressing one of the off switches before changing settings (voltage level or mode) on the pulser.

(2) The main generator is rated 230 V, 11.7 A. Do not operate for extended periods with *any* of the three ac ammeters reading more than 11.7 A.

(3) The 12-volt generator is rated 12 V, 55 A. This system is identical to that on an automobile and should be monitored as in an automobile by observing the 60-0-60 A ammeter on the generator control box.

3 Circuit Protection

(1) The main generator is protected by a 15-ampere circuit breaker in the generator control box. This breaker functions as a manual on-off switch as well as the circuit protective device. It is reset by simply returning it to the on position after correcting the overload condition.

(2) The 12-volt circuit is protected by a 60-ampere fuse and the control circuit by a 1.0-ampere fuse, both mounted in the generator control box.

(3) A special fuse inside the pulser protects the pulser circuits against direct short circuits. This fuse cannot be changed in the field.

4 Start Up Procedure

In general, optimum electrofishing effectiveness is attained at full rated output. The generator output is always measured with the three ac ammeters on the transformer unit regardless of the electrofishing mode. Since the dc mode places the heaviest load on the generator, the following start up procedure is intended to yield electrode and voltage level adjustments which result in full output of approximately 11 A on the ac ammeters with the pulser mode control set on dc.

(1) Consult Table 8 and set the electrodes as indicated. If a reasonable estimate of the water conductivity is not available, start with the table entry for a conductivity of 600.

(2) Set controls as follows: (a) Mode switch to dc; (b) Transformer switches to low voltage; (c) Anode switch to off.

(3) Move the boat to a location which approximates the type of area to be fished.

(4) Start the generator, energize the electrodes, and observe the ac ammeter readings. All three meters should read approximately the same in the dc mode.

(5) If the readings are greater than 7 A, stop the generator and return to shore. Reduce the electrode exposure or number of droppers and repeat steps 3 and 4.

(6) If the readings are less than 7 A, press an off switch, turn the anode switch on, and re-energize the electrodes.

(7) With the anode switch on, correct electrode choice is indicated by ac ammeter readings in the range of 10 to 11 A.

(8) If the currents are not in this range, stop the generator and return to shore to make electrode adjustments.

(9) If proper currents cannot be attained with maximum electrode exposure, use the voltage control switches to increase voltage.

(10) In very low conductivity water, 10 to 11 A will not be attainable even with maximum electrode exposure and maximum voltage. The ac-pulsed dc electrofishing boat can be used but will not be fully effective under these conditions.

5 Operation

With the system adjusted for full output in the dc mode, the unit is ready for use and can be operated in any mode without additional electrode adjustments.

(1) DC Operation

(a) Set mode control to dc.

(b) ac ammeters should all read nearly the same and preferably be in the range of 10 to 11 A.

(2) AC Operation

(a) Set mode control to ac.

(b) Be sure anode switch is on.

(c) ac ammeters will normally not all read the same. The largest reading must always be less than 12 A.

(d) In some cases it will be possible to operate at a higher voltage than in the dc mode. If the largest current is 8 A or less, press an off switch and then raise the voltage. If the largest current is less than 12 A, operation is acceptable.

(3) Pulsed DC Operation

(a) Set duty cycle switch to 50 %. Turn mode switch to desired pulse rate. The dc ammeter should now read approximately 50% of the reading obtained with the mode switch on dc. If it does not, the pulser is misfiring on this setting. Try other pulse rates or reduce dc current by adjusting electrode.

(b) With duty cycle switch on 25% or 10% the dc ammeter should drop to 25% or 10% of the reading on dc for any of the available pulse rate settings. Failure to read these levels indicates misfiring of the pulser.

(c) Misfiring of the pulser will not cause harm to the equipment but may not give good electrofishing results. Reducing the current by adjusting the electrodes will usually cure the misfiring.

(d) If the pulser should stop pulsing and go into the dc mode while set for pulsing, try interrupting the power momentarily by pressing an off button and then a start button. This type of malfunction can be caused by a stray pulse or switching transient and is not harmful to the pulser circuitry.

6 Electrofishing Guidelines

The comments in this section are intended to assist in rapid development of effective utilization of the ac-pulsed dc electrofishing boat. The material is based on field use of the experimental boat. Additional information of this type will be developed by surveying field use of the new equipment.

(1) General Comments

(a) Full output operation (10 to 11 A on ac ammeters) produces highest electrofishing effectiveness. Adjust for this condition whenever possible.

(b) Large electrodes and low voltage operation is superior to operation at higher voltages. Use higher voltages only when low water conductivity makes it necessary.

(c) The safety switching system can be used as a control to turn the power on and off. This can be effective in approaching areas of possible high fish concentration without power on and energizing at appropriate time. The net handlers can exercise this control.

(2) DC Operation

(a) dc will attract fish to the anodes without stunning. This can be advantageous where there is a water current or where weeds or algae prevent reasonable visibility.

(b) The range of dc is minimal. Low pulse rate pulsed dc electrofishing is usually better than dc.

(3) AC Operation

(a) ac does not attract fish but has the largest range of action.

(b) Occasionally, better performance is obtained at reduced output if fish are being stunned too far from the electrodes.

(4) Pulsed DC Operation

(a) Low pulse rates (5-15 pps) are similar to dc except they have greater effective range.

(b) Higher pulse rates (40-80-120) have greater range but fish will be stunned as they approach the anodes.

(c) Pulse duty cycle appears to have only secondary effects; 50% and 25% settings appear to give similar results and hence 25% is preferable since it conserves power; 10% appears to be less effective. More data are needed.

(d) Some species selectivity is possible. Although only qualitative observations have been made, the following may be useful. Additional data are needed.

(1) Trout, largemouth bass, carp, bullheads respond well to higher pulse rates and will approach quite close to the anodes before being stunned.

(2) Walleye, white bass, yellow perch, bluegills are more easily stunned and lower pulse rates are required to bring them close to the anodes.

(3) There appears to be an optimal pulse rate for each species, but at this time quantitative data are lacking. In general, the following ranges have been found useful.

Bluegill 15-40
Carp 40-120
Largemouth bass 40-120
Walleye 5-40
White bass 15-40
Trout 40-120
Bullheads 80-120
Yellow perch 15-40

Safety Procedures

There are a number of reasons why boat-carried electric shockers are more dangerous than land-based ones. The footing may be treacherous, space to move in is limited, rough weather or objects in the water are navigation hazards, noise from the generator and boat motor are distracting and limited visibility (at night) is frustrating.

For these and other reasons the following safety precautions should be always observed:

1. Always wear Coast Guard approved life jackets.
2. Always wear hip boots or waders.
3. Store all gear and keep boat in neat condition.
4. Avoid excess fatigue or drowsiness and be constantly alert.
5. Authorize one person to be in charge and his authority should not be questioned during an operation.
6. Instruct all personnel in the fundamentals of electricity.
7. Thoroughly familiarize all personnel with all phases of the equipment and its operation.
8. Make sure that all equipment is in good condition and properly used.
9. Make sure that there is a first aid kit and fire extinguisher on the boat.

TABLE 8. Suggested Electrode Configuration

Conductivity micromhos/cm	No. of Droppers	Exposure cm (inches)
600	10	none
500	12	none
450	15	none
400	15	0.3-0.6 (1/8-1/4)
350	15	1.3 (1/2)
300	15	1.9 (3/4)
250	15	2.5 (1)
200	15	3.8 (1 1/2)
150	15	7.6 (3)
100	15	15.2 (6)
Below 100	Raise Voltage	

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3500-3J40123-74

ACKNOWLEDGMENTS

We wish to acknowledge Prof. Theodore Bernstein, Dept. of Electrical and Computer Engineering and Harry H. Miller, Instrumentation Systems Center, University of Wisconsin-Madison who designed and fabricated the transformer and pulser; Leon Johnson, Fishery Research Biologist at Spooner who designed and tested some of the ac electrofishing systems; Louis E. Spink, Mechanic at Southern District Headquarters who fabricated the ac-pulsed dc electrofishing boat and the assistance of numerous Fishery Research and Fish Management personnel who helped collect the field data, provided equipment and offered suggestions.

The project was supported in part by funds from the Federal Aid in Fish Restoration Act under Dingell-Johnson Project F-83-R.

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