METHODS OF USING BALANCED-MAGNET CHRONOSCOPES

KNIGHT DUNLAP

The Johns Hopkins University

The following schemes may be used equally well for installing the Johns Hopkins chronoscope¹ or the Hipp as used by my method² without armature springs. The diagrams (figs. 1 and 2) are given for the former instrument: in setting up the latter, the circuits which operate the synchronous motor of the Johns Hopkins chronoscope are of course to be omitted.

The Johns Hopkins chronoscope operates either on (1) direct current, with tuning fork interruption for the motor circuit, or (2), alternating current for the motor circuit, without fork, and direct current for the clutch circuits. The alternating current of the usual house lighting circuit is 60 cycle, and power circuits are sometimes 25 cycle: it will be assumed that one or the other of these frequencies is to be employed. The first system is represented in figure 1: the second system in figure 2.

THE MOTOR CIRCUIT

The motor circuit and the clutch circuit may be drawn from the same direct current source, which may be the 110 to 120 volt power circuit as indicated in figure 1, or may be storage battery or rotary transformer circuit. Otherwise, the motor circuit and the clutch circuit are entirely distinct, and may be usefully described separately.

In using alternating current 110 to 120 volts (the potential

¹ Dunlap: The Johns Hopkins chronoscope. 1917, *Jour. of Exper. Psychol.*, ii, 299-252.

² Dunlap: The Hipp chronoscope without springs. 1912, *Brit. Jour. of Psychol.*, v, 1-7.

Poffenberger and Morgan: The Hipp chronoscope: its use and adjustments. 1916, *Jour. of Exper. Psychol.*, i, 185-190.

of the usual house lighting circuits), lamp resistance or a rheostat may be used to control the current; or a rectifier of the proper type may be used without resistance. The scheme with resistance is shown in figure 2. The standard four-receptacle voltage-reducing lamp board (lamp board no. 1) is here represented, but

FIG. 1. CHRONOSCOPE OPERATED ON DIRECT CURRENT; THROUGH TUNING-FORK INTERRUPTER

Set up for visual discrimination reaction utilizing same current source.

lamps are to be used in the two primary receptacles (the left-hand ones in the cut) only. Obviously a two-receptacle lamp board is all that is necessary, since the motor circuit is closed. One receptacle is sufficient if a single lamp of appropriate wattage fits the requirements, but two receptacles connected in parallel is better, since it makes possible lamp combinations to fit all cases.

FIG. 2. CHRONOSCOPE OPERATED ON ALTERNATING CURRENT

Set up with voice keys for association reaction, with battery for clutch connections.

Two 100 to 120 watt lamps (of the voltage of the circuit), or one 100 to 120 watt lamp and one 50 to 60 watt lamp, will be found satisfactory. There is considerable latitude in amount of current permissible in any case, since the speed of the motor is not dependent on the current, but on the frequency. Enough

current to give sure operation, and not enough to heat the motor seriously, or make starting difficult, is the easy requirement. The motor will run on a single 60 watt lamp, although hard to start on so small current, and easily put out of phase and stopped by the slight jar of the clutch action. The current practically needed depends on the adjustment of the clutch, and the amount of current in the clutch circuit. On the average, lamps totaling 150 watts will do very well; 100 watts may be satisfactory; more than 240 should never be used; and more than 180 will heat the motor if used continuously.

Lamp resistance is advised, because of its safety. The lamps act as tell-tales, showing clearly whether the current is on or off, and there is no danger of damage from accidentally putting on too much current, as is apt to happen in moving a rheostat handle in the wrong direction. By having the connections at the lamp board covered, all danger from shock is eliminated.

If a rheostat be used instead of lamp resistance, one of 120 ohms total resistance, and 2 amperes continuous capacity is advised. The Jagabi 1506, James G. Biddle, fills these specifications. The resistance should never be allowed to fall below 50 ohms; hence a stop should be put on the slide, a little less than half way from the zero end.

The motor has been run experimentally on the whole range of frequencies between 15 and 120 per second: the conditions for this test were arranged by M. W. Pullen of the Department of Electrical Engineering, and I have not standardized the resistances to be used with the 25 cycle circuit. The determination of the proper resistance is very simple, but there are probably few places where this frequency would be available.

The speed of the motor, when operated on the unrectified 60 cycle current may be too great. Since there are ten poles to the motor, and the 60 cycle current has 120 impulses per second, the armature will make 12 revolutions per second and the measuring unit of the dial will be one twelve-hundredth of a second. Not only is this unit needlessly small, even for the measurement of simple reaction times, but the difficulty in starting the motor is high (see below). With 25 cycle unrectified current the arma-

ture speed is 5 rotations per second, the measuring unit of the dial is 2 sigma—which is small enough for all purposes—and the motor is easily started. If a rectifier is used with the 60 cycle current the impulses are reduced to 60 per second, the measuring unit is one six-hundredth of a second, the motor starts easily and runs well without heating. I have found the small size “Tungar” rectifier, General Electric Company, very satisfactory when connected directly in the circuit without resistance.

A small transformer may be used directly in the circuit, reducing the voltage to the point required to force the proper amount of current through the field coils. This has the advantage of economizing current, a large proportion of which is wasted in the resistance of the above described arrangements. The transformer should step the voltage down one-half; i.e., should reduce the 120 volt potential to 60, or the 110 to 55.

It is necessary to bear in mind that the nominal cycles per second of a lighting or power circuit are only approximate, and that there is a slight variation from the standard from time to time. The alternating current can be used for demonstration purposes, and for practise work where accuracy is not essential, without check. But, for research purposes it is necessary to use a frequency-meter from time to time to determine the actual frequency; or else to obtain from the power house data on the diurnal variations in frequency. In many situations it will be found that the variations at the hours at which the apparatus is used are small enough to be neglected in the calculations. Since the frequency determines the value of the units of measurement of the chronoscope, reaction times obtained while running the motor on a current of uncertified frequency are not worth much.

For the above reasons, it is recommended that the motor be operated on direct current, with tuning fork interruption wherever possible.

In using direct current in the motor circuit, an electric fork is necessary to interrupt the circuit periodically. If the 120 or 110 volt current is used, a voltage-reducing lamp board should

be introduced. This set-up is shown in figure 1. In this lamp-board four 100 or 120 watt lamps are satisfactory, and all are left permanently screwed down. Four 120 watt lamps reduce the voltage to about 50, when the circuit is broken.

Storage cells may be used as a source of direct current, the voltage of the battery depending on the fork somewhat. In some cases a standard 12 volt battery will serve, but a twenty to twenty-five volt set, with adjustable resistance capable of carrying 1 to 1.5 amperes and a maximum of 12 to 18 ohms is preferable. Edison storage cells are recommended on account of their requiring less care; and they may be used in the same room with the apparatus, as they have no fumes deleterious to steel as do the acid cells. The variations in voltage of the Edison cells do not affect the measurements.

If the fork-magnet is high-wound, it may be necessary to arrange a shunt around it, to provide sufficient current for the motor field without forcing too much through the fork. I have not found this necessary with any of the standard wound forks.

The fork contacts should be of dental gold alloy (gold and platinum), which is cheaper than platinum and far more satisfactory. Tungsten contacts might possibly be employed, but I am unable to say definitely that tungsten is satisfactory. Much trouble will be found if platinum be used and I do not find that the motor operates satisfactorily with a platinum contact fork. I find dental wire of 18 gauge (Brown and Sharpe) works well: 19 or 20 might perhaps be used. The table on which the wire strikes should be surfaced with a section (disc) of large gauge wire.

With any fork interrupting a large current (more than a small fraction of an ampere) a condenser ought to be used. The small size 2 microfarad condenser made by the Western Electric Company is cheap in price and quite satisfactory. The condenser must be connected across the gap of the fork contact, and must not include the electro-magnet (of the fork) between its terminals. In other words, when the fork-contact is broken, the circuit must be traceable unbroken from one contact of the condenser through the magnet windings. For convenience, an

extra pair of binding posts should be mounted, one on the shank of the fork itself, or, as in the figure, on the metal mounting (base) of the fork (fig. 1, electric fork, 3); the other on the metal support of the fixed part of the contact. If the fork be connected as described, and then, while it is in operation, one of the condenser connections be momentarily broken, the large increase in the spark at the break of the fork-contact will demonstrate the value of the condenser in preventing burning up of the contact and consequent loss of adjustment.

The adjustment of the fork-contact is a matter of trial and error. I find it best to adjust to the smallest amplitude of vibration which gives uniform vibration. The contact should be broken when the fork is at rest. It should be hardly necessary to warn against touching the steel of the fork with the hand in starting the fork, but with students this is always necessary.

Once in operation, the motor should run for hours with no adjustments. If the motor stops, it may be due to one of several causes. (1) Insufficient current. (2) Bad adjustment of the fork-contact, so that the break of the circuit is not sufficiently long. (3) Too tight adjustment of the bearing of the motor shaft. The adjustment is a delicate matter, but once made should be good for a long time. The shaft should not be loose, but should yet spin freely. (4) Too much current in the clutch circuit. Under this condition the jar of the clutch sets the armature "hunting" and it kills itself. The fact is to be emphasized that the variations in current and contact do not affect the speed of the motor unless they stop it completely.

STARTING THE MOTOR

A simple synchronous motor will not start itself: the armature must first be put in rotation at the speed required by the frequency of the current, or the frequency of the interruption, and must "get in step" with the current phases. Given this start, the motor will continue to run as long as the current is adequate, until it is overloaded, or until a jar starts it "hunting."

On the 25 or 50 vibration fork, on 25 cycle alternating current

with resistance, or 60 cycle alternating current with rectifier, starting the motor is simple. With the thumb and forefinger the armature shaft is given a spin in the proper direction. Wrapping a string around the shaft, to get a pull, is not satisfactory. On first trial with the thumb and finger method, a great many spins will perhaps be necessary before the proper knack is acquired. The commonest error is spinning too fast. Another common error is taking hold of the shaft for a fresh spin, before noting whether the preceding one was effective; thus spoiling a good start. After a little practise facility is acquired, so that the motor may be started with little difficulty; usually on the first, second or third spin.

On the 60 cycle unrectified current, since the speed of rotation is relatively high, the finger and thumb method may be difficult. In that case, wrap a strip of adhesive tape—electrician's or surgeon's—around the shaft spirally to make a smooth single thickness, and start by drawing the fingers across the wrapped part of the shaft. It may be easier to spin the armature with current off, closing the main switch as the fingers leave the shaft,

THE CLUTCH CIRCUIT

The clutch circuit must always be direct current, and should have an amperage just sufficient to give sharp, not violent, action to the clutch. The exact voltage will necessarily vary with the accessory instruments used, and it is well to have a rheostat in the circuit, as in figure 2, so that the current may be properly controlled.

The essential feature of the Johns Hopkins chronoscope, and the Hipp without armature springs is, that within certain limits, variations in the current strength do not alter the measurements, since the clutch is moved in by one electromagnet, and moved out by another which is the exact mate of the first in core and windings. The two magnets are connected in parallel so that variations in the current affect both equally. In consequence of this feature, it is necessary to avoid differences in resistance and in inductance between the two branches of the clutch circuit.

This requirement is to be borne in mind in connection with the details which follow.

For the set-up in figure 2, with voice keys³ for the association reaction, storage cells connected in series to give over four volts will operate the clutch. The higher voltage with resistance, as in figure 1, is more desirable. In the arrangement shown in figure 1, a voltage-reducing lamp-board is used, with one 100 watt lamp and one 60 watt lamp in the primary (left-hand) pair of receptacles, and two 100 watt lamps in the secondary (right-hand) pair. With this arrangement the total current in the two branches of the clutch circuit, the master key being completely closed, is approximately 0.6 ampere.

The current is divided through the two branches of the circuit through the master key (refer to figure 2: figure 1 is more complicated), which, as will be noticed, completes the circuit through the anterior magnet (the non-rotating magnet) a moment before completing the circuit through the posterior (rotating) magnet in the other branch. This is necessary in order that the clutch shall always be locked in the non-rotating position when the key is pressed. The master key is a two-contact key of new design, involving three strips of spring brass, or better, or phosphor bronze, so arranged as to be self-scouring, and therefore needing no gold contacts. When the master key is released, current is "off" both branches of the clutch circuit, thus permitting resetting of the register hand, and making the clutch circuit perfectly safe.

OPERATION IN THE ASSOCIATION REACTION

The set-up of figure 2 has now been completely described, with indication of alternatives in both motor circuit and clutch circuit. The method of operation will now be described before proceeding to the more complicated set up of figure 1.

Operator and reactor being in position before their respective

³ For description of the voice key, see *Psychological Review*, 1913, xx, 250-253. The Ewald chronoscope described there as satisfactory proved later very unsatisfactory, it got out of adjustment and could not be put in repair again.

voice keys, the operator commands "ready:" the master key being open, his voice has no effect on the mechanism. Next he closes the master key: current now flows through both branches of the clutch circuit, the armature automatically taking its position against the non-rotating magnet. Holding the key closed, the operator speaks the stimulus word against the diaphragm of the voice-key at the right of the cut: the vibrations of which cause the current through the anterior magnet to be interrupted momentarily, allowing the armature disc to be attracted to the posterior magnet. The armature shaft and the register hand thereupon commence to rotate, and continue until the reactor, by speaking the response-word against the diaphragm of the other (left-hand in cut), voice key, interrupts the current through the posterior magnet, thus allowing the anterior magnet to attract the armature disc and stop its rotation. With good adjustment, there is nearly perfect balance both of the latent periods of the two magnets, and of the slip of the armature on the pole of each, so that the time between the beginning of the interruption of the first branch and the beginning of the interruption of the second branch, is accurately registered on the dial. The operator releases the master key as soon as the register hand stops, takes the reading, and sets the hand for the next reaction.

SET-UP AND OPERATION FOR MEASUREMENT OF SIMPLE AND DISCRIMINATION REACTIONS

It is essential that the circuit through the anterior magnet, after being opened by the stimulus, shall be reclosed before the circuit through the posterior magnet is opened, or else the registration will fail. In the association set-up, this reclosure is automatically effected by the voice key, and the time-relations of the reaction are such that this is always effective. For reactions employing a different sort of stimulation, such as light or faint sound, provision must be made for reclosure. A variety of devices are possible for this purpose. Where a pendulum or shutter is employed to control a light stimulus, the breaking and remaking

of the stimulus branch of the clutch circuit may be arranged with a precise interval between. In other cases, a simple relay of low resistance and inductance has been employed with no appreciable error resulting, the unbalancing of the two branches being slight. In general, the use of a simple relay is not safe, and hence the balanced relay shown in figure 1 has been developed. As shown in the diagram, the closure of the master key will automatically set the armature lever of the relay against the stop on the side of magnet 3-4, and when the master key is completely closed, current will flow equally through this magnet and through magnet 1-2: and since these magnets are duplicates, and one is in the circuit of each of the clutch magnets, the two branches of the circuit are perfectly balanced. On depressing the stimulus key, contact is made between 1 and 2 (of the stimulus key), thus giving the stimulus, at the same moment that contact is broken between 2 and 3, interrupting the circuit through the anterior chronoscope magnet. The armature lever of the relay being released from magnet 3-4, moves over to the opposite stop, and reCompletes the circuit through the anterior clutch magnet, through the third relay magnet, thus again balancing the circuits, and assuring also that the armature lever of the relay will be held in the new position even after the current through magnet 1-2 is interrupted by the movement of the reactor. In the diagram, the pneumatic reaction key which has been found most reliable, is shown, without the rubber bulb which the reactor squeezes. The stimuli are schematically shown as flashes of two low-wattage mazda lamps, either one being switched in before the measurement. For discrimination, lamps of two colors might be used, enclosed both in the same box with a milk glass window, so that the color would always appear in the same place.

In the set-up of figure 1 both master key and stimulus key must be held down from the time each is pressed until the end of the registration. The balanced relay is self-setting, so that the actual procedure is simple. The time of action of the relay must be well inside of the reaction limit, and must be over 15 sigma, in order to allow leeway for the chronoscope clutch.

Action time between 20 sigma and 90 sigma may readily be secured, or if pathological or anticipatory reactions are to be measured, the action may be made within the limits of 20 and 50 sigma.

For other types of stimulus, variations in the above scheme are required, but the balanced relay will in almost all cases be the main accessory. For the reaction circuit, no special apparatus or wiring are needed on account of the balanced circuit, since the reaction circuit does not have to be reclosed.

GENERAL CAUTIONS

The Johns Hopkins chronoscope, like the Hipp, requires careful testing to assure balance of the magnet latencies and of the armature slips, but once set up and thoroughly tested, no further checks are needed unless the instrument is allowed to get badly out of condition. We have found that chronoscopes which were properly balanced, have become unbalanced in shipment, either through bending of the armature disc or other injury. The anterior clutch magnet (or in later designs, the magnet-core) has so far been made so that it can be rotated by hand; an adjustment which is not needed in most work, and can be dispensed with. This magnet bearing must be tight enough so that the magnet will not creep under the torsion of the armature disc at stopping. Oil on the magnet face or armature disc will cause clinging. The clutch must be kept clean.

The chronoscope should be set on a square of thick harness felt. If the tuning fork is in the reaction room, it also should be set on harness felt. The hum of the apparatus is then reduced to a negligible intensity. In using voice keys, they should be supported on a heavy, solid table, to avoid their being susceptible to the jar of the master key and movements of the operator's hand.

To remove the most probable source of error in the Johns Hopkins chronoscope, I propose to replace the friction clutch by a modification of the Hipp toothed clutch. It seems advisable also in the next model to gear back the register hand so that

the units of measurement will be larger. Five sigma units are small enough for any work, and 10 sigma units are most satisfactory for association reactions. A chronoscope arranged to read five sigma units on a 50 vibration fork will read ten sigma units on a 25 vibration fork.