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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A HIGH-POWER, LOW-SPEED STROBOSCOPE

Also

IN THIS ISSUE

STROBOSCOPIC OPERATION at low speeds, below, say, about 600 r.p.m., has been hampered seriously by the lack of a really powerful lamp, giving sufficient light to impress a positive image on the retina of the eye, in spite of normal room lighting and the comparatively long interval between flashes.

At low speeds the light flashes from the more usual stroboscopic lamps are sufficiently short to arrest the motion under observation, but the other factor usually considered necessary for successful stroboscopy, namely, persistence of vision, is no longer present. At speeds of 10 a second, flicker is evident, becoming more pronounced as the flash speed is lowered. The amount of light reaching the eye per unit of time also becomes progressively less, and successful observations can often be made only in darkened surroundings.

To a great degree, this difficulty can be overcome by increasing the power in the flash, so that the image from the flash is much more intense than that from the background light. For use where lighting conditions are favorable, the General Radio Company has supplied special Strobotacs with an additional low-speed range, 10-to-1 down from the standard low range. These have been used

Figure 1. View of the Strobolume with lamp mounted in case.

with considerable success in a number of industries, but they have never been catalogued, because their successful use depends so greatly on the experience and ingenuity of the user.

In the Type 1532-A Strobolume the problem of adequate light has been successfully solved. This new stroboscope gives a brilliant light flash of about 10-microsecond duration, so intense that, for prolonged observation, goggles are recommended. This high-power flash overrides background illumination sufficiently to make possible successful repetitive observations at speeds as low as one per second. When adjustable density Polaroid goggles are used, the illumination level can be controlled, so that background lighting is effectively eliminated, and the stroboscopic image reaches the eye at a comfortable level. The tendency of the eye to try to follow the motion of the subject between flashes is also removed by this procedure.

As shown in Figure 1, the strobolume is a small compact unit containing a power supply and a lamp. The lamp is removable from the case and connects to the power supply by a 15-foot cable (see Figure 4). The lamp housing is tapped for tripod mounting (¼-20 thread).

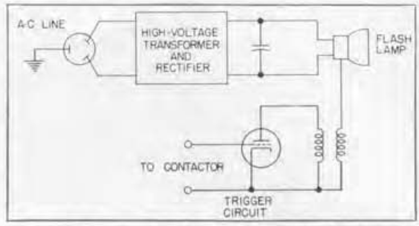
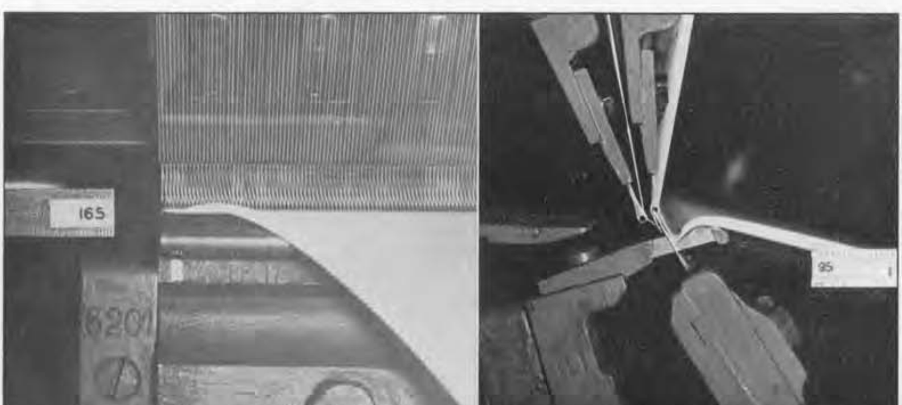


Figure 3. Functional circuit diagram of the Strobolume.

The power supply consists of a transformer and rectifier, which charge a 4-μf capacitor to about 2000 volts, giving an energy per flash of 8 watt-seconds. The flash is triggered by a pulse from a high-voltage Strobotron, which ionizes the gas in the lamp sufficiently to initiate the discharge of the capacitor through it. The average rate of energy dissipation during the discharge is several hundred kilowatts. The elementary circuit of the Strobolume is shown in Figure 3.

The Strobolume can be flashed from a push button, a contactor, or a special slow-speed Strobotac. For observations of machinery, the Type 549-P2 Hand Contactor is often used. For single flashes, the push button, which is furnished as an accessory with the Strob-

Figure 2. Front view (left) and side view (right) of a warp knitter in operation, as seen by the Strobolume.



olume, is adequate. For general observation and measurement work, the Type 631-BS18 Strobotac provides a flashing means that is adaptable to a variety of applications. To connect the Strobotac to the Strobolume, a Type 1532-P2 Cable must be used.

The Strobolume opens up for stroboscopic measurement a vast field of slow-speed machinery. Looms, printing presses, heavy grinding and crushing equipment, and packaging machines are a few of these. In addition to its use as a stroboscope, it is an excellent light source for single-flash, ultra-high-speed photography, two examples of which are shown in Figure 2.

The range of flashing rates obtainable with the Strobolume is shown in the specifications below. Note that the safe operating time varies with the flashing rate. A built-in circuit breaker gives assurance that this time will not be exceeded and hence protects the instrument from damage.

Figure 4. View showing lamp removed from case.

—W. R. Saylor

SPECIFICATIONS

Duration of Flash: Approximately 10 microseconds.

Flashing Control: External contactor or Strobotac. Special Strobotacs for these low speeds can be supplied.

Tubes:

1	Rectifier	Type 816
1	Strobotron	Type OA5
1	Flash Lamp	Type 1532-P1 (GE Type FT-220)

Flashing Speed Range: Continuous, 45 flashes per minute, maximum; intermittent, or for short periods, up to 1200 flashes per minute. Maximum safe operating time is as follows:

TABLE I

Flashes per Minute	*Approximate Time for Breaker to Open*
60	——
300	1 min. 45 sec.
600	30 sec.
900	20 sec.
1200	15 sec.

Accessories Supplied: Power cord with ground terminal; push button; flash control cord for connection to contactor or push button.

Other Accessories Required: None, if lamp is to be flashed manually by push button. For stroboscopic work, a contactor or a special Strobotac is needed.

Mounting: Metal case with rounded top; lamp is removable; storage space for lamp cable is provided in case. Tripod mounting thread (¼-20) is provided in lamp housing.

Power Supply: 105 to 125 (or 210 to 250) volts, 50 to 60 cycles.

Power Input: 70 watts at 60 flashes per minute; 500 watts at 1200 flashes per minute.

Dimensions: 13 x 7½ x 11 inches, over-all.

Net Weight: 18½ pounds. Lamp only, 2 pounds.

Type		*Code Word*	*Price*
1532-A	**Strobolume**	TITLE	**$225.00**
1532-P1	**Replacement Lamp**	TOWEL	**24.50***

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*Including Federal tax.

THE VERSATILE VOLTAGE-DIVIDER

PART II

DESIGN TRICKS

The usual departure desired by a circuit designer from a standard potentiometer having a rectangular mandrel is a resistance-rotation curve which is something other than a straight line. What can be accomplished in meeting the requirement depends almost entirely on the shape of the curve. There are a number of tricks that can be employed. In general, the greater the curvature, the more drastic are the tricks required and the greater their cost. Some of the methods of meeting curves are these:

1. **Sectional Windings.** The most usual dodge employed in the industry is to wind the mandrel with two or more different wires, differing from one another in diameter, resistivity, or both. Naturally, such a scheme does not really meet the curve. Rather, it produces a dog-leg instead of a curve, a succession of straight lines, approximately chordally related to the desired curve. The locations of the intersections of the chords can be chosen to minimize the deviations from the curve. The more sections there are, each using different wire, the more chords there are, and the more closely the curve is approximated. Unfortunately, the method is somewhat costly, and there is possibility of trouble in meeting the curve at the several joints between sections. The joints are also a possible danger source if they open up.

2. **Tapered Mandrel (Trapezoidal).** The next easiest mandrel shape to make, other than a rectangular one with parallel sides, is a trapezoidal or straight-tapered one. These are very easily manufactured by use of a long rectangular notching punch and die. The resistance-rotation curve from such a form wound with one size and kind of wire is part of a parabola. The curve does not start at the origin, since the narrow end does not have zero width. The ratio of widths between wide and narrow end determines how nearly the small end of the parabolic curve approaches the origin. In general, it is possible to wind such mandrels with any desired spacing between wires without collapse of turns. Hence, adjustment of wire spacing can be employed as a means of making the over-all resistance accurately the desired one.

3. **Double Sawtooth (2 Trapezoids).** Where it is necessary that the ratio between the slopes at the two ends of the resistance-rotation curve must be greater than can be realized with one trapezoid (something like 8 or 10:1), the mandrel can be shaped to have two trapezoidal sections (see Figure 4). The wire size and/or resistivity must be changed between sections to provide the proper resistance per unit area of the mandrel.

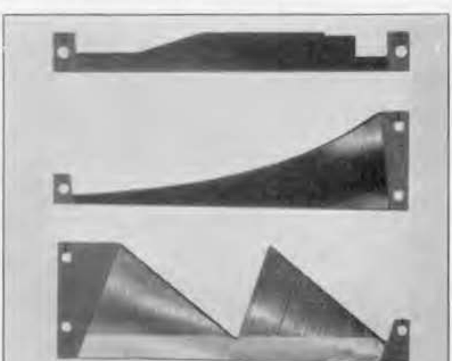

Figure 4. Three types of mandrels shaped to give desired resistance variations. At the foot is a double sawtooth, in the center a logarithmic, and at the top a combination of shapes.

Figure 6. Double logarithmic mandrel for 30-db range.

4. **Logarithmic Shape.** Another desired type of resistance variation with rotation is the logarithmic one (see Figure 4). Such a potentiometer used as a rheostat in a Wheatstone Bridge will be adjustable with constant fractional accuracy at all parts of an attached dial. The mandrel is made with one edge straight and the other edge curved. The logarithm of the width of the mandrel is proportional to the rotation angle. In practice, since the mandrel and the wire have some thickness, it is necessary to make allowance for these facts by reducing the width of the mandrel at the narrow end, because what must vary exponentially is really the resistance per turn of the winding, hence, the length of each turn.

5. **Double Logarithmic.** A single logarithmic mandrel for a Type 371 Potentiometer, having a $2\frac{1}{2}''$ diameter barrel and a $2\frac{1}{16}''$ mandrel width cannot be made for more than 20 db or a 10:1 ratio between extreme turn lengths, without making the mandrel impractically fragile at the narrow end. The same trick of using a double sawtooth, as described in (3) can be used to get a higher ratio. A considerable number of double sawtooth 30-db (about 30:1) logarithmic potentiometers have been made using the mandrel shown in Figure 6.

Figure 5. View of double-sawtooth card being wound. Note the arrangement of pulleys and springs to take up variations in tension as the card is rotated.

6. **Combinations.** If the resistance-rotation curve is too steep at the high end to be windable, it is sometimes still possible to provide an acceptable approximation. The mandrel might have a curved shape for the majority, say 75 or 80%, of the rotation. Over this area a single sort of wire would be wound. The remaining small portion of the mandrel would have parallel sides, and one, two, or more sections could be wound with different wires to provide a chorded approximation to the steep end of the curve (see Figure 7). This dodge can, of course, only be employed if the closeness of tracking at the steep end is not as critical as it is elsewhere.

Another combination mandrel shape is shown at the top of Figure 4.

LIMITATIONS

In the listing of Design Tricks given above for meeting special resistance-rotation curves, no indications have been given of the limitations imposed on the universal applicability of such tricks by the materials used and the equipment available for manufacture. Such limitations, however, do exist:

1. **Ratio of End Widths.** There is a limit to the ratio of end widths which eventually limits the curve shape no matter which of the tricks mentioned are employed to secure desired curvature. This ratio depends on mandrel width and is naturally larger for wider mandrels. It will be obvious, for instance, that the trapezoidal shape has to be trapezoidal; it cannot be made triangular. There must be a finite width at the narrow end to provide juncture with a projecting end or tab to be used for fastening to the molded base.

2. **Minimum Width at Narrow End.** The narrow end width is limited by at least two factors. In the case of the edge-contacting potentiometers, the limitation is the strength of the narrow end. When being wound, the mandrel is mounted under tension between jaws in a lathe (see Figure 8). Also, the mandrel in assembly is bent around the base, sometimes with a protective enveloping strip which helps strengthen it at the weak point. However, the width must be great enough to prevent breakage in either of these operations. A minimum width of 3⁄16″ is preferred, although with some difficulty minimum widths of 5⁄32″ or even 1⁄8″ can be handled. In determining ratios of end turn lengths, the thickness of mandrel and diameter of wire should be allowed for. In the case of multifingered take-off brushes (Types 314 and 471), the narrow-end width of either single-straight-taper or double-sawtooth mandrels must be greater than the width of the contacting fingers. It *should* be the full width of the projection of the mandrel in assembly above the barrel portion of the molded base. This minimum is around 7⁄16″.

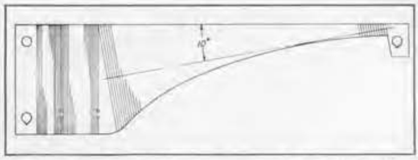

Figure 7. A combination mandrel, on which the curved portion is wound with a single kind of wire and the straight portion with several different kinds to approximate the desired characteristic.

3. **Maximum Slope at Wide End.** The width at the wide end is usually the maximum that will be accommodated by the molded base, in order that the maximum winding area can be obtained. The limitation at that wide end is the largest slope of the curved edge of the mandrel (see illustration, in Figure 6, of a so-called 30-db form for a Type 371 Voltage Divider, each half of which is logarithmic for 15 db when provided with a proper series end resistor). It is probably quite apparent that there will be some slope above which successive turns will not stay anchored to one another, but will slide down the slope and collapse. The 30-db form illustrated represents about that limit.

The speed of winding on steep slopes is drastically reduced and occasionally it is necessary to hand-wind small portions of such mandrels, as shown in Figure 9.

It should here be noted that this mandrel is windable only as a result of

Figure 8. Close-up of the double sawtooth during winding, showing how the mandrel is clamped in the lathe.

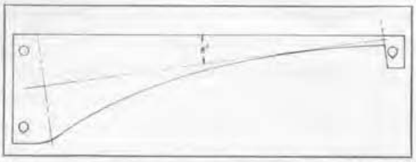

Figure 10. Mandrel widths are laid out perpendicular to the winding axis as shown here by the center line.

minimizing the slope somewhat by so locating the mandrel when clamping it in the winding machine that the winding axis is at a fair angle to the straight edge. This angle is determined by having the winding axis bisect the chords of the shaped mandrel at the extreme narrow and wide ends as illustrated in Figure 6. This angle for the 30-db form is about 15°, and the expedient of tilting the form when winding reduces the effective slope at the widest portion by almost the whole of this 15°. The maximum slope with respect to the winding axis is about 43°.

4. **No Spacing Between Turns.** The slope of the curved side of the mandrel at the steep end of logarithmic potentiometers is generally so great that adjacent turns must be wound immediately against one another in order to prevent sliding down hill of the turns and complete collapse. This means that spacing the turns at will cannot be used as a means of making the total resistance come out to any arbitrary desired value. Except as the outside diameter of the enameled wire varies slightly, the resistance values which can be obtained on forms having very steep portions occur in a series having equal geometric spacing. In the B & S gauge system, adjacent wire sizes are related in diameter by the factor of $\sqrt[6]{2}$ (very closely) and in area by the $\sqrt[3]{2}$. This means that, for a change of one wire size, the resistance on a mandrel will be changed by the $\sqrt{2}$. It is then possible that, under the most unfavorable conditions, the resistance value realized might be related to the desired resistance value by the $\sqrt[4]{2}$, or might come anywhere between 84% and 119% of desired value. If it is necessary to come closer than this, resort must be had to the questionable expedients of looking for wire nominally the same, but actually different, in diameter, or of hoping that a wire of different size and different resistivity will fall nearer to the wanted value.

A rough means of ascertaining the maximum slope and the minimum width of a mandrel is as follows: First, plot on cross-section paper the curve of resistance vs. rotation. By matching a straight edge to the curve at successive points, to simulate a tangent, determine the slope of the curve at these points. The units in which the slope is expressed are unimportant so long as they remain the same for all points. The largest slope corresponds to the full width of the mandrel (for example, $2\frac{1}{16}''$ for Type 371) and the widths corresponding to other slopes can be determined by simple proportion, making correction, of course, for the mandrel thickness.

Next, a scale drawing of the mandrel must be prepared. The mandrel widths should be laid out perpendicular to the

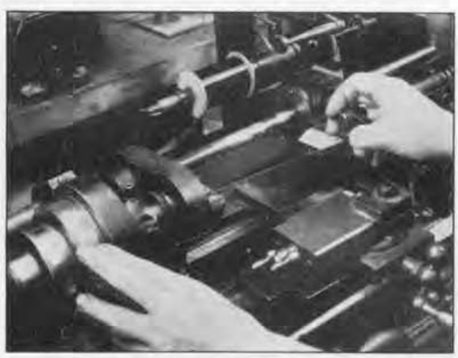

Figure 9. Hand winding, as shown here, is often used on steeply sloping mandrels.

winding axis, rather than to the straight edge of the form, if the two are not parallel (see Figure 10). From this drawing, the maximum slope can be measured, while the minimum width comes directly out of the width table.

ECONOMICS

It is probably not difficult to see that there may be considerable difference between what is possible technically and what is advisable economically. Each new mandrel shape requires a number of separate operations, each individually tailored to the particular requirement.

1. **Design of Mandrel.** The process described just above must be gone through, but with somewhat more accuracy, since the purpose this time is the manufacture of a complying article. If the resistance-rotation curve can be expressed analytically by an equation, it is usually simpler thus to calculate the slopes needed to determine the mandrel shape, by the use of the differential calculus rather than graphical methods. A logarithmic voltage divider is a case in point.

2. **Drafting.** Sufficient new drawings must be prepared to assure that a proper article is manufactured, and that it can be duplicated at some time in the future should that be desirable.

3. **Production.** Tools of some sort must be provided for shaping the mandrel. If there are only a very few similar voltage dividers to be manufactured, the mandrels can be prepared by hand by the use of a nibbler, notcher, milling machine, band saw, filing machine, or even by hand with a hacksaw and file, with or without a guiding steel template. If the quantity is as great as 50 or 100, it will probably pay to purchase one of the inexpensive short-run punch-and-die combinations from a tool concern specializing in making such tools. Such a punch and die can often be obtained for $35.00 to $75.00, after which the punching by the tool manufacturer costs only a few cents per piece, if ordinary rectangular mandrels are supplied him from which to work. Control of dimensions to a very few thousandths is possible by this method.

Whether or not a given project is feasible must be decided on its own merits. The cost involved must justify itself to the purchaser, and the amount of engineering required must not be so inordinate as to make it seem not worth while to the manufacturer.

—P. K. McElroy

This is the second installment of a three-part article By Mr. McElroy. Part I appeared in February. Part III will be published in an early issue.

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