

[54] **MULTIVIBRATOR FOR STATIC RELAYS
HAVING LINEAR TIME DIAL**

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[51] Int. Cl. **H02h 3/08, H01h 47/18**

[58] Field of Search..... **317/33 R, 36 TD,
317/141 S**

[56]

References Cited

UNITED STATES PATENTS

3,164,755	1/1965	Holt et al.	317/153
3,202,884	8/1965	Bullock.....	317/141 S

3,319,127	5/1967	Zocholl et al.	317/36 TD
3,327,171	6/1967	Lipnitz et al.	317/33 SC
3,573,555	4/1971	Lipnitz.....	317/33 SC

Primary Examiner—L. T. Hix

Attorney—Sidney G. Faber et al.

[57]

ABSTRACT

A static relay utilizing an R-C network to provide a time current characteristic wherein inverse time-relationship is obtained for appropriately controlling tripping or other protective operations in power transmission and distribution networks. A multivibrator clamp circuit is employed in the static relay to control the time delay characteristic over a large range of values without altering the time delay wave shape and further incorporates a linear time dial setting to facilitate adjustment and usage of the static relay.

2 Claims, 11 Drawing Figures

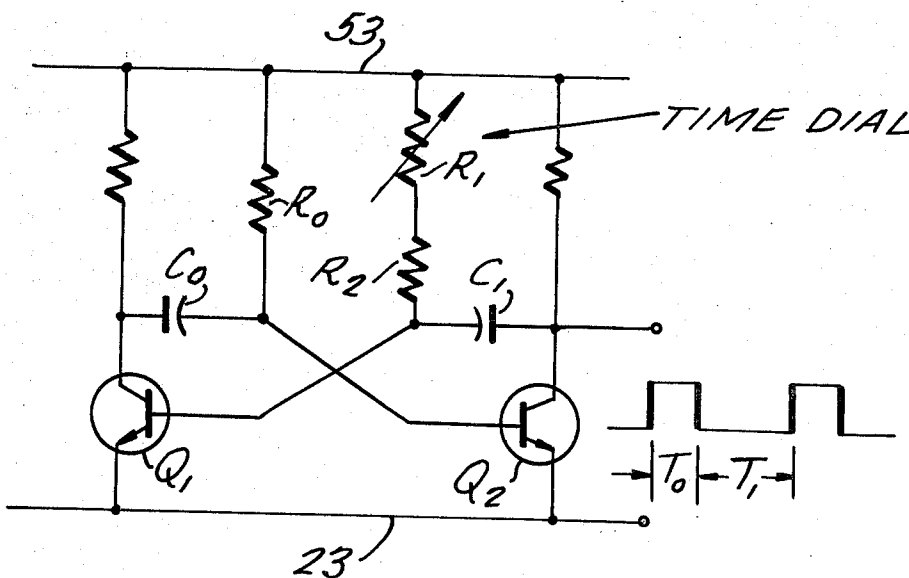


FIG. 1

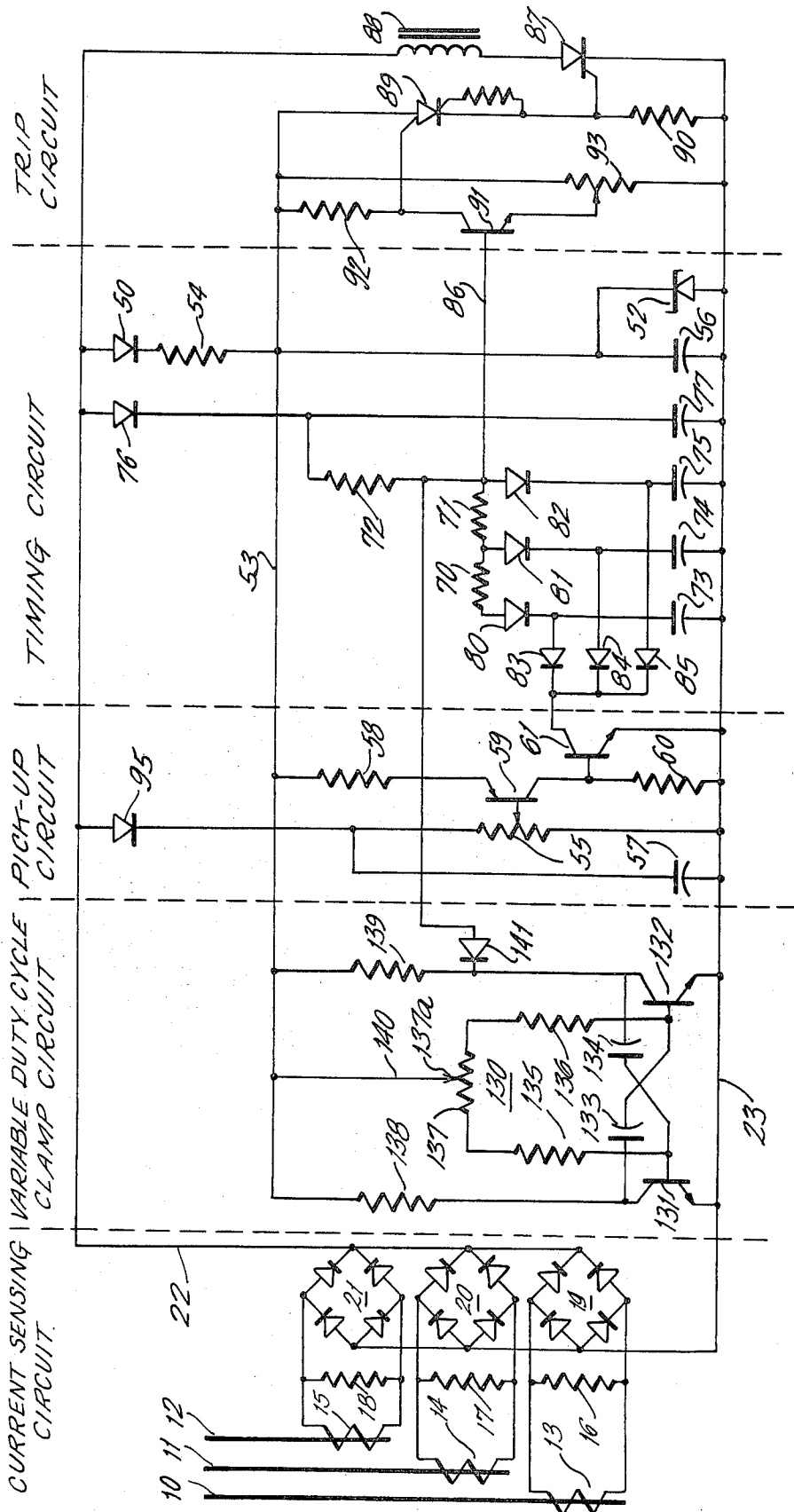


FIG. 2.

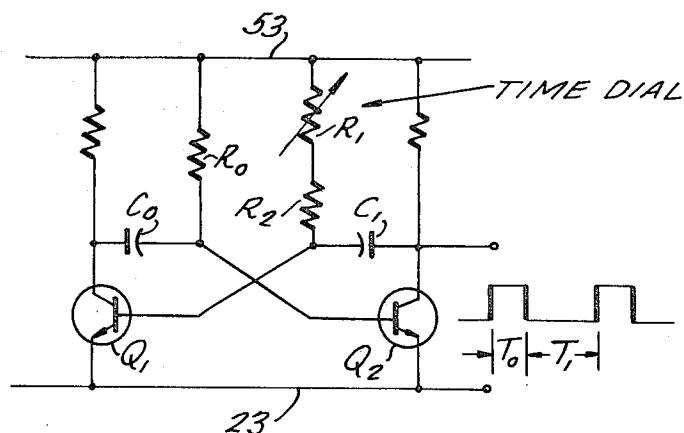


FIG. 3.

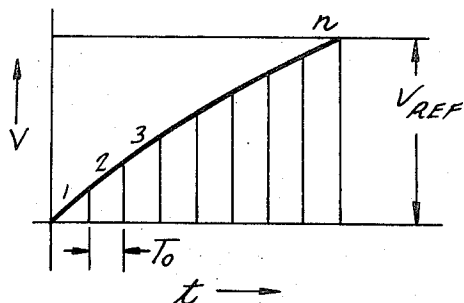


FIG. 4.

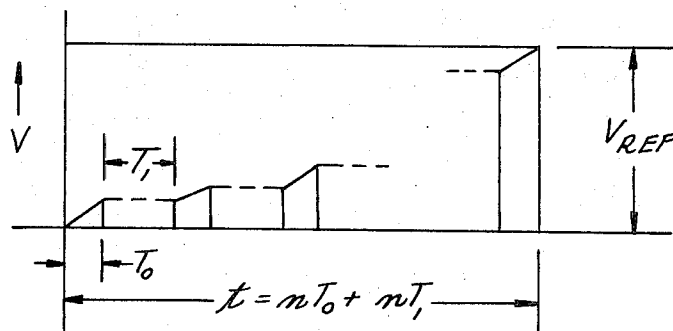


FIG. 5.
INVERSE DIAL MARKING FOR
10:1 RANGE OF TIME CONTROL

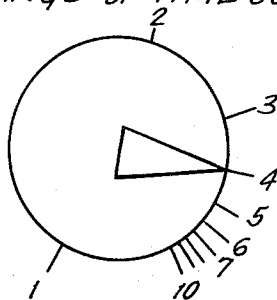


FIG. 6.
LINEAR DIAL MARKINGS

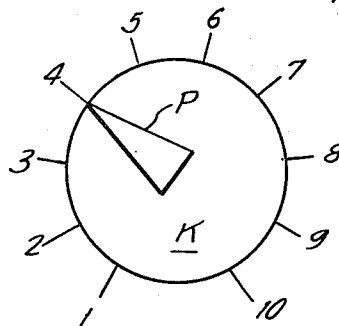


FIG. 7
T.D. CIRCUIT #1 FOR 51E O.C. RELAY
(RELAY CIRCUIT)

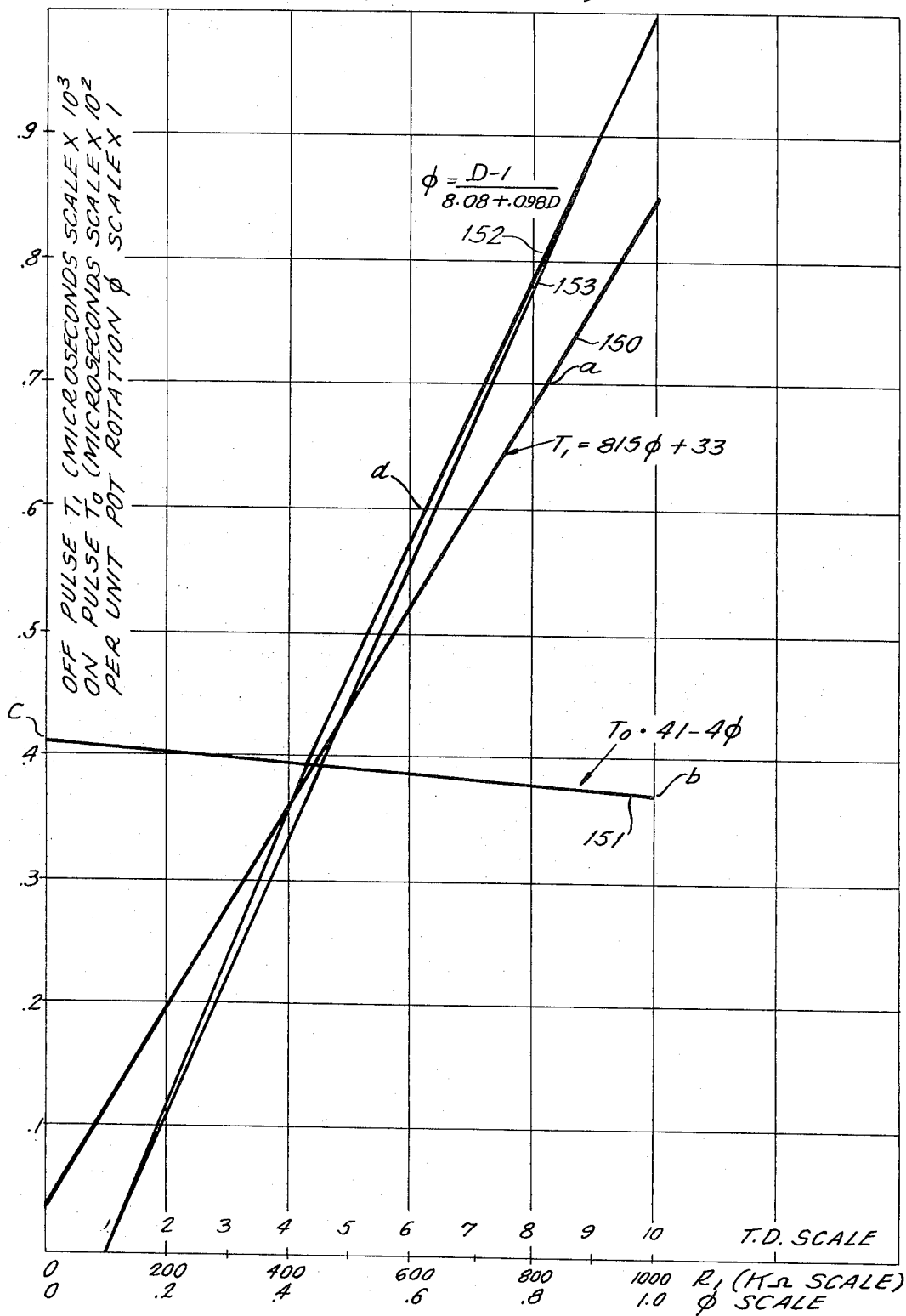


FIG. 8.
T.D. CIRCUIT #2 FOR SIE O.C. RELAY
(SEPARATE CIRCUIT D.C. INPUT)

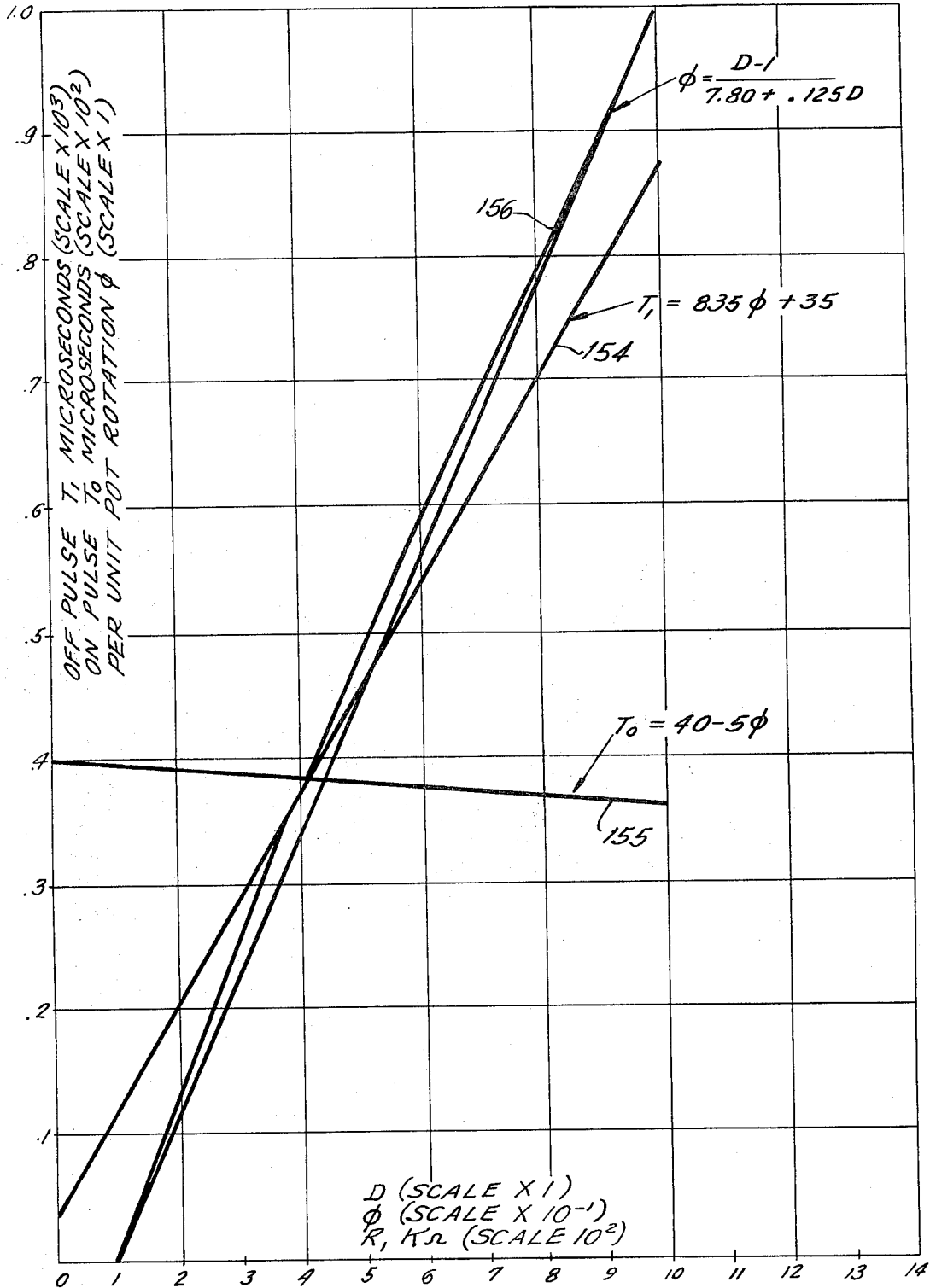


FIG. 8.

CORRELATION BETWEEN CALCULATED τ FROM
MEASURED RESPONSE OF MULTI ξ ACTUAL TIME VALUES

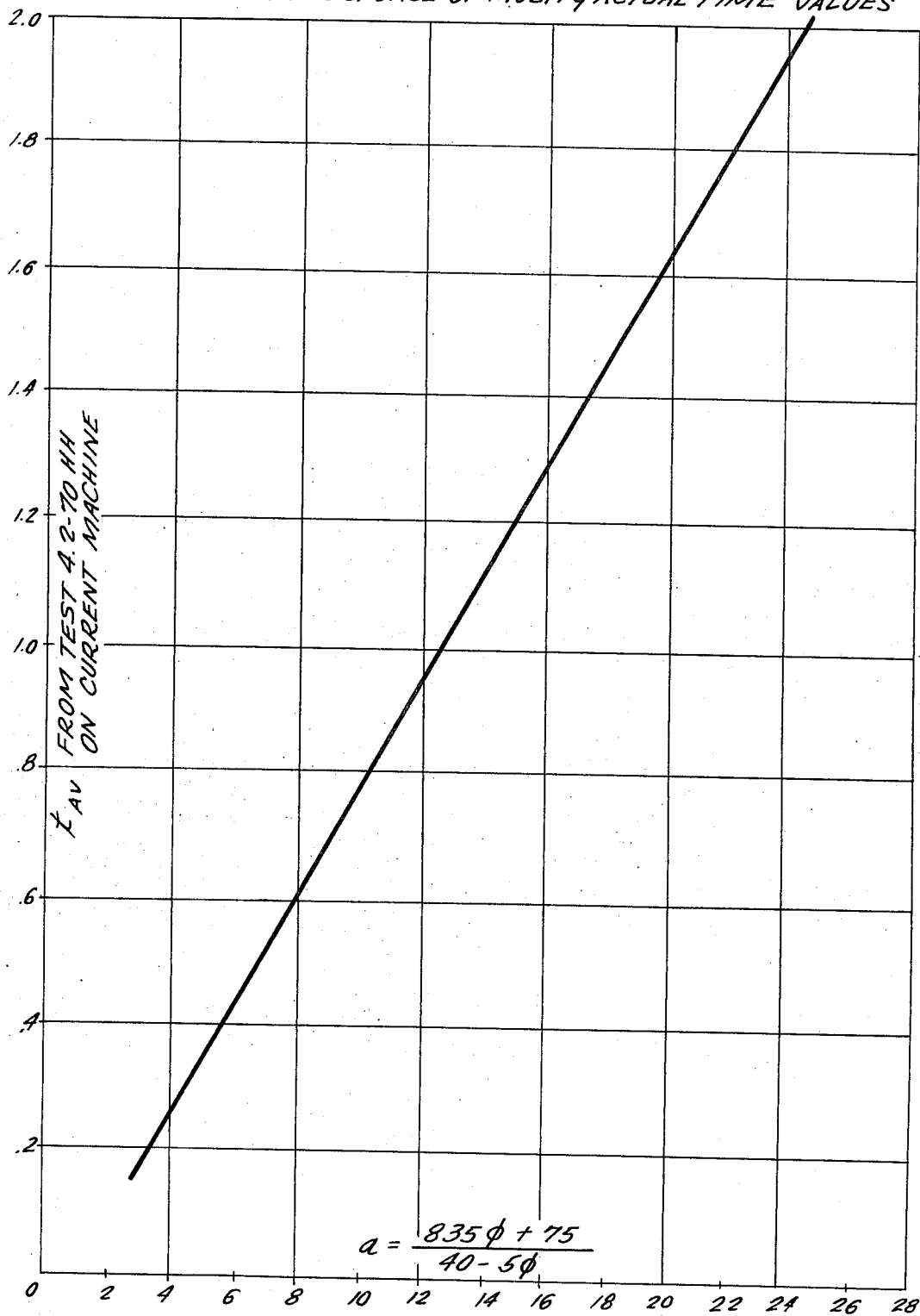


FIG. 10.

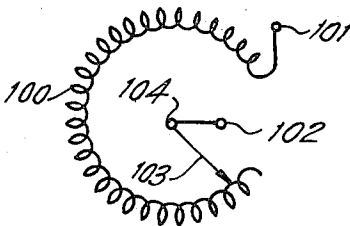
TABLE I

ϕ	R1	$\pm 2X$	$\pm 3X$	$\pm 4X$	$\pm 6X$	$\pm 8X$	$\pm 10X$
0	0	.68	.240	.130	.064	0.42	.031
.2	200K	2.45	.77	.40	.23	.146	.110
.4	400K	4.5	1.42	.78	.40	.270	.21
.6	600K	6.8	2.15	1.14	.60	.39	.30
.8	800K	9.2	2.9	1.56	.80	.52	.40
1.0	1000K	12.3	3.7	2.0	1.01	.66	.50

TABLE II

ϕ	R1	$\pm 2X$	$\pm 3X$	$\pm 4X$	$\pm 6X$	$\pm 8X$	$\pm 10X$	$\pm av$	a
0	0	.13	.13	.13	.13	.13	.13	.13	1.87
.2	200K	.47	.40	.47	.44	.46	.46	.44	6.18
.4	400K	.86	.77	.78	.81	.85	.88	.83	10.7
.6	600K	1.30	1.17	1.14	1.22	1.21	1.26	1.21	15.5
.8	800K	1.76	1.57	1.63	1.61	1.68	1.68	1.63	20.5
1.0	1000K	2.35	2.0	2.0	2.03	2.13	2.10	2.10	28.5

FIG. 11.



MULTIVIBRATOR FOR STATIC RELAYS HAVING LINEAR TIME DIAL

The present invention relates to static relays and more particularly to a novel clamping circuit utilizing linear time dial settings which simplify adjustment utilization of the equipment.

The present invention is an improvement of the static relays described and claimed in U.S. Pat. Nos. 3,319,127 to Zocholl et al.; 3,327,171 to Lipnitz et al. and 3,573,555 to Lipnitz, all of which patents have been assigned to the assignee of the present invention.

The above-indicated patents describe static relay devices having an inverse time-current characteristic and which replace electromechanical relays which were previously employed to obtain the desired characteristic. Static relays of the type described in the aforementioned U.S. patents eliminate the moving mechanical parts employed in prior art electromechanical devices while having the capability of retaining the desirable time current characteristic curves previously obtainable only through the use of electromechanical relays.

BACKGROUND OF THE INVENTION

Static relays of the above U.S. patents are basically comprised of a pickup circuit; a timing circuit which is charged from the pickup circuit when the circuit being monitored develops or otherwise generates an output which exceeds a given threshold value; and a tripping circuit which is operated in accordance with the inverse time-current relationship so as to be tripped when the condition in the circuit being monitored exceeds predetermined values over time intervals associated therewith. In this respect, it should be understood that overcurrent conditions of large magnitude will cause faster time-out of the timing circuit to initiate a tripping operation and conversely, overcurrent conditions of small magnitude must persist for a greater time interval to cause initiation of the tripping operation.

It is extremely desirable to provide such static relays with the capability of being adjusted over relatively large time delay ranges of the order of ten-to-one or fifteen-to-one, for example. One technique for accomplishing this in the prior art consists of varying the size of the capacitors in the time delay network. This technique requires the use of relatively large components causing an accompanying significant increase in the cost of the relay. Moreover, it has been found that any efforts to provide adjustment over a large time range result in significant changes in the basic wave shape of the timing network. Thus, in accordance with the technique employed in the above-mentioned U.S. Pat. No. 3,327,171, it is necessary to simultaneously adjust all capacitors and resistors of the timing network to obtain discrete adjustments of the time delay, making this approach rather complicated and expensive.

Another technique, described in U.S. Pat. No. 3,573,555 utilizes a variable duty cycle clamp circuit which is powered by the line being monitored and which operates in a free-running manner (i.e. as a free-running multivibrator) whose "on" and "off" times are adjustable in accordance with an adjustable resistance element to obtain adjustments over a substantially wide time range without altering the desired curve shape of the time-current characteristic.

However, the variable duty cycle clamp circuit employed in U.S. Pat. No. 3,573,555 which is provided with a time dial setting knob results in an impractical

inverse marking of the potentiometer dial with the time dial graduations representing the various settings are arranged in a non-uniform manner which arrangement is extremely tedious and complex in both design and assembly and use.

BRIEF DESCRIPTION OF THE INVENTION

The present invention is characterized by providing a variable duty clamp circuit design which retains all of the desirable characteristics of the static relay described in U.S. Pat. No. 3,573,555 while providing means for time range adjustment which is substantially completely linear, thus simplifying design assembly and operation of the device.

The variable duty cycle clamp circuit of the present invention employs a multivibrator design having a resistance element whose resistance may be simply and readily adjusted through an adjustable knob having linear (i.e. equispaced) graduations or markings. The adjustable resistance element, contrary to the design employed in the above-mentioned U.S. Pat. No. 3,573,555 provides substantially constant "off" time intervals and adjustable "on" time intervals resulting in an adjustable frequency of operation which makes it possible to provide a static inverter having a truly linearized adjustable time dial.

It is therefore one object of the present invention to provide a variable duty cycle clamp circuit for use in static relays and the like having an adjustable "off" timing interval which significantly simplifies the design thereof to provide a static inverter having a linear time dial adjustment means to simplify both design and operation of the static inverter.

BRIEF DESCRIPTION OF THE FIGURES

The above as well as other objects of the present invention will become apparent when reading the accompanying description and drawings in which:

FIG. 1 is a schematic diagram of a static inverter of the type described in U.S. Pat. No. 3,573,555.

FIG. 2 is a schematic diagram of a variable duty cycle clamp circuit employed in the static inverter of the present invention.

FIGS. 3 and 4 are plots showing the relationship of charge voltage to time and which are useful in describing the advantages of the present invention.

FIGS. 5 and 6 show the adjustable dial controls required for the static inverters of the prior art and of the present invention respectively.

FIGS. 7, 8 and 9 are plots showing the relationship of the dial positions to the time delay intervals.

FIG. 10 shows tables compiling the experimental results obtained through the use of the present invention.

FIG. 11 is a schematic drawing of an adjustable resistance element which may be employed in the present invention.

DETAILED DESCRIPTION OF THE FIGURES

FIG. 1 shows a static inverter of the type described in U.S. Pat. No. 3,573,555. Since this circuit is described in detail in the aforesaid patent, only a brief description of its operation will be given for purposes of simplicity.

If a fault or overload current is developed in any one or more of the three lines 10, 11 and 12 being monitored, the maximum voltage condition, after a.c. to d.c. conversion, appears across buses 22 and 23. The series

connected circuit of diode 50, resistor 54 and zener diode 52, coupled across buses 22 and 23, establishes a constant voltage level in conductor 53. The series circuit comprised of diode 95 and resistor 55, coupled across buses 22 and 23 applies the d.c. voltage level to the base of transistor 59. When this value exceeds the constant voltage reference value in line 53, transistor 59 is rendered non-conductive, causing transistor 61 to be rendered non-conductive. This removes a short-circuit condition from the cathode electrodes of diodes 80, 81 and 82 enabling the d.c. current to flow from bus 22 through diode 76, resistor 72 and resistors 70 and 71 and diodes 80, 81 and 82 into capacitors 73, 74 and 75 to develop an output applied to the input line 86 coupled to the base of transistor 91 whose collector is coupled to the trigger electrode of a controlled rectifier 89 which is provided to conduct and hence trigger controlled rectifier 87 to energize a trip coil 88 when the level at line 86 reaches a predetermined threshold value which will require a longer time interval in the presence of overload currents of low magnitude and alternatively, a shorter time interval in the presence of overload currents of significantly greater magnitude.

In order to provide a time adjustment range over which the static relay may be operated, the variable duty cycle clamp circuit 130 is provided. The circuit operates as a free-running multivibrator having "on" and "off" time intervals whose time durations are controlled by the adjustment of movable wiping arm 137a of adjustable resistance element 137. It can be seen, for example, that the movement of the wiper arm 137a toward the left decreases the resistance between the wiper arm 137a and the left-hand terminal of resistor 137 while necessarily increasing the resistance between the wiper arm 137a and the right-hand terminal of resistance 137. This design, while providing an adjustment for the time interval of the "on" time of the multivibrator, provides a corresponding inverse adjustment in the "off" time of the multivibrator duty cycle which necessarily affects the time dial setting to have an inverted non-linear arrangement for the reasons set forth hereinbelow.

The circuit of FIG. 1 provides an impractical inverse marking of the potentiometer dial which will be described in detail hereinbelow:

Principle of Operation

FIG. 2 shows a multivibrator with variable reostat R_1 . R_1 is the time dial control. Transistor Q_2 has an "off" time of $T_o = R_o C_o$ and an "on" time of $T_1 = (R_2 + R_1) C_1$. Q_2 controls the input to the RC time circuit of an over-current relay such that Q_2 allows input for a time T_o and no input for a time T_1 . Diodes are required in the RC circuit to prevent capacitor discharge during the "off" time.

TIME FUNCTION

FIG. 3 shows the charge voltage of the RC circuit divided into n T_o increments. A fixed time of T_1 will be added for each T_o increment as shown in FIG. 3. Therefore

$$t = t_{RC} + n T_1$$

$$n = (t_{RC}/T_o)$$

$$t = t_{RC} (1 + [T_1/T_o]) = t_{RC} ([T_o + T_1/T_o])$$

(1)

It should be noted that T_1 is a linear function of R_1 , since $T_1 = R_2 C_1 + R_1 C_1$.

Turning now to a consideration of the variable duty cycle clamp circuit of FIG. 1:

Let 130 be a resistor of value R_1

135 and 136 be resistors of value R_2

133 and 134 be capacitors of value C Therefore, using the above reasoning and notation:

$$T_1 = (a R_1 + R_2) C$$

$$T_o = [(1-a)R_1 + R_2] C$$

$$T_1 + T_o = (R_1 + R_2) C = K \text{ (a constant)}$$

where a describes the variability of the resistor R_1 . The time response of the timing circuit controlled by the clamp circuit is then:

$$t = (T_o + T_1) t_{RC}/T_o \quad (1)$$

$$t = K t_{RC}/T_o$$

(2a)

Since T_o is a linear function of R_1 and T_o is in the denominator of equation (2a), the resulting dial marking is inverse and non-linear. For example, FIG. 5 attached shows a dial marking resulting for a 10:1 range in time.

The new circuit connection corrects this condition and provides a linear dial marking as shown in FIG. 6.

Derivation of Pot Rotation Angle

The time dial rotation θ in terms of maximum pot rotation θ_M is derived as follows:

Using equation (1) let

$$a = (t/t_{RC}) = (T_1 + T_o)/T_o \quad (1)$$

$$T_1 = (a - 1) T_o$$

$$T_1 = (R_1 + R_2) C_1 \quad (2)$$

$$T_o = R_o C_o$$

(3)

$$(R_1 + R_2) C_1 = R_o C_o (a - 1)$$

let $R_2 = R_o$ and $C_1 = C_o$ then

$$(R_1 + R_o) C_o = R_o C_o (a - 1)$$

$$R_1 = (a - 2) R_o$$

(4)

$$a = 2 + (R_1/R_o)$$

(5)

let $\theta = 0$ for $R_1 = 0$, then $a = 2$

For a 15:1 time dial range a ranges from 2 to 30, and the maximum value for R_1 is given by equation (4) with $a = 30$.

$$R_1 (\text{max}) = 28 R_o$$

(6)

R_1 expressed in terms of pot rotation is then:

$$R_1 = (\theta/\theta_M) 28 R_o = (a - 2) R_o$$

(7)

where θ_M equals max. rotation. Therefore

$$\theta = [(a - 2)/28] \theta_M$$

For 10 markings to give the 15:1 time range let

$$a = 2 + (28/9) (N - 1)$$

where $N=1, 2, 3 \dots 10$ substituting (9) in equation (8) gives

$$\theta = (N - 1/9) \theta_M$$

Supporting Tests

The above analysis predicts a multivibrator circuit will give a linear time dial. The linearity results from varying the "off" time T_1 while the "on" time remains constant.

Measurements of the multivibrator circuit of the type shown in FIG. 2 show that the "on" time decreases slightly as a function of "off" time T_1 . This causes a slight non-linearity in pot marking.

The above prediction has been confirmed by experimentation in which the pot marking equation was derived from measured data of two sample multivibrator circuits and times measured for a static relay of the type shown in FIG. 1, but employing a clamp circuit of the type shown in FIG. 2.

Test Apparatus

- a - Time Delay Circuit No. 1
- b - Time Delay Circuit No. 2
- c - Laboratory Current Machine
- d - 800/5 Current Transformer
- e - Tektronix scope, type 564B

Procedure

1. The "on" time T_0 and "off" time T_1 of circuits (a) and (b) above were measured for values of pot resistance. The results are plotted in FIGS. 7 and 8. Curve 150 of FIG. 7 represents the observed time duration values T_1 of an OFF pulse plotted against the resistance of the potentiometer for Time Delay Circuit No. 1. For example, for an OFF pulse time T_1 duration of $0.7 \times 10^3 \mu\text{sec}$, the measured pot resistance is $820 \times 10^3 \text{ ohms}$ (see point a on curve 150). Curve 151 of FIG. 7 indicates that the ON time of the multivibrator deviates slightly from a perfectly constant value. For example, at a value of $1,000 \times 10^3 \text{ ohms}$ pot resistance (see point b on curve 151) T_0 is $0.37 \times 10^3 \mu\text{secs}$, and for a pot resistance value of 0.0 ohms (see point c on curve 151) T_0 is $0.41 \times 10^3 \mu\text{secs}$. The deviation of T_0 from a constant value was found to be due to the effects of pot resistance upon the operating characteristics of the components (resistors, transistors, and the like) employed in the static relay circuit. However, the deviation is small enough to be ignored for practical applications.

Curves 154 and 155 in FIG. 8 show similar results for the time delay circuit No. 2.

2. The pot angle for each time dial setting was calculated for each circuit using the T_0 and T_1 test data. The results are also plotted in FIGS. 7 and 8. Curve 152 in FIG. 7 represents the angular setting of the potentiometer shaft plotted against the OFF pulse times T_1

observed, where the time dial angular settings are expressed as a fraction of the maximum angular rotation through which the time dial shaft may be rotated between zero ohms and 1.0 megohm. For example, for a value $T_1 = 0.6 \times 10^3 \mu\text{secs}$. (see point d on curve 152) $\phi = 0.61$. Dotted straight line 153 has been provided in FIG. 7 to show the slight deviation of curve 152 from a straight line. The observed deviation is small enough to be ignored for practical purposes.

FIG. 8 shows that similar results were obtained in testing time delay circuit No. 1 wherein curve 156 represents OFF time intervals T_1 plotted against time dial angles ϕ . Dotted straight line 157 shows the slight deviation of curve 156 from a straight line.

3. Using the test equipment (c), (d) and (e) set forth above, the time-current curve for test circuit (a) was measured for values of Time Delay pot resistance. The resulting data is recorded in Table I of FIG. 10.

4. The values in Table I are referred to the t_{4x} times and then averaged. The results are recorded in Table II of FIG. 10.

5. The average time values are plotted against a in FIG. 9, where $a = (T_1 + T_0/T_0)$ calculated from the data of FIG. 8.

Conclusions

1. The correlation of T_a versus a is a straight line showing that the derived relation holds.

2. As a result the time dial pot angle as a function of D (where D is the time dial markings 1, 2, 3 10) is given as follows:

$$a = 1.88 - (25.8 - 1.88/9) (D - 1)$$

$$a = 2.66 D - 0.78 = (830\phi + 75/40 - 5\phi)$$

$$\phi = (D - 1/7.75 D + 0.125 D)$$

$$\phi = [8(D - 1)/62 + D]$$

Derivation of $a = t/t_{rc}$ for T.D. Circuit No. 2

$$a = (T_0 + T_1/T_0)$$

$$a = [(835\phi + 35) + (40=5\phi)/40-5\phi]$$

$$a = (830\phi + 75/40 - 5\phi)$$

Summarizing the multivibrator structure of FIG. 2, it can be seen that the placement of the adjustable resistance element in the collector circuit of transistor Q2 provides a constant "on" time T but an adjustable "off" time providing a decided advantage over the clamping circuit shown in FIG. 1. In addition thereto, by equation (5), given the ratio of total cycle to "on" time, it is possible to design a linear time dial marking arrangement in accordance with equation (5) to obtain the time dial marking as shown in FIG. 6. It should be understood that the time dial marking is comprised of a rotatable knob K having a pointer indicia P, while the front face of the static relay housing is provided with the graduations 1 10 as shown in FIG. 6. The shaft (not shown for purposes of simplicity) upon which knob K is mounted is then appropriately mechanically coupled to variable resistance element R_1 of FIG. 2 which may, for example, take the form of a wound resistance 100 shown in FIG. 11, having the first end terminal 101 and a second end terminal 102 for electrical connection into the circuit of FIG. 2. Wiper arm 103 is arranged to rotate about a shaft 104 which may be either common with the shaft to which knob K is

mounted or may otherwise be electrically connected thereto.

Although there has been described a preferred embodiment of this novel invention, many variations and modifications will now be apparent to those skilled in the art. Therefore, this invention is to be limited, not by the specific disclosure herein, but only by the appending claims.

What is claimed is:

1. A static relay comprising:

a current-sensing circuit;

a charging network connected to said current-sensing circuit said charging network having input terminals connected to said current-sensing circuit, and output terminals; the voltage at said output terminals increasing with time according to a predetermined curve after said current-sensing circuit is connected to said input terminals of said charging network;

pickup circuit means connected between said current-sensing circuit and said input terminals of said charging network; said pickup circuit means energizing said input terminals of said charging network when the output of said current-sensing means exceeds a predetermined value;

output circuit means connected to said output terminals of said charging network and being energized when the output of said output terminals exceeds a predetermined value;

and continuously operating switching circuit means comprising a multivibrator means having first and second transistors each having first, second and control electrodes;

first capacitor means (C_o) coupled between the control electrode of said first transistor and the first electrode of said second transistor;

second capacitor means (C_1) coupled between the control electrode of said second transistor and first electrode of said first transistor;

first and second resistance elements each having a

first terminal connected respectively to the first electrodes of said first and second transistors and a second terminal coupled to said current sensing circuit;

a third resistance element (R_o) coupled between the control electrode of said second transistor and said current sensing circuit;

fourth and fifth resistance means being connected in series between the control electrode of said first transistor and said current sensing circuit;

said resistance means comprising a variable resistance element having an adjustable member;

dial means including an adjustable knob means and face plate having uniformly spaced graduations co-operating with a pointer on said knob means for adjustably setting the desired time setting of said multivibrator;

said knob means being connected to said adjustable member to vary the resistance of said fourth resistance means;

the uniform graduations being obtained by the proportional relationship between said fourth resistance means (R_1) and said third resistance means given by the equation:

$$R_1 = (R_o C_o / C_1) (a - 1) - R_2$$

where $a = (T_1 + T_o / T_o)$ and T_o is the time interval during which said second transistor is non-conductive and T_1 is the time interval during which said second transistor is conductive.

2. The device of claim 1 wherein said knob means is rotatable and wherein the angular spacing between said graduations is given by the equation:

$$a = (K_1 \theta + K_2 / K_3 - K_4 \theta$$

K_1 , K_2 , K_3 and K_4 are constants whose ranges are: Where $800 < K_1 < 850$; $50 \leq K_2 \leq 100$; $20 \leq K_3 \leq 40$; and $1 \leq K_4 \leq 10$.

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