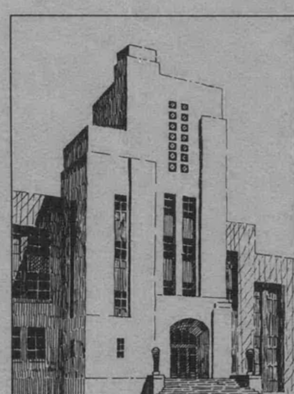
THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

THE TMB LINEAR SWEEP OSCILLATOR

BY ENSIGN G. ROBERT MEZGER



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BUREAU OF SHIPS

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WASHINGTON, D.C.

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INTRODUCTION

The development by the David W. Taylor Model Basin of the linear "round-trip" sweep oscillator for use with commercial cathode-ray oscillographs has occasioned a considerable interest in this design. It possesses certain advantages over other sweep-circuit oscillators and, inasmuch as it is not of such confidential nature as other sections of the TMB report from which it was taken, it is reproduced herewith to permit the wider distribution which has been demanded of this material.

SWEEP-CIRCUIT DESIGN

The only sweep circuits which are available and which are supplied as an integral part of commercial cathode-ray oscillographs are unsuited for the quantitative measurements conducted at the Taylor Model Basin. In particular, the lack of linearity with respect to time of the sweep voltage as generated by commercial equipment interferes seriously with the accuracy of measurement. This has led, finally, to the development of a new type of linear time-base, to which various other features have been added to increase its flexibility and versatility. These include both single-sweep and recurrent operation, automatic single-sweeping at a predetermined rate, automatic control of the electron beam in the cathode-ray tube to turn the beam on only during the sweep cycle, and variable-rate sweeping on both the forward and return trace of the spot.

The sweep circuit developed by the Taylor Model Basin is entirely self-contained. It draws its power from any 60-cycle single-phase source, and it delivers a sweep signal which may be used with any cathode-ray oscillograph by connecting it directly to the horizontal deflection system of any electrodynamically deflected cathode-ray tube. Certain features of this sweep circuit are designed especially for use with the particular circuit of the Du Mont Type 208 Cathode-Ray Oscillograph; these will be apparent in the description of the sweep-circuit operation now to be given.

As shown in the schematic representation of the sweep circuit in Figure 1, the oscillator consists of two gas-filled triodes, or "thyratrons," T_9 and T_{10},* operating in a manner similar to a push-pull circuit, but with their plate circuits fed by two current-limiting pentodes which are used to alter the normally logarithmic

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* For convenience, circuit symbols are keyed with the complete schematic circuit given in Figure 4.

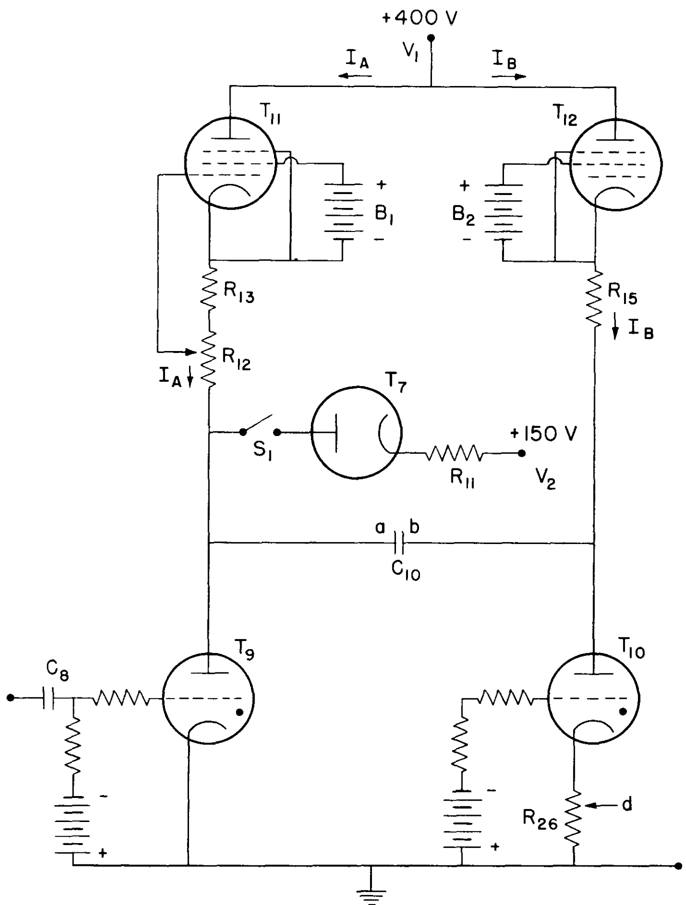

Figure 1 - Simplified schematic circuit of sweep-oscillator

charging of C_{10} to a linear charging rate to provide a linear sweep voltage output. The details of the circuit operation are as follows.

Condenser C_{10} is the "charging" condenser which is alternately charged and discharged by each side of the circuit to develop the sweep-voltage across the points a and b. The bias on each of the gas-filled triodes, T_9 and T_{10}, is adjusted so that either tube will ionize at a plate potential of 155 volts. If, now, the cathode of the diode T_7, which is a Type 6N7 tube with both grids and both plates connected together to form a diode, be held at a fixed potential of 150 volts with switch S_1 closed, T_9 cannot conduct current because the applied plate potential will never reach the required breakdown potential of 155 volts. It will be necessary, therefore, to permit T_9 to conduct, to apply a positive tripping pulse between C_8 and ground to lower momentarily the breakdown potential of T_9. Under conditions of operation when no tripping pulse is applied, the current I_A which flows through the left side of the circuit of Figure 1 will all pass through T_7 to the 150-volt supply to the cathode of T_7 and, eventually, to ground. Since the voltage drop across R_{11} and T_7 in series is relatively small, point a remains essentially at 150 volts positive with respect to ground.

The current I_B, which flows through the right-hand side of the circuit from the same 400-volt source which supplied I_A, flows through the current limiter T_{12} until the potential at point b reaches 155 volts. Condenser C_{10} is not yet charged since both points a and b are virtually the same potential, which is 155 volts above ground. Points a and b differ by only 5 volts (approximately). At this moment, however, the triode T_{10} becomes conducting. The voltage drop across T_{10} is approximately 15 volts, which becomes the potential of point b, and condenser C_{10} is then charged to a potential of 150 minus 15 or 135 volts. At the same moment, with the usual phasing of deflection-plate connection, point a is positive with respect to point b, and the electron beam is held at the extreme left end of its excursion. The position of the electron beam in a perfect cathode-ray tube is, of course, determined by the relative potential between plates of a deflecting pair and not by the potential of either or both plates with respect to ground.

The foregoing are the static conditions in which the sweep circuit will be found, after its power supply has been turned on preparatory to operation of the circuit.

If a positively-polarized tripping pulse is now applied to the grid circuit of T_9, between C_8 and ground, T_9 will be caused to conduct and it will immediately drop the potential of point a to + 15 volts (tube voltage drop in T_9). In doing so, potential of point b will be dropped below that of ground (cathode potential) by an amount equal to the charge on C_{10} less the voltage drop in T_{10}. The plate potential of T_{10} is thus dropped below its cathode potential, and the tube becomes non-conducting. The current I_B then flows through condenser C_{10} and through T_9 to ground in the direction from point b to point a. T_9, then, is conducting both I_B and I_A. As current flows into C_{10} from b to a, C_{10} charges in opposite polarity to its previous condition, and b becomes positive with respect to a.

When the potential at point b reaches 155 volts with respect to ground, T_{10} again becomes conducting, causing the plate of T_9 to be driven negative with respect to its cathode and de-ionizing T_9. T_{10} is then conducting both I_B and I_A which pass through C_{10}. This causes the potential across C_{10} to reduce from its previous value to zero and ultimately to 135 volts (135 volts across its terminals or 150 volts from point a to ground) with point a positive with respect to point b. At this potential, T_7 becomes conducting and the flow of current I_A then transfers from T_{10} to T_7 and through R_{11} to ground. If T_9 is tripped again, the cycle is repeated. If it is not tripped, the single sweep which has occurred is not repeated.

If switch S_1 is opened the cycle will repeat itself indefinitely, and the device will operate as a recurrent sweep-voltage oscillator.

During the time that T_7 is conducting, a potential is developed across R_{11}. During the conducting time of T_9, however, which is the time during which the single sweep is taking place, no potential drop appears across R_{11}. A square wave of voltage is thus developed during the sweep cycle; this may be amplified and used to excite the control grid of the cathode-ray tube to increase the beam current and cause the spot to appear during the sweep cycle only.

During the conducting time of the gas triode T_{10}, the cathode current of this tube develops a potential across R_{26}. T_{10} conducts during the last half of the cycle only, and if this potential is connected to a suitable instantaneous position-control circuit, such as the control grid of the second Type 6V6 in the vertical deflection amplifier of the Type 208 cathode-ray oscillograph, it will be possible to obtain a vertical displacement between the forward- and return-trace lines on the

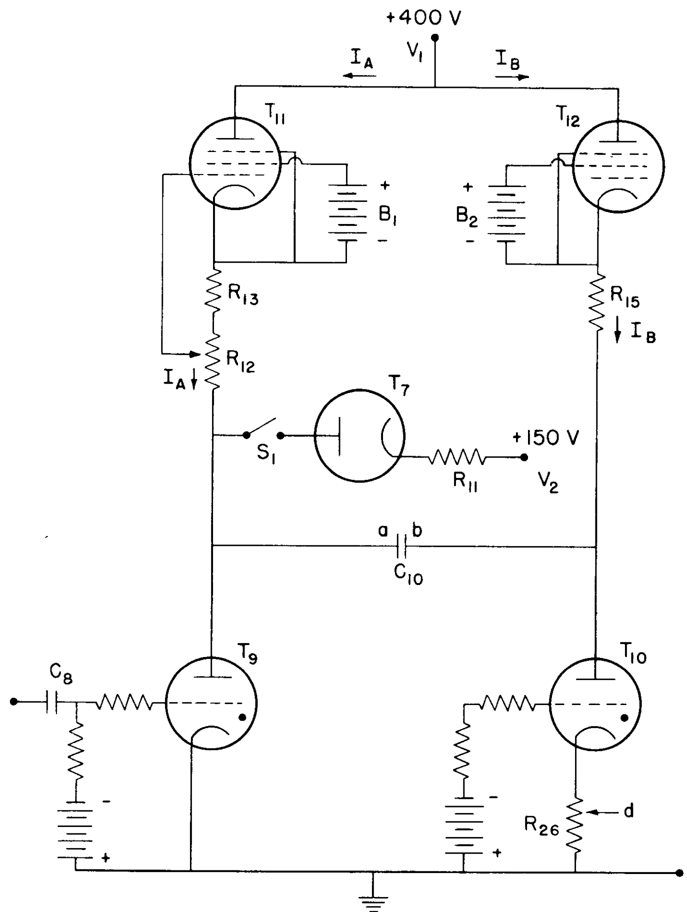

Figure 1 - Simplified schematic circuit of sweep-oscillator

cathode-ray tube, the magnitude of which can be controlled by the potential taken from the variable arm of potentiometer R_{26}.

Inasmuch as the charging current into C_{10} is fed first through T_{12} and then through T_{11}, it is possible to vary the resistance in the two feed circuits so that the time rate of charge of one circuit can be different from that of the other circuit. This adjustment is provided in the cathode of T_{11} by means of R_{12}, and by adjusting this control the velocity of the spot during the "forward" sweep can be made different from its velocity during the "return" sweep. This feature can be valuable, for example, where it is desired to examine one portion of a phenomenon on a fast time scale while using a total time scale which is sufficiently long to observe a greater span of time history of the phenomenon. By making the sweep rate of, say, the left-to-right excursion three times that of the right-to-left excursion, there is obtained, effectively, a cathode-ray-tube screen four times as wide as the tube, as measured on a time basis.

The excursion of the luminous spot on the face of the cathode-ray tube during its cycle of operation is worthy of some consideration. Under the static operating conditions described in the foregoing, where the circuit is waiting for a pulse to be applied to the grid of T_9 to commence operation, and where the circuit is adjusted so that $I_A = I_B$, the vertical displacement voltage taken from point d across R_{26} is adjusted to be of sufficient magnitude to hold the spot in position as shown in Figure 2a. The spot rests at the left side of the screen because C_{10} is charged with point a positive in potential with respect to point b. When T_9 is then ionized by applying a tripping pulse, the spot is illuminated due to control-grid modulation of the cathode-ray tube by the square wave of voltage taken from across R_{11}. The spot jumps up owing to the cessation of current I_B through R_{26}, since T_{10} is now de-ionized, and then starts moving from left to right at a linear rate across the screen, owing to the flow

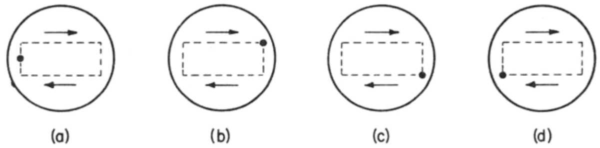

Figure 2 - Motion of spot as produced by TMB linear time-base generator

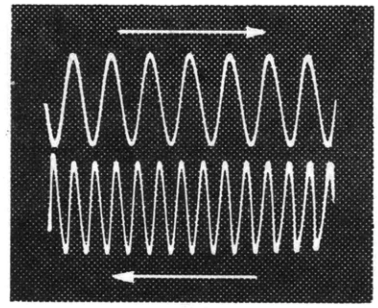

Figure 3 - Example of double sweeping of TMB linear time-base generator

The successive phases of the sweep cycle shown in Figure 2 appear in this sample record; the upper part is the rapid sweep and the lower part the slow one. Oscillograms of this sort, made with voltage of known amplitude and frequency, are regularly made for purposes of calibration.

of I_B through C_{10}. As the potential across C_{10} passes through zero, the spot passes through the center of the screen, and as point **b** swings positive with respect to point **a**, the spot moves to the right side of the screen as shown in Figure 2b. As T_{10} becomes ionized, T_{10} conducts both I_A and I_B, the voltage-drop across R_{26} is twice what it was before T_9 was tripped, the spot jumps to the lower position shown in Figure 2c, and then moves from right to left at a rate which is linear with respect to time. The potential across C_{10} again changes polarity, and when the potential of point **a** reaches the voltage level of the cathode of diode T_7, owing to the flow of current I_B, the spot is in the position shown in Figure 2d. When I_A transfers from T_{10} to T_7 as T_7 becomes conducting, the spot jumps up to its original position as in Figure 2a. Since current is again flowing in R_{11}, the spot is extinguished immediately.

A sample oscillogram, showing the same sinusoidal signal sweeping left to right above and right to left below, is shown in Figure 3.

The complete schematic diagram of this sweep circuit is shown in Figure 4 in detail. The instrument contains its own power supply. T_5, which is a Type 5Z4 rectifier, supplies all potentials which are positive with respect to ground; and T_8 which is a Type 6X5 rectifier, operates as a source of all negative potentials. Tubes T_1, T_2, T_3, and T_4 comprise a conventional electronic voltage regulator which is employed to maintain the proper potential on the cathode of T_7. T_6, which is a Type VR150 voltage-regulator tube, operates as a source of + 150 volts to provide plate-supply potential for T_{13}.

The small neon tube, T_{14}, and its resistance-capacitance network operates as a low-frequency pulse generator to "single-sweep" the cathode-ray tube at a repetition rate of about 2 seconds for adjustment of focus and intensity controls for the cathode-ray tube.

The pentode T_{13} is an amplifier for the square-wave voltage developed across R_{11} for intensity control of the spot on the cathode-ray tube. The output of this amplifier is fed into the voltage-limiting diodes, T_{15}, to maintain a constant spot brilliance during the entire sweep cycle, and to maintain a maximum negative-bias

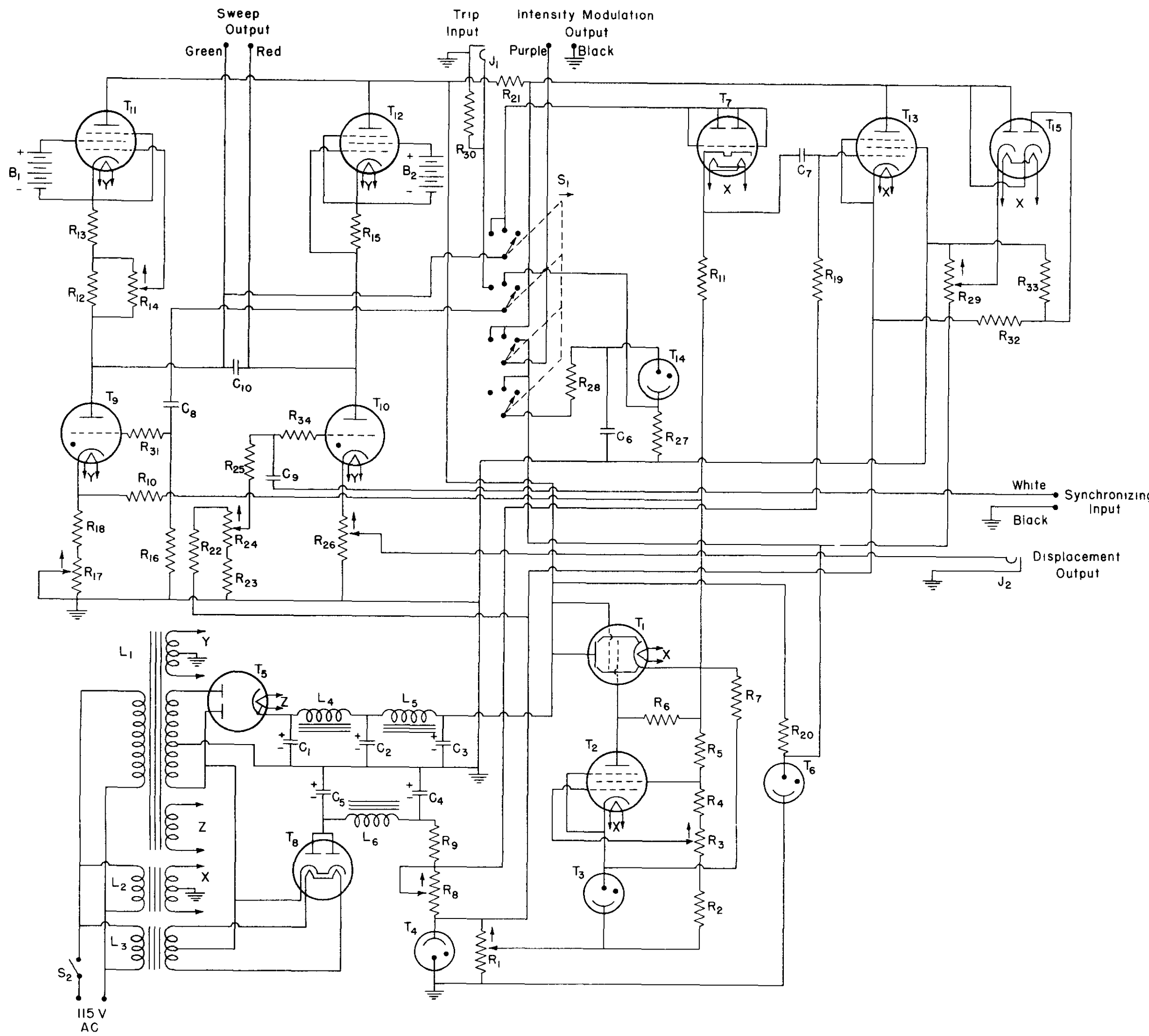

Figure 4 - Detail Diagram, David Taylor Model Basin Sweep Oscillator

Parts List

Condensers

C_1 - 10 mfd. 450 volt, electrolytic

C_2 - 10 mfd. 450 volt, electrolytic

C_3 - 10 mfd. 450 volt, electrolytic

C_4 - 12 mfd. 450 volt, electrolytic

C_5 - 8 mfd. 450 volt, electrolytic

C_6 - 0.5 mfd. 600 volt, paper

C_7 - 3 mfd. 600 volt, paper

C_8 - 0.001 mfd. 500 volt, mica

C_9 - 0.01 mfd. 600 volt, paper

C_{10} - Decade condenser boxes in parallel as follows:

- 0 to 1.0 mfd. in 0.1-mfd. steps
- 0 to 0.1 mfd. in 0.01-mfd. steps
- 0 to 0.01 mfd. in 0.001-mfd. steps
- 0 to 0.001 mfd. in 0.0001-mfd. steps

(Continued on following page)

Parts List, Figure 4 (continued)

Resistors

- R_1 - 15K potentiometer
- R_2 - 10K - 1/2 W
- R_3 - 10K - potentiometer
- R_4 - 25K - 1 W
- R_5 - 10K - 1 W
- R_6 - 500K - 1/2 W
- R_7 - 300K - 1/2 W
- R_8 - 100-ohm potentiometer
- R_9 - 4K - 10 W
- R_{10} - 6K - 10 W
- R_{11} - 5K - 1/2 W
- R_{12} - 20K - 1/2 W
- R_{13} - 1.5K - 1/2 W
- R_{14} - 20K potentiometer
- R_{15} - 1.5K - 1/2 W
- R_{16} - 50K - 1/2 W
- R_{17} - 200-ohm potentiometer
- R_{18} - 800-ohm - 1/2 W
- R_{19} - 2000K - 1/2 W
- R_{20} - 10K - 10 W
- R_{21} - 200K - 1 W
- R_{22} - 30K - 1/2 W
- R_{23} - 1.25K - 1/2 W
- R_{24} - 7.5K potentiometer
- R_{25} - 50K - 1/2 W
- R_{26} - 1K potentiometer
- R_{27} - 5K - 1/2 W
- R_{28} - 10,000K - 1/2 W
- R_{29} - 50K potentiometer
- R_{30} - 100K - 1/2 W
- R_{31} - 25K - 1/2 W
- R_{32} - 50K - 1 W
- R_{33} - 50K - 1 W
- R_{34} - 10K - 1/2 W

(K = Kilo = 1000 ohms)

Tubes

- T_1 - Type 6L6, voltage regulator
- T_2 - Type 6SJ7, voltage regulator amplifier
- T_3 - Type CD2005, regulator voltage-reference
- T_4 - Type VR105/30, voltage regulator
- T_5 - Type 5Z4, rectifier
- T_6 - Type VR150/30, voltage regulator
- T_7 - Type 6N7, diode voltage limiter
- T_8 - Type 6X5, rectifier
- T_9 - Type 884, relaxation oscillator
- T_{10} - Type 884, relaxation oscillator
- T_{11} - Type 6SK7, current-limiting pentode
- T_{12} - Type 6SK7, current-limiting pentode
- T_{13} - Type 6SJ7, amplifier
- T_{14} - Type CD2005, pulse generator
- T_{15} - Type 6H6, voltage limiter

Inductances

- L_1 - Thordarson power transformer Type T-13R14, secondaries:
  - 700V at 120 ma. c.t.
  - 6.3V at 4.7 amp. c.t.
  - 5.0V at 4 amp.
- L_2 - Heater transformer 6.3V - 6.0 amp.
- L_3 - Heater transformer 6.3V - 6.0 amp.
- L_4 - 12-henry choke coil
- L_5 - 12-henry choke coil
- L_6 - 12-henry choke coil

Batteries

- B_1 - 67 1/2 volts dry battery
- B_2 - 67 1/2 volts dry battery

Switches

- S_1 - 4-gang, three-position
- S_2 - SPST toggle switch
- J_1 - Single-circuit jack
- J_2 - Single-circuit jack

Note: S_1 in left position gives single-sweep operation; in center position gives internally-pulsed single sweeps, repeating every 2 seconds; right position of S_1 places unit in recurrent-sweep operation.

limit for the cathode-ray tube.

Condenser C_{10} consists of four standard decade condensers* connected in parallel. Sweep rates which are variable over the range from 1 to 35,000 sawtooth cycles per second are obtained. Since the voltage output of this sweep circuit is relatively high, no amplifiers are required, and distortion from this source is eliminated. The period of the sweep may be made as long as desired by adding condensers in shunt with C_{10}. The deflecting plates of the cathode-ray tube do not behave as a load on the circuit even at high sweep frequencies, since they are effectively part of the condenser C_{10}. The capacity of the deflection plates and other stray circuit capacities will, however, limit the highest sweep frequency obtainable. Stray circuit leakage across C_{10} also should be avoided.

The two current-limiting pentodes, T_{11} and T_{12}, are arranged in a self-biasing circuit; and, since their screen current does not flow through the self-biasing resistors, any circuit tendency to alter plate current by a plate-to-cathode voltage change is self-compensating. The use of this circuit limits deviations from uniform sweep-voltage change as a linear function of time to within less than 1 per cent. The supply potential to the current limiters T_{11} and T_{12} needs no regulation, for the charging current to C_{10} is kept constant by the compensating action of T_{11} and T_{12}. The instrument, therefore, exhibits remarkable frequency stability.

The resistance network which consists of R_{10}, R_{17}, and R_{18} is an automatic bias-compensating circuit for the gas-filled triode T_9. When the amplitude of voltage output of the unit is changed by varying the potentiometer R_1, which raises or lowers the voltage level of the voltage-limiting diode T_7, the breakdown voltage of T_9 will change. If the bias on this tube were not changed, a higher and higher tripping-pulse potential would be required to ionize the tube as the plate voltage is lowered, since the bias necessarily must be high enough to prevent ionization at the highest plate voltage. With this circuit, however, as the plate voltage on T_9 is reduced by lowering the voltage-limiting level of T_7, the bias on T_9 is reduced proportionately, and the tripping-pulse amplitude required for ionization remains constant regardless of the voltage output of the unit.

The velocity of sweep is unaffected by changes in the amplitude controls R_1 and R_{24}. This means that the time-rate of travel of the spot across the screen, say, in inches per second, is unaffected by the amplitude of deflection and indicates, therefore, that sweep frequency is directly dependent upon amplitude adjustment. When using recurrently operating sweep circuits, this is often considered a disadvantage. Since the greater part of the work carried on at the Taylor Model Basin, however, is of a transient nature, this feature is rather an advantage since it permits extension of the time scale, within limits, to study a greater or lesser portion of the signal as may be desired.

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* Standard condenser boxes as manufactured by the Cornell-Dubilier Corporation are used so that wiring of condenser banks and switches is unnecessary.

PERSONNEL

The equipment described in this report was designed by George W. Cook under the leadership of Gilbert H. Curl. This report is the work of Ensign G. Robert Mezger, C-V(S), USNR.