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DESIGN AND PERFORMANCE CHARACTERISTICS OF A MECHANICALLY DRIVEN VESTIBULAR STIMULATOR

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In order to determine basic response characteristics of mammalian vestibular systems, the systems so important for spatial orientation, a device to provide programs of controlled angular accelerations about the vertical axis was required. The small rotation device described in the present report was designed to meet this need.

Rotatory Structure

The basic structure of the turntable is a modified section of a surplus K-4 navigational computer previously used in a B-47 aircraft. The case holding the stabilization unit[1] from the computer was inverted and legs added to form the turntable base. Thus, the slip ring system of the unit is at the bottom of the structure, and the outer gimbal and its ball bearings at the top. To the latter, the formica-covered, wooden table-top, 4 feet in diameter, was added. The table-top actually rests on two additional circular wooden bases, 1 and 2 feet in diameter, respectively, to provide additional support. A Statham unbonded strain gage angular accelerometer[2] with (a) a liquid rotor, (b) a range of ± 1.5 rad/sec^2, (c) infinite resolution, and (d) a 4 cps natural frequency, is mounted within the stabilization unit (see Figure 1).

The size and other characteristics of the rotator super-structure are such that its most efficent use is limited to relatively light weights (less than 50 lb.) if the subjects are to be positioned away from the center of rotation. Considerably more weight (up to 150 lb.) can be tolerated without affecting characteristics of the acceleratory stimulus for a wide range of values, if the weight is positioned directly over the center of rotation.

Drive System

The drive system consists of 2 major components:

1) Bodine Type NC1-34RH constant speed motor[3]; 1/15 hp with 86.0 rpm output; 29 in. lb. torque rating.

2) Ball-and-disc integrator[4] with overall dimensions of 8″ × 6 3/4″ × 6″. The disc-to-cylinder ratio can be varied from 1:4 clockwise, (CW), through 1:0, to 1:4 counterclockwise (CCW) by turning the ball-positioning control wheel approximately 4.1 times.

The Bodine motor drives the integrator disc at 86.0 rpm while the control system, to be described below, displaces the ball carriage of the integrator from its center position by values determined at the control panel. The output shaft of the integrator is activated by the rotary motion of the ball. The latter is immobile when positioned at the center of the disc. As the ball is displaced from center, it revolves at rates determined by the speed of the disc and the radial position of the ball on the disc. Displacement of the ball is accomplished by means of a gear-driven shaft extending from the control unit to the integrator.

Output from the integrator is translated into motion of the turntable by means of a short, linking shaft. The latter is attached, at one end, to the integrator. At the other end, a precision-ground, rubber-coated, steel disc, 1″ in diameter, is in spring-loaded contact with

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[1] National Cash Register Company, part no. 667126.

[2] Model no. AA 17-1.5-350.

[3] Bodine catalog no. B 3810-20 H.

[4] C & H Co. (Pasadena, California) stock no. BDI -107.

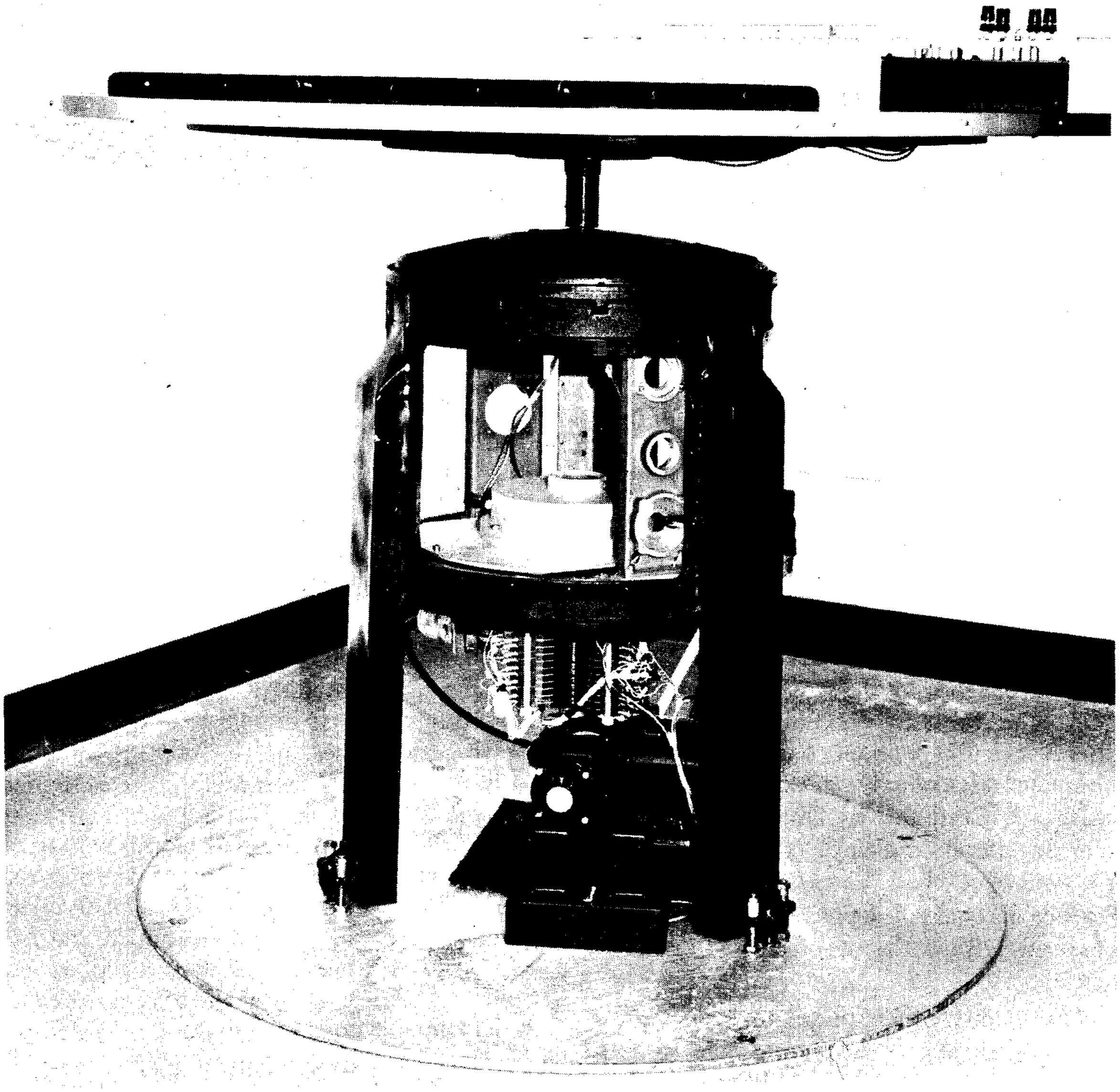

FIGURE 1. Front view of the rotatory device with side panels removed. A portion of the drive shaft leading back into the control room is evident behind the motor.

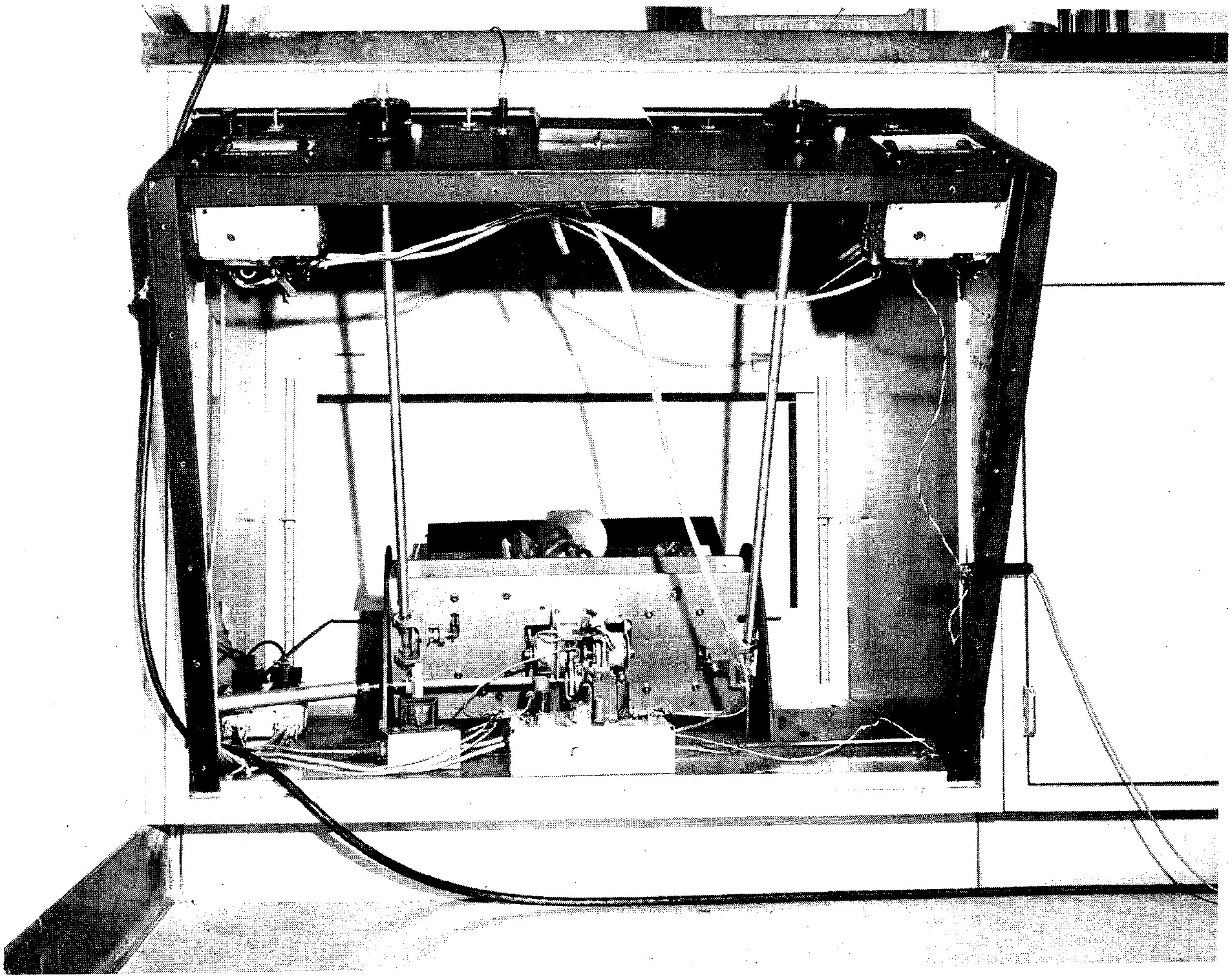

FIGURE 2. Control panel with front cover removed.

the rotatory part of the stabilization unit. To prevent damage to the system, limit switches are secured to each end of the integrator ball carriage. The switches de-energize the magnetic clutch in the control system when the ball carriage approaches the limit of its vertical displacement. A zero switch is also located on the integrator. The arm of this microswitch is activated by a cam fastened to the end of the drive shaft connecting the turntable and the control unit.

Control System

The control unit is shown in Figure 2. The unit is activated by a toggle switch on the control panel which starts two 1/70 hp shaded pole motors,[5] one for CW and the other for CCW rotation of the drive shaft.

Each motor is coupled to the output shaft of a small ball-and-disc integrator,[6] thereby driving the shafts at constant rates. The shafts, in turn, drive the ball and the position of each ball carriage is adjusted and set so that the integrator discs are rotated at a particular rate (in this case, approximately 13 rpm) determined during calibration procedures. These small mechanical integrators were used in lieu of a variable speed motor to provide a readily adjustable means of calibrating output from the control unit to the acceleration dials on the control panel.

The disc of each of the two small integrators noted above is coupled directly to the disc of a companion large integrator.[7] Thus, the discs of the latter two (large) integrators turn

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[5] Dayton 50 rpm gear motors, 4 in. lb. torque full-load amps 0.63.

[6] Tracking computer assembly no. R5257677.

[7] Tracking computer assembly no. 824118.

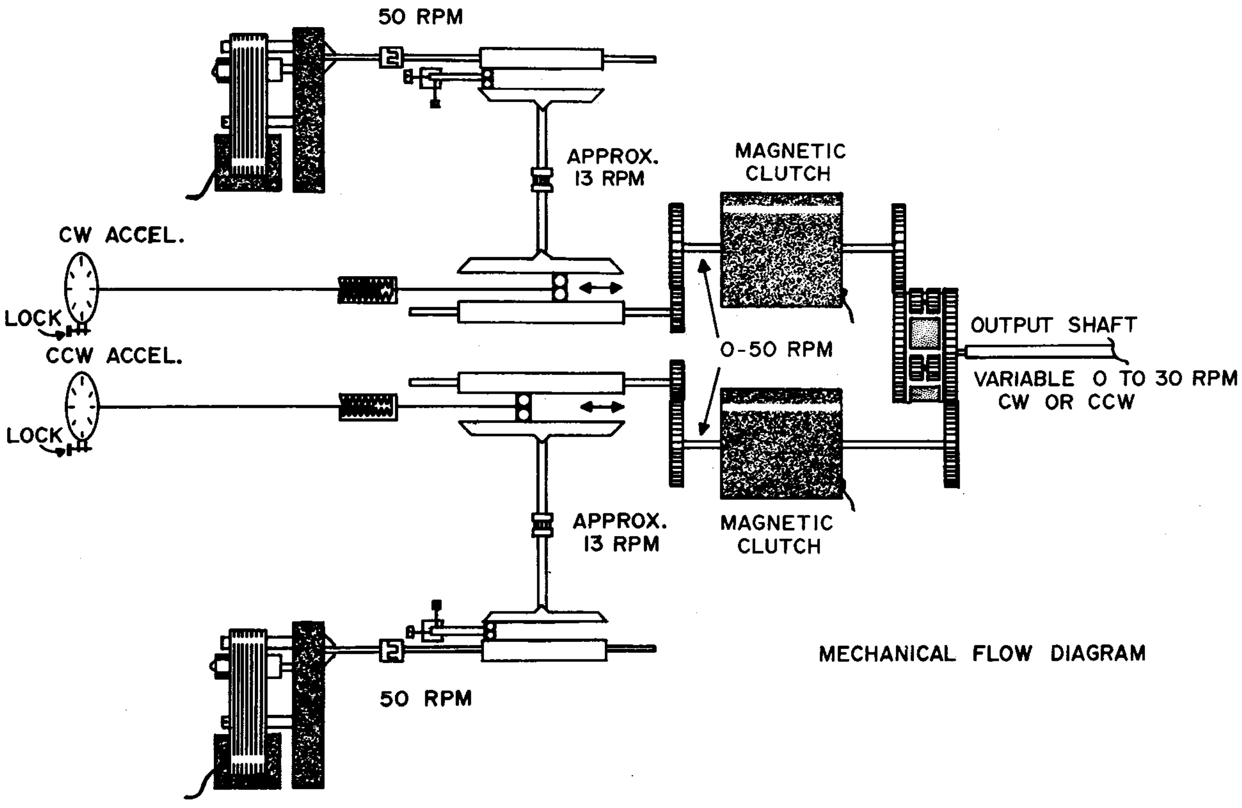


FIGURE 3. Mechanical flow diagram.

at constant rates (approximately 13 rpm) as determined by the disc speed of the small integrators.

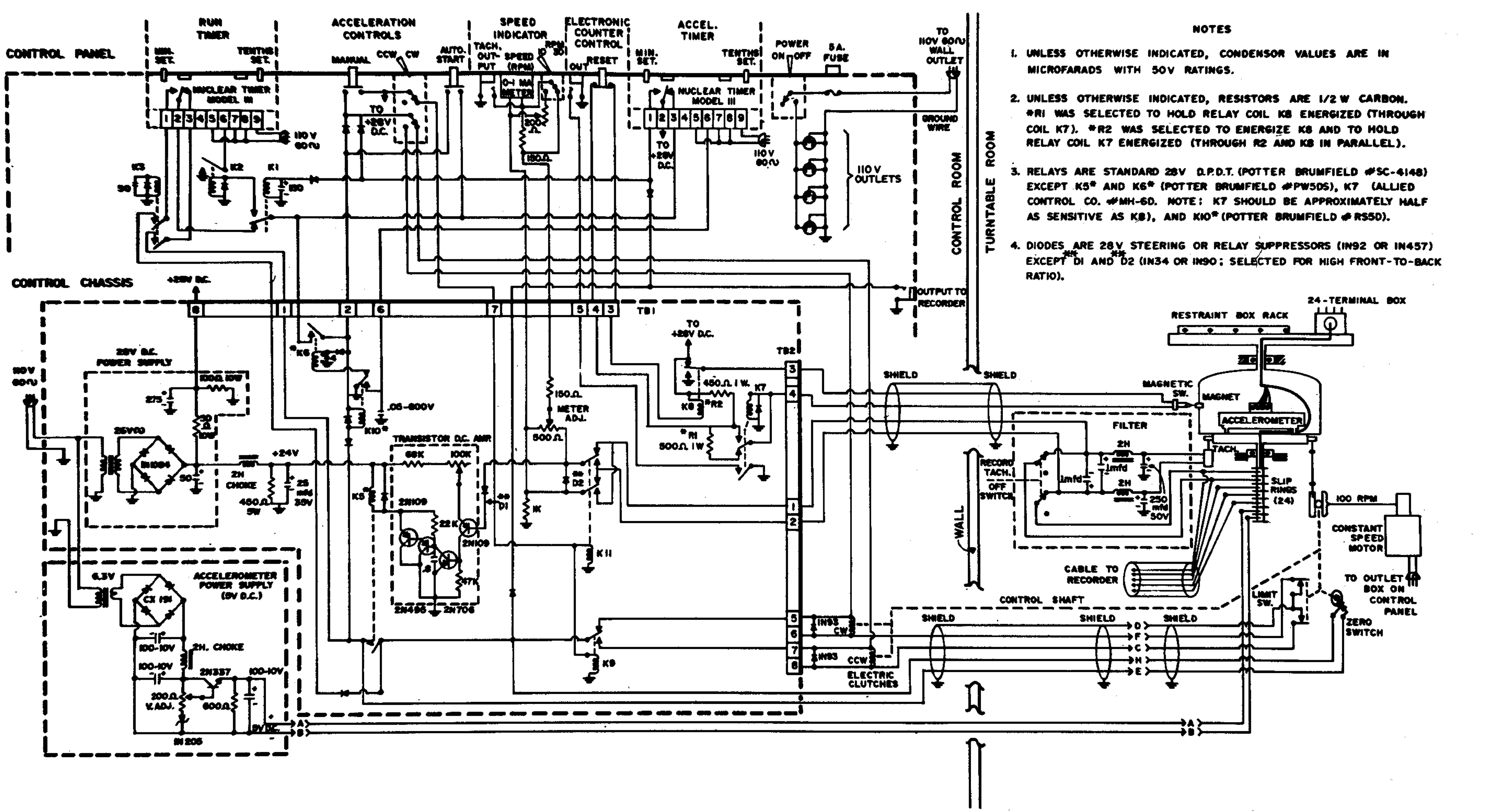
A shaft couples each of the two large integrator ball carriages to its respective acceleration dial on the control panel (see Figure 3). Changes in the dials, then, vary the position of the ball carrriages and, thereby, the output speed of the integrators. This output is coupled, through gears, to a magnetic clutch (one for each integrator) which is energized and controlled by a Libel-Flarsheim Nuclear Timer (Model III). When de-energized, the output shafts of the clutches are held against a brake (although the input shafts continue to turn). The clutch outputs (from both the CW and CCW drives) are coupled through a single planetary gear differential to the turntable drive shaft. A schematic diagram of the circuitry involved in control of the turntable appears in Figure 4.

Control Panel

The control panel is depicted in Figure 5. At the extreme left of the figure are located the acceleration timer and the toggle switch, which in the "on" position starts the two shaded pole motors of the control unit, the two timer motors, and the drive motor in the turntable room. The acceleration timer controls the duration of the acceleration only. The deceleration time is determined directly by the rate of deceleration.

At the extreme right of the figure, the automatic start button and the run timer are evident. The latter determines the period of constant velocity before deceleration begins. The start button initiates a complete cycle of activity, i.e. from acceleration through constant velocity through deceleration to the stop position.

A milliameter, connected to the output of the tachgenerator, is located in the center of the control unit and is calibrated to provide the



NOTES

1. UNLESS OTHERWISE INDICATED, CONDENSOR VALUES ARE IN MICROFARADS WITH 50V RATINGS.
2. UNLESS OTHERWISE INDICATED, RESISTORS ARE 1/2 W CARBON. *R1 WAS SELECTED TO HOLD RELAY COIL K8 ENERGIZED (THROUGH COIL K7). *R2 WAS SELECTED TO ENERGIZE K8 AND TO HOLD RELAY COIL K7 ENERGIZED (THROUGH R2 AND K8 IN PARALLEL).
3. RELAYS ARE STANDARD 28V D.P.D.T. (POTTER BRUMFIELD #SC-4148) EXCEPT K5* AND K6* (POTTER BRUMFIELD #PW5DS), K7 (ALLIED CONTROL CO. #MH-6D. NOTE: K7 SHOULD BE APPROXIMATELY HALF AS SENSITIVE AS K8), AND K10* (POTTER BRUMFIELD #RS5D).
4. DIODES ARE 28V STEERING OR RELAY SUPPRESSORS (IN92 OR IN457) EXCEPT** D1 AND** D2 (IN34 OR IN90; SELECTED FOR HIGH FRONT-TO-BACK RATIO).

FIGURE 4. A completely detailed schematic of the circuitry employed in the control system of the turntable.

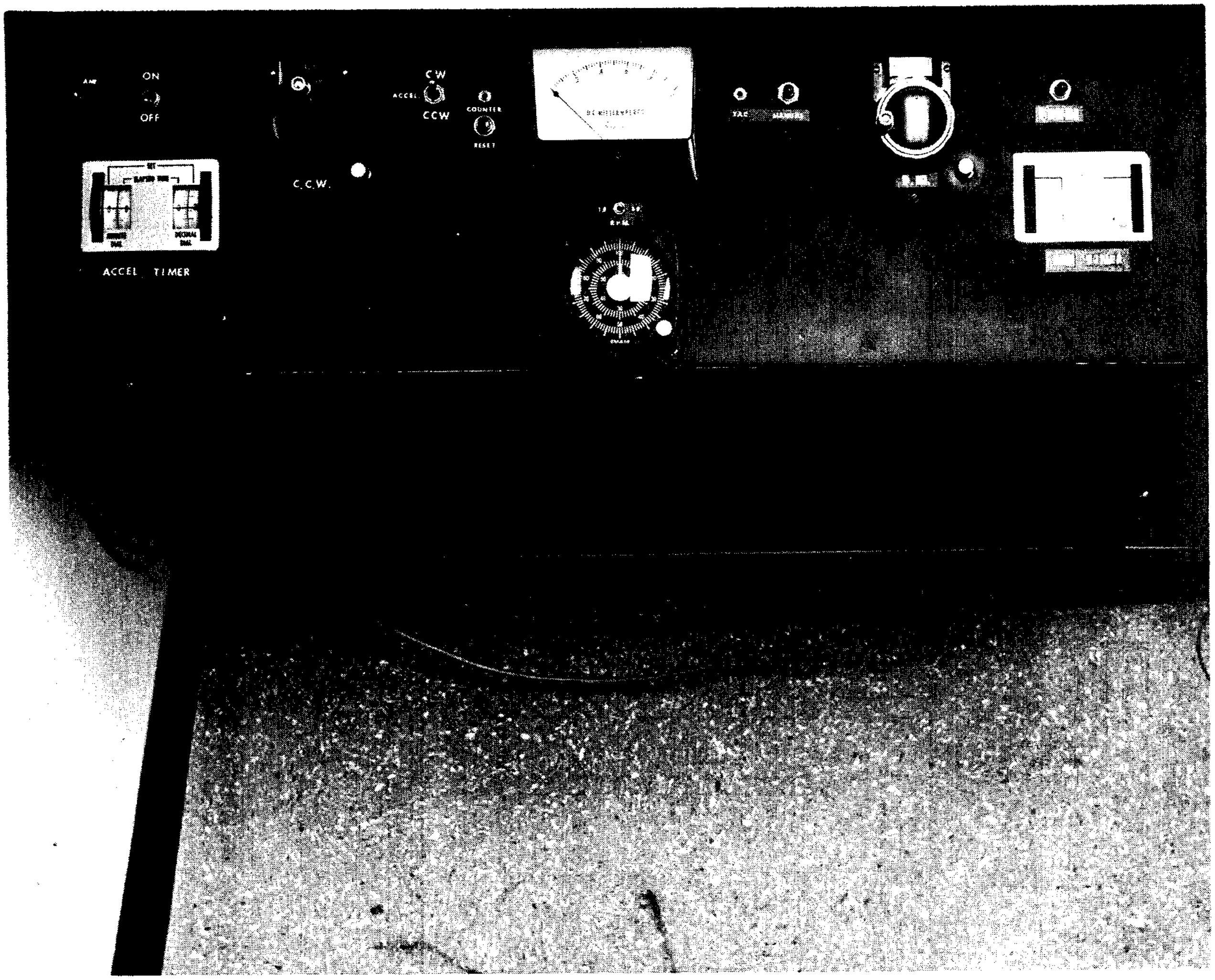


FIGURE 5. View of control panel.

operator with a constant indication of the rotatory velocity of the turntable. A small toggle switch beneath the meter permits conversion from a full-scale deflection equal to 10 rpm to a full-scale deflection equal to 30 rpm. A Cramer stop-clock[8] is mounted below the toggle switch and permits a ready means of monitoring the terminal velocity reached by the turntable. The clock reads in hundredths-of-a-second and is started and stopped by a magnetic switch on the turntable.

Multi-turn counter dials[9] are positioned on each side of the ammeter, one for setting CW, and the other for CCW, acceleration rates. Lock screws below the panel dials secure the dials to their adjusted positions. Between the CCW dial and the ammeter are located a toggle switch for determining direction of acceleration and a jack for plugging in an electronic counter. A "reset" button for the counter is set just below the jack. With the acceleration toggle switch in the CW position, a CW acceleration is initiated by depressing the "start" button. The rate of acceleration is determined by the position of the CW acceleration dial, and its duration by the setting on the acceleration timer (activated by closing of the zero switch on the turntable). A period of constant velocity (or none, if so desired) follows and is of a duration determined by settings on the run timer. The latter then, by means of relays, actuates the deceleration. The rate of deceleration, in this case, is determined by the CCW dial settings and its duration by the time required to bring the turntable to a complete stop.

Between the ammeter and the CW dial are located a manual button and an auxiliary jack for tachometer recordings when desired. The

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[8] Model no. 691 H - 60S.

[9] E. F. Johnson part no. 116-208-X.

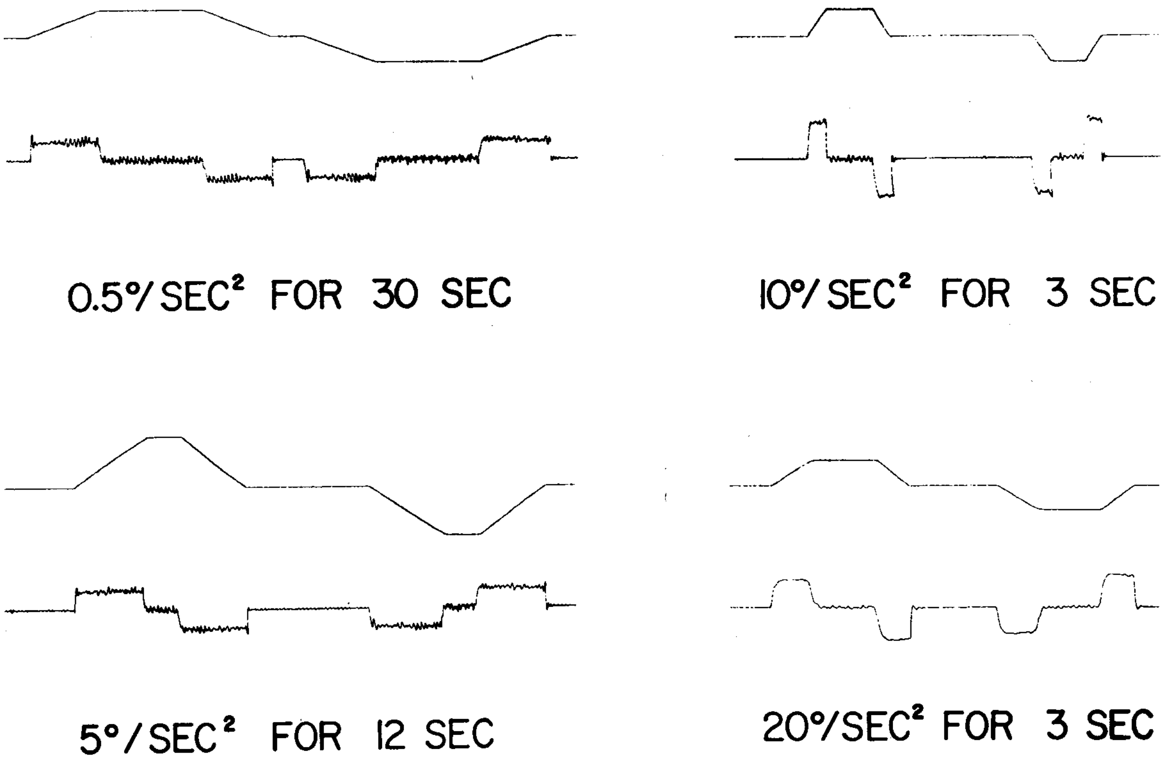

FIGURE 6. Tach-generator (upper tracing of each set) and accelerometer (lower tracing of each set) recordings for 4 rates of angular acceleration.

manual button allows the operator to have complete control over the accel-decel cycle but also requires changes on the acceleration toggle switch when it is desired to decelerate the turntable. The rates of acceleration and deceleration are still determined by settings of the CW and the CCW dials.

Calibration

Three types of data were obtained relevant to the performance characteristics of the turntable: (a) accelerometer recordings, (b) tachgenerator recordings, and (c) measurements made by an electronic counter of the time required for a complete revolution of the turntable following a given acceleration.

The tachgenerator recordings indicate linearity of acceleration and deceleration responses in both the CW and CCW directions (see Figure 6). Recordings from the accelerometer indicate that little variation in the acceleration rate and in the rate of turning at terminal velocity occurred. The maximum noise range recorded from the accelerometer during motion of the turntable (including vibration) was less than 1.5°/sec^2 at any given instant. These statements hold for all acceleration rates up through 25°/sec^2 and for all terminal velocities less than 25 rpm.

Other data were obtained with a Hewlett-Packard Electronic Counter (Model 5215). Under these conditions, the acceleration counter dial was set at a given value (e.g., at 5 to give a nominal acceleration rate of 5°/sec^2). Acceleration time was then varied and the number of seconds required for a complete revolution of the turntable was obtained from the electronic counter during the period of constant velocity following the acceleration. Three readings for each acceleration rate-duration combination were averaged for the data points

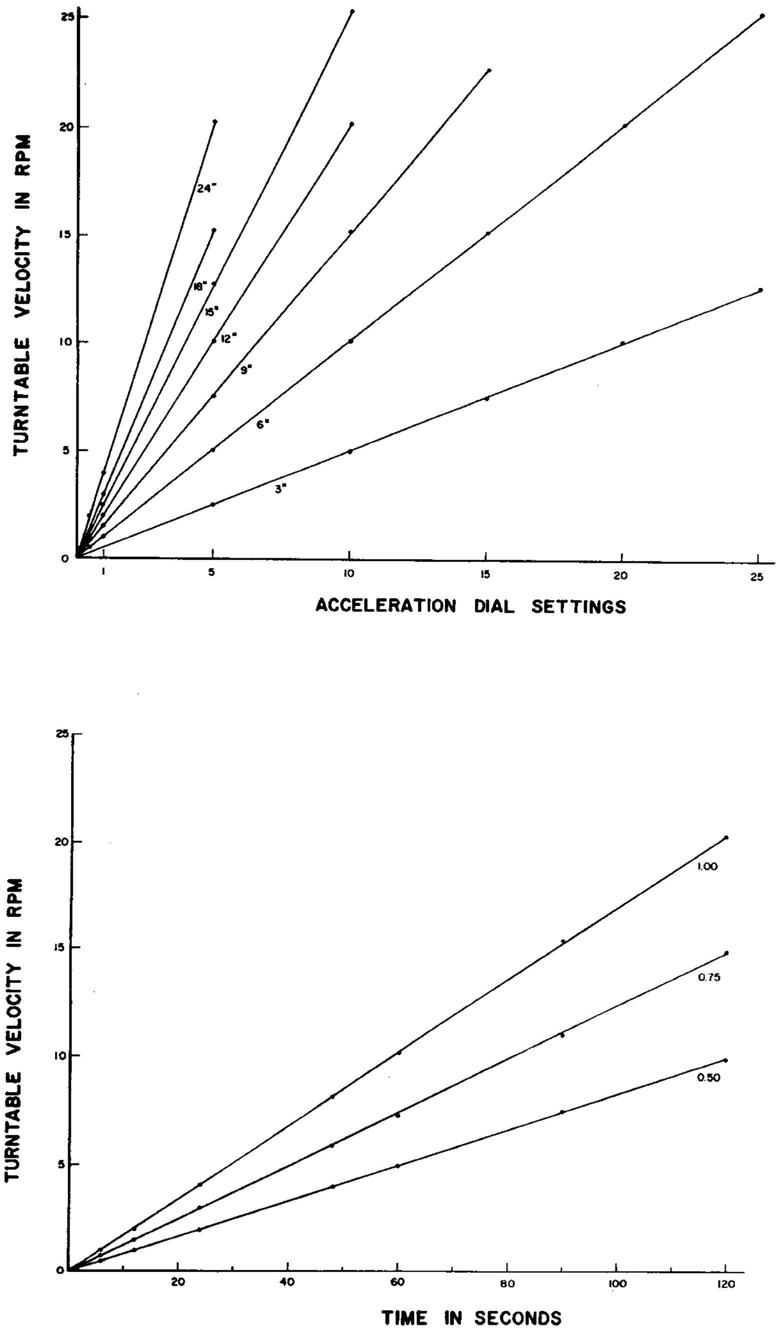

FIGURE 7. Performance data from the turntable. Each point is based on a mean of 3 readings. Upper graph: time of stimulus (3″-24″) was held constant for each rate of angular acceleration tested. Thus, after every 3 readings, the acceleration dial setting was changed. Lower graph: table performance at low (0.50, 0.75, and 1.00°/sec^2) rates of angular acceleration.

in Figure 7. These data indicate that: (a) up to 25 rpm there is a linear relationship between turntable velocity and settings of the acceleration dial. Above this level, velocity tends to fall below expected values. (b) the dial settings are very closely calibrated to acceleration rates. That is, for both CW and CCW directions, the rate of acceleration is almost exactly that indicated by the numbers on the corresponding counter dial setting. Differences are less than 0.1°/sec^2.

TABLE 1

Maximum variability in angular acceleration rates as a result of re-setting acceleration dials. Several durations of the acceleration stimulus were examined for each rate. Each rate-duration test consisted of 10 independent settings of the acceleration dials.

Acceleration Rate (°/sec^2)	No. of rate-durations tested	Maximum Variability (± °/sec^2)	% ± Maximum Variability is of rate
0.25	10	.02	8.0
0.50	10	.01	1.0
1.00	10	.01	1.0
5.00	9	.05	1.0
10.00	4	.07	0.7
15.00	2	.11	0.7
20.00	2	.13	0.7
25.00	2	.60	2.4

Data were also obtained to provide an indication of the reliability of accelerations with re-settings of the counter dial. Two to 10 durations for each of 8 rates of acceleration were examined. For each rate-duration combination, 10 re-settings were made and readings were obtained from the counter at terminal velocity. These values were translated into rates of angular acceleration and the maximum range (°/sec^2) for each rate appears in Table 1. At 0.25°/sec^2, maximum variability is only ± 0.02°/sec^2. From 0.50°/sec^2 through 20°/sec^2 variability ranges from ± 0.01 to ± 0.13°/sec^2, but does not exceed ± 1.0% of the rate of acceleration. Above 20°/sec^2 variability increases markedly and reaches levels which preclude the use of those higher acceleration rates if precise control of the stimulus is required from trial-to-trial. For all rates of acceleration, stimulus durations of 3 sec or less resulted in somewhat wider divergences than those depicted in Table 1.

CONCLUSION

A mechanical-drive angular accelaration device was designed and constructed for use as a vestibular stimulator. Calibration data obtained with a tachgenerator, an angular accelerometer, and an electronic counter indicate that: (a) accelerations at all rates below 25°/sec^2 and to all terminal velocities less than 25 rpm are linear; (b) maximum trial-to-trial variability between 0.25°/sec^2 and 20°/sec^2 does not exceed ± 0.02°/sec^2 or ± 1.0% of the acceleration rate, whichever is larger. Thus, the stimulator may be used for a large number of vestibular experiments where rates of acceleration and terminal velocities are not required to exceed 20°/sec^2 and 25 rpm, respectively.