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A TORQUE MOTOR SERVOROTATOR FOR VESTIBULAR APPLICATION

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SUMMARY PAGE

THE PROBLEM

Earlier investigations of the dynamic response characteristics of the oculovestibular system have involved the measurement of the magnitude and phase of ocular *nystagmus* elicited by sinusoidal angular acceleration stimuli of variable magnitude and frequency. Initially it was hoped to describe the system behavior in terms of the undamped characteristic angular frequency and damping parameters of servomechanism design practice. Due to equipment limitations in generating the required sinusoidal stimuli, the investigations were limited to frequencies not exceeding 0.2 cps, although the data indicated that the natural frequency would lie considerably above this limit for many normal human subjects.

FINDINGS

A novel servorotator, the Periodic Angular Rotator (PAR), has been developed for vestibular studies. A low speed, direct-coupled, DC torque motor is operated as a velocity or displacement mode power servomechanism to achieve a drive system with low acoustic noise and mechanical vibration properties, fast dynamic response characteristics, and a high degree of coupling stiffness. The device has a maximum angular velocity of 100 rpm, a maximum angular acceleration of 100 deg/sec^2, and can be programmed to produce sinusoidal angular acceleration stimuli extending to beyond 2.0 cps, an upper limit which is an order of magnitude greater than that previously available.

INTRODUCTION

As part of the over-all research program in vestibular function being carried out at the Naval Aerospace Medical Institute under joint USN-NASA sponsorship, a series of studies of the dynamic response of the oculovestibular system to angular motion has been carried out (4-7). The Human Disorientation Device (3) has been used to generate periodic angular acceleration stimuli of sinusoidal form to the subject and his resulting ocular nystagmus recorded. From measurements of the phase shift of the response, it was theoretically possible to derive values for the undamped characteristic angular frequency of the transducer, the horizontal semicircular canal, being stimulated. It soon became apparent that the natural frequency would be considerably higher than 0.2 cps in a large number of normal subjects. Unfortunately, the available rotator, because of certain inherent mechanical limitations such as gear backlash and a relatively large moment of inertia, restricted the upper limit of stimulus frequencies to about 0.2 cps. Further progress in quantifying the natural frequency required that the stimulus range be extended by at least an order of magnitude. The primary factor in the establishment of the various design criteria for a new vestibular rotator, named the Periodic Angular Rotator (PAR), was this need to extend the stimulus range for investigations of transient and steady-state responses to sinusoidal angular accelerations of variable magnitude and frequency.

A second application of PAR requiring a fast drive system involves the use of biological signal sources as original command for direct control of motion-producing machines where the over-all system can be operated in either open or closed-loop configurations. Of particular concern is the performance of the oculovestibular system when a subject is exposed to a situation in which motion serves as an external feedback element in the real sense. As an example, the instantaneous displacement of the eyes in the horizontal direction from a dead-ahead-position reference can be measured with corneo-retinal potential techniques and the resulting signals amplified and directed to the command-signal-position input of PAR to control the instantaneous angular displacement of the device. When a subject seated within the device moves his eyes relative to his head over a known angle, the device will rotate the subject over the given angle in the same or opposite direction, depending on the relative polarity selected for the feedback operation. The resulting angular displacement of the head and the attendant stimulation of the oculovestibular system produce eye motions, usually of nystagmic form, that tend to amplify or attenuate the original self-initiated eye motion of the subject. Of specific interest are the form and time course of the response of the over-all system over a wide range of stimulus conditions for both labyrinthine-normal and labyrinthine-defective subjects.

It is quite apparent that the production of such stimuli requires a drive system which has negligible slippage or backlash, can deliver considerable controlled power as the device reverses direction of rotation through 0 rpm, and has fast dynamic response characteristics. For most drive sources which have a relatively high upper speed rating, problems usually arise in the coupling media commonly selected to interconnect the chair payload and the drive motor: typically, slippage in friction or belt drive systems; loose coupling or the lack of stiffness with belt or chain-drive systems when reversing direction of rotation, and backlash with gear-coupled systems.

These considerations led to the authors' decision to key the development of the rotator to a torque motor, a form of drive motor which has found widespread application in stable-platform and rate-table equipment, but had not been used in vestibular test devices. The primary advantages of this form of motor include a low rpm rating, permitting the motor shaft to be directly coupled to the rotating payload; a linear relationship between armature current input and torque output; fast response characteristics; and the ability to deliver its rated output torque at any shaft speed including 0 rpm. This last factor is of special importance in the generation of sinusoidal angular acceleration stimuli about a zero-velocity reference since maximal acceleration, and hence power, are required as the device goes through 0 rpm. A secondary advantage from the vestibular viewpoint is the reduction in acoustic noise and vibration levels achieved through elimination of gearing. In implementing this concept, the actual design, development, and construction of the rotator to be described was carried out at the Engineering Experiment Station of the Georgia Institute of Technology under the direction of Mr. Winston Boteler (1). The same concept was applied in the concurrent development of a rotary drive system for the Coriolis Acceleration Platform (2), a combined linear and angular motion research device recently installed at this activity by the KPT Manufacturing Company.

GENERAL DESCRIPTION

The primary structural elements of PAR include a rotatable chair for the subject, a removable lightweight canopy attached to and enclosing the chair, and a pedestal which supports the chair-canopy combination and houses the rotating components of the drive system. Front, side, and rear view photographs of the chair and pedestal with the canopy removed to show interior details are presented in Figure 1. The subject's chair is equipped with a combination head-clamp and bite-bar assembly which is adjustable vertically to allow for variation in the seated heights of subjects and horizontally to permit the center of the head to be prepositioned on the axis of rotation. The primary head-clamping apparatus (not illustrated) is a set of neoprene bladder assemblies, filled with granulated plastic particles, which are formed to the contours of the head and then evacuated to obtain rigid constraint. The chair is also provided with adjustable foot and arm rests, two pistol-grip response switches, a data patch panel and related input/output connectors to terminate the slip-ring circuitry and the various on-board data acquisition instruments that may be used in a specific experiment, and a distribution panel for 115 VAC, 60-cps power service. As illustrated in the photograph at the left in Figure 2, quick-release nylon straps are provided for chest, lower torso, thigh, and foot restraint of the subject; straps, not shown, are also provided for restraint of his arms.

A photograph of the complete installation is shown at the right in Figure 2. The canopy, approximately 6 feet in diameter and 6 feet in height, is attached to the base of the chair assembly and thus rotates with the subject. To reduce the moment of inertia of the canopy, lightweight aluminum channel construction is used throughout. The raised-figure deck plate partially visible below the floor in Figure 2 is a nonrotating structure installed to give working access to the interior of the device without having to step on the lightweight floor of the canopy proper. To provide the shell with a high degree of mechanical rigidity, the wall and ceiling panels were formed from a polyester-impregnated glass fiber material. All interior surfaces were finished with a flat black paint to minimize light-reflection problems when performing tests involving the presentation of low intensity, illuminated targets within the darkened compartment. Front and rear access is provided by two lightproof hinged doors that are electrically interlocked to prevent rotation of the device when they are not properly secured. Two incandescent lamp fixtures are installed in the ceiling of the capsule for general illumination. Two exhaust fans driven by brushless motors mounted within two lightproof ducts in the canopy floor and an inlet duct in the ceiling provide positive ventilation. To lessen the potential for 60 cps power-line interference during the recording of low-level electrophysiological data, the illumination lamps and ventilation fans are energized from a 24 VDC power source.

The pedestal structure is comprised of two cylindrical cast housings: the upper section containing the main rotary drive motor and an angular velocity feedback tachometer, the lower section containing two 18-circuit slip-ring assemblies and an infinite resolution rotary potentiometer used to supply angular displacement feedback information to the system. A tubular drive shaft, approximately 3 1/2 inches in diameter, is positioned vertically in the center of the pedestal and is supported by tapered roller bearings installed at the top and bottom of the upper section. The drive shaft passes directly through the center of the toroidal armatures of the drive motor and tachometer, as well as through the center of the two slip-ring assemblies. The bottom of the shaft terminates in a precision coupling which is connected in-line to the shaft of the displacement feedback potentiometer. The upper end of the shaft terminates in a welded plate bolted to a flanged steel tube, approximately 12 inches in diameter and 6 inches deep, which, in turn, is bolted to the understructure of the subject's chair. Three equally spaced wing brackets bolted to the base of the pedestal fasten the device to the floor. All external wiring is routed through covered cable trenches (see Figure 1).

DRIVE SYSTEM

The main drive motor is a DC torque motor (Inland Motor Company Model T-10035A) with permanent-magnet field excitation, has a maximum speed of 114 rpm, and is rated to deliver an output shaft torque of 100 lb-ft with an armature input current of 20 amperes. Other pertinent manufacturer's specifications include electrical and mechanical time constants of 6×10^{-3} sec and 14×10^{-3} sec, respectively; a power input requirement of approximately 1000 watts when delivering peak-rated torque under stall conditions; a friction torque of 1.0 lb-ft; and an average ripple torque of 4 lb-ft

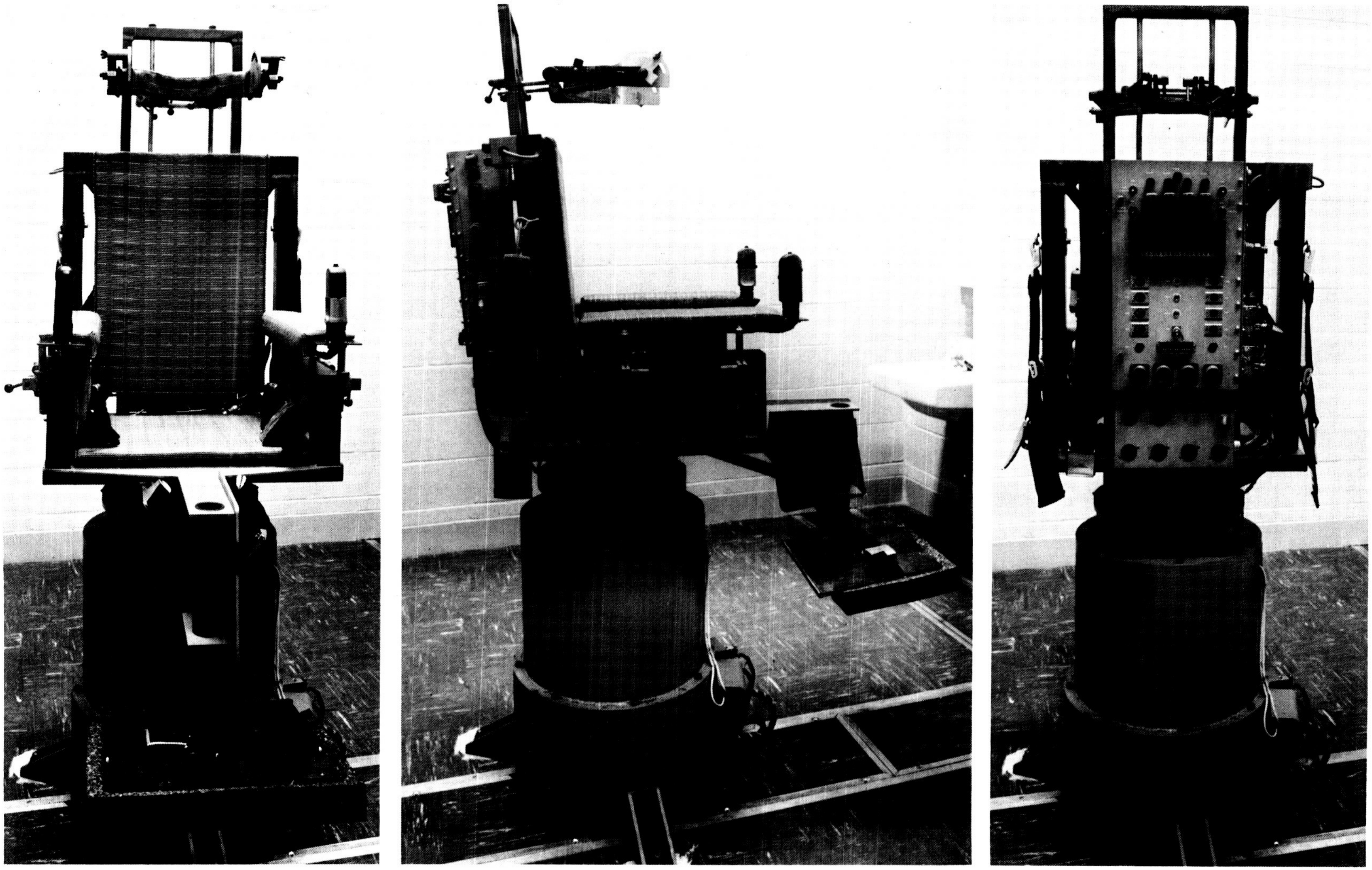

Figure 1

Front, side, and rear view photographs of the PAR subject chair and pedestal assembly.

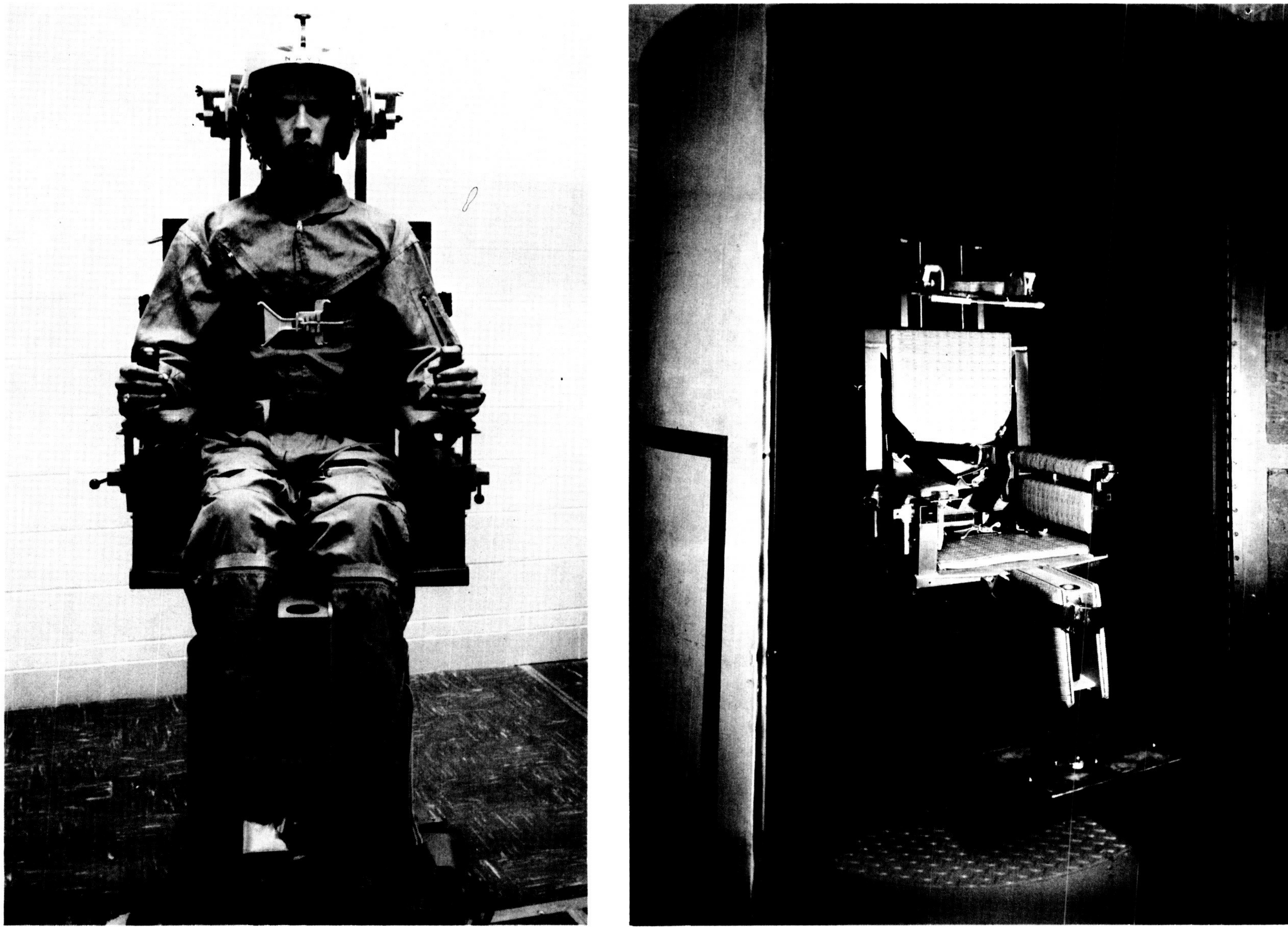

Figure 2

View of the PAR device with a subject (left) and with the removable canopy in place (right).

with a frequency of 190 cycles per single revolution. The motor weighs 110 pounds and is approximately 13 1/2 inches in diameter and 5 1/2 inches long. The velocity tachometer is also a DC torque-type unit (Inland Motor Company Model TG-10017B) rated to deliver approximately 20 volts/rad/sec. Of particular advantage to this project was the fact that both the drive motor and the tachometer could be obtained from the manufacturer without shafts or bearings. With this feature, the armatures could be keyed directly to the drive shaft, thus resulting in a drive system in which all rotating parts are tightly interconnected to form a single rigid rotor assembly with a high degree of coupling stiffness.

Armature current to the drive motor is supplied by a 1000 watt rotary amplifier (Inland Motor Company Model 3315A) with a center-tapped field winding. It in turn is driven by a 100 watt, solid-state control amplifier (Inland Motor Company Model 625). Input to this control amplifier is derived from a chain of chopper-stabilized DC operational amplifiers which serve to amplify the error signal, shape the system frequency response for optimal stability and speed characteristics, and perform certain ancillary control and monitor functions. When the system is operated in the velocity mode, the instantaneous angular velocity of PAR is proportional to the instantaneous magnitude and polarity of a DC command signal which is scaled so that ±1 volt equals ±2 rpm. In this mode, PAR is rated to produce a maximum angular velocity of 100 rpm at angular accelerations extending to 100 deg/sec^2. With the canopy removed to reduce the moment of inertia, the upper frequency limit for sinusoidal oscillation is well above 2.0 cps. In the displacement mode the instantaneous angular position is also proportional to a DC command signal with a ±1 volt input producing a ±3 degree displacement where the maximum deviation is ±150 degrees from a center reference.

A close-up view of the master control panel used in the setup and operation of PAR is shown in Figure 3. In general, the design concept for the panel follows that developed for the Human Disorientation Device (3). All basic control functions involved in the operation of the device and all control operations required to implement the related experimental program are centralized at a single operating station. The control elements used in the construction of the panel are illuminated, push-button, indicator-switch assemblies which serve a display as well as a switching function. The group of four switches located at the upper left of the panel is used to control application of power to the drive system and its related equipment. In the corresponding row at the right, an alternate-action switch allows the operator to select the velocity or position mode of operation; the remaining three switches are used to select one of three different signal sources as the basic PAR command signal. These sources include a manually operated, multiturn, wire-wound potentiometer with a calibrated dial scale (seen at top center in Figure 3); a low-frequency function generator (Servomex Model LF-51) which produces ramp, triangular, square,and sinusoidal waveforms with manual control of frequency and amplitude; and an auxiliary source input which might be, typically, a magnetic tape instrumentation recorder or analog computer.

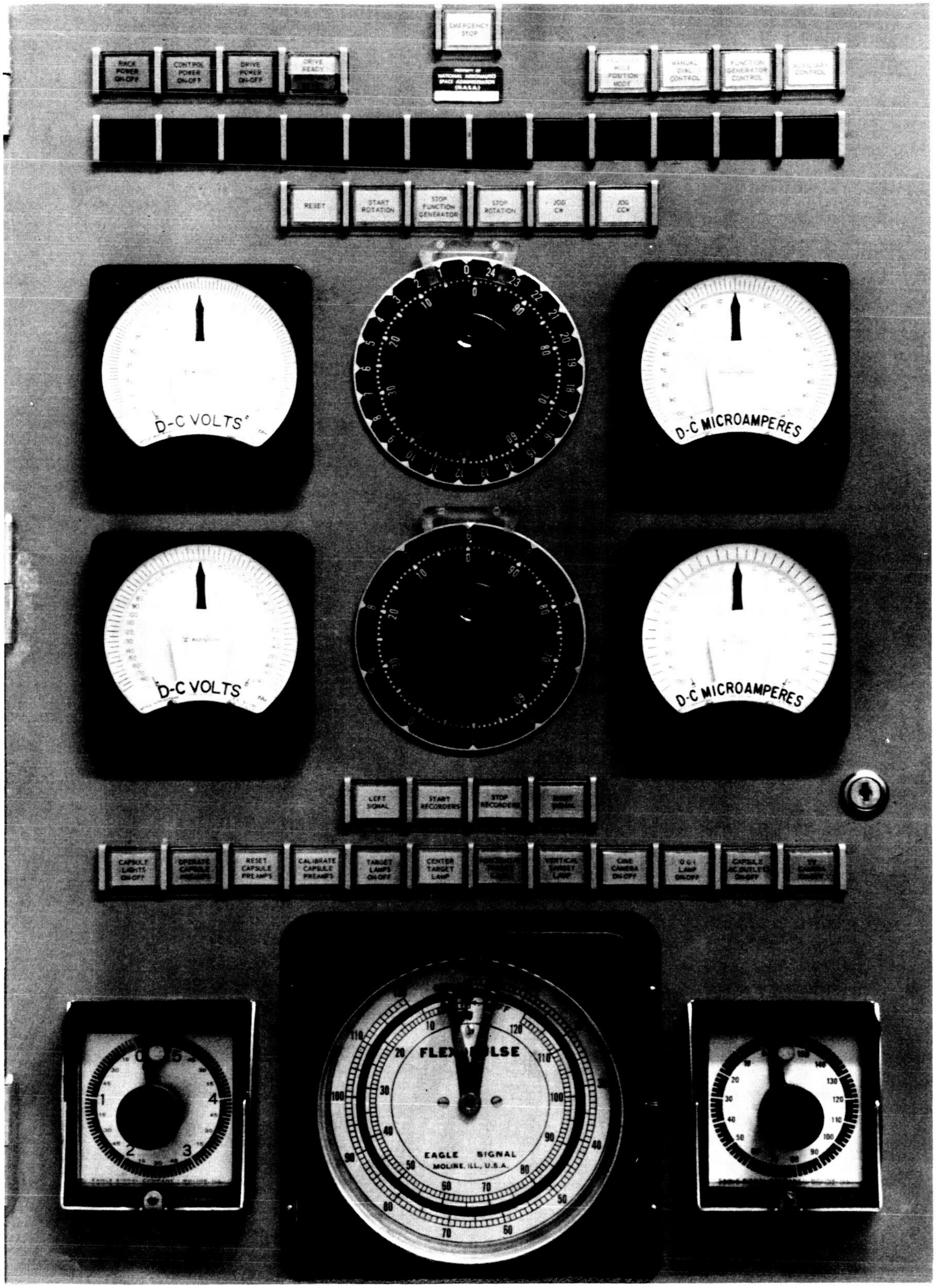

Figure 3

Close–up view of the PAR Master Control Panel.

All operations involved in actually placing the device in motion are centered in the row of six switches located immediately above the various monitor meters and control potentiometers. The magnitude and polarity of the selected command signal are monitored by the meter at the top left. When the device is in the velocity mode, the meter at the top right indicates the magnitude and direction of the capsule velocity. When in the position mode, the meter at the lower left serves a similar monitor function for the actual angular displacement of the device. The meter at the lower right is used to display the output of a force-balance angular accelerometer installed at the center of the flanged cylinder joining the base of the chair and the pedestal drive shaft. The multiturn potentiometer seen at the bottom center of the panel is used by the operator to preselect a given upper velocity which, if exceeded, will automatically stop the device. The device can be dynamically braked to a quick stop under emergency conditions by depressing the uppermost switch on the panel.

The continuous row of indicator-lamp assemblies extending across the panel at the top are chiefly elements to monitor operational status; they are illuminated only when a malfunction occurs in the system. Representative malfunctions for which visual identification is provided are overspeed, error limit, and open canopy-hatch interlocks.

The two rows of switches seen toward the bottom of the panel are used primarily for experiment-related control functions. The outer switches in the upper row can be used to signal the subject visually by lamps located within the canopy or tactually by vibrators built into each of the subject's pistol-grip controllers. Conversely, the lamps in these two indicator-switch assemblies are illuminated when the subject depresses related push buttons installed within the pistol grip. The two central switches are used by the operator to start and stop recording equipment. The bottom row contains switches for automatic calibration of on-board preamplifiers, sequential illumination of visual target lamps used to calibrate eye movements, operation of the three timers seen at the bottom of the control panel, and activation of the on-board AC power services and miscellaneous devices such as a closed-circuit television camera, oculogyral illusion lamps, canopy lights, and a ventilating fan.

INSTRUMENTATION

The control and instrumentation equipment for PAR is housed in three relay racks with forced-air ventilation which are installed in the experimental room adjacent to the device. These racks and an eight-channel, direct-writing recorder are shown in Figure 4. The master control panel and the related operational amplifier and relay logic circuitry are installed in the rack at the left. The center rack contains an audio loudspeaker, a low-frequency function generator used as the primary command signal source, and miscellaneous regulated DC-voltage power supplies used to energize the various control amplifiers and drive equipment. A monitor oscilloscope, a shielded-cell patch panel, a digital clock and time-interval meter chassis, and audio amplifiers for two-way voice communications are installed in the rack at the right.

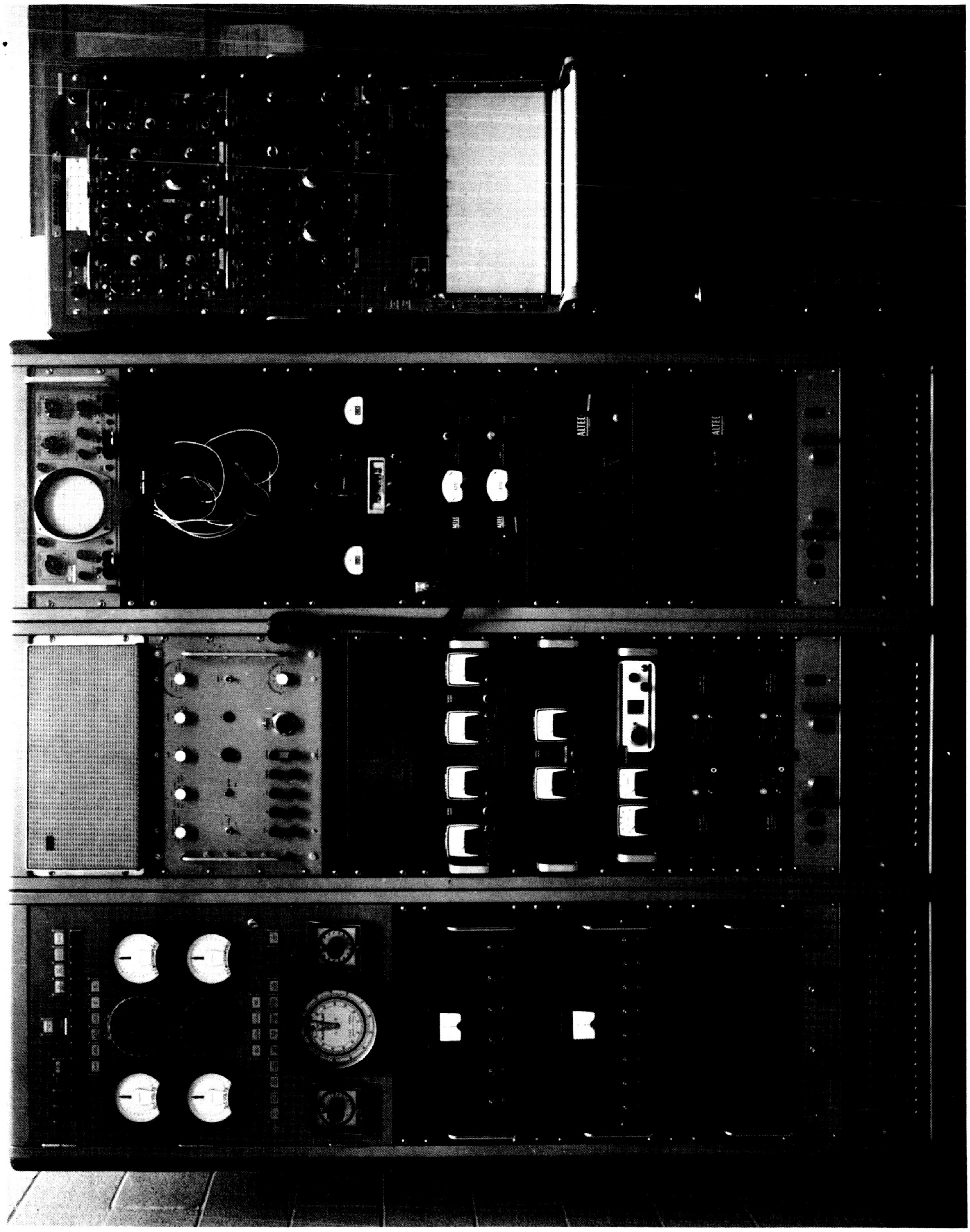

Figure 4

Photograph of the PAR control and instrumentation equipment.

Routing of electrical power and signals between the central control and instrumentation racks and the chair is provided by two 18-circuit slip-ring assemblies and RG-174/U coaxial cable connections. The cables from the rotating slip rings are terminated at a patch-panel station attached to the rear of the subject chair. This station, a close-up view of which is shown in Figure 5, contains a small, shielded-cell patch panel and various relays, control switches, and input/output receptacles for operation of, or access to, remotely located experimental equipment. In general, the functional layout of the panel follows that of the Capsule Patch-Panel Station developed for the Human Disorientation Device (3). In fact, provision has been made for the direct interchange of various experimental equipment,such as nystagmus preamplifiers, helmet communication components, and response switches, between the two devices without the need for additional connector interfaces.

A listing of the various circuits terminated at the subject's station is provided by the front-panel layout drawing of the chair patch panel shown in Figure 6. The panel proper is a 7x17 matrix of 119 individually shielded, nylon-insulated circuit cells with contact springs that are prewired from the rear with 0.053-inch taper pins. The cells are color coded according to circuit function, identified in alpha-numeric code, and interconnectible from the front by means of coaxial cable patch cords. The contacting surfaces of the springs, taper pins, and patch cords are gold-plated for minimum contact resistance. As may be seen in this figure, seventeen circuits of the top slip-ring assembly are made available at the B1-B17 row of cells. The eighteenth slip-ring circuit is used to carry the commoned shields of the interconnecting coaxial cables to a high-quality Earth-ground installation. The bottom set of slip rings is similarly terminated in the F1-F17 row.

Other circuits and equipment terminated at this panel include the output of a two-channel nystagmus preamplifier, the output of the angular accelerometer mounted beneath the chair, the response switches and the vibrators for audiotactile communications installed in the pistol grips, the output of a hand-operated controller that can be used by the subject to control the motions of PAR, the video output of a closed-circuit television camera, and the input to an oculogyral illusion test lamp. Also included are four DPDT relays for general-purpose access to the patch panel, and the circuitry associated with an eye-movement calibration system utilizing the cyclic presentation of visual targets of known angular displacement in relation to the subject.

The cables which terminate the nonrotating brush structures of the two slip-ring assemblies are terminated at a central data patch panel located in the instrumentation racks. This patch panel, a layout drawing of which is presented in Figure 7, has 391 individually shielded cells arranged in a 17x23 matrix. A solid circle on any line dividing two adjacent cells in this figure denotes that the cells are electrically interconnected at the rear of the panel by means of soldered cable jumpers. Two access cells are provided for each slip-ring circuit; i.e., the top slip rings are available in the N1-N17 row as well as in the M1-M17 row, while the bottom rings are available in the T1-T17 and U1-U17 rows.

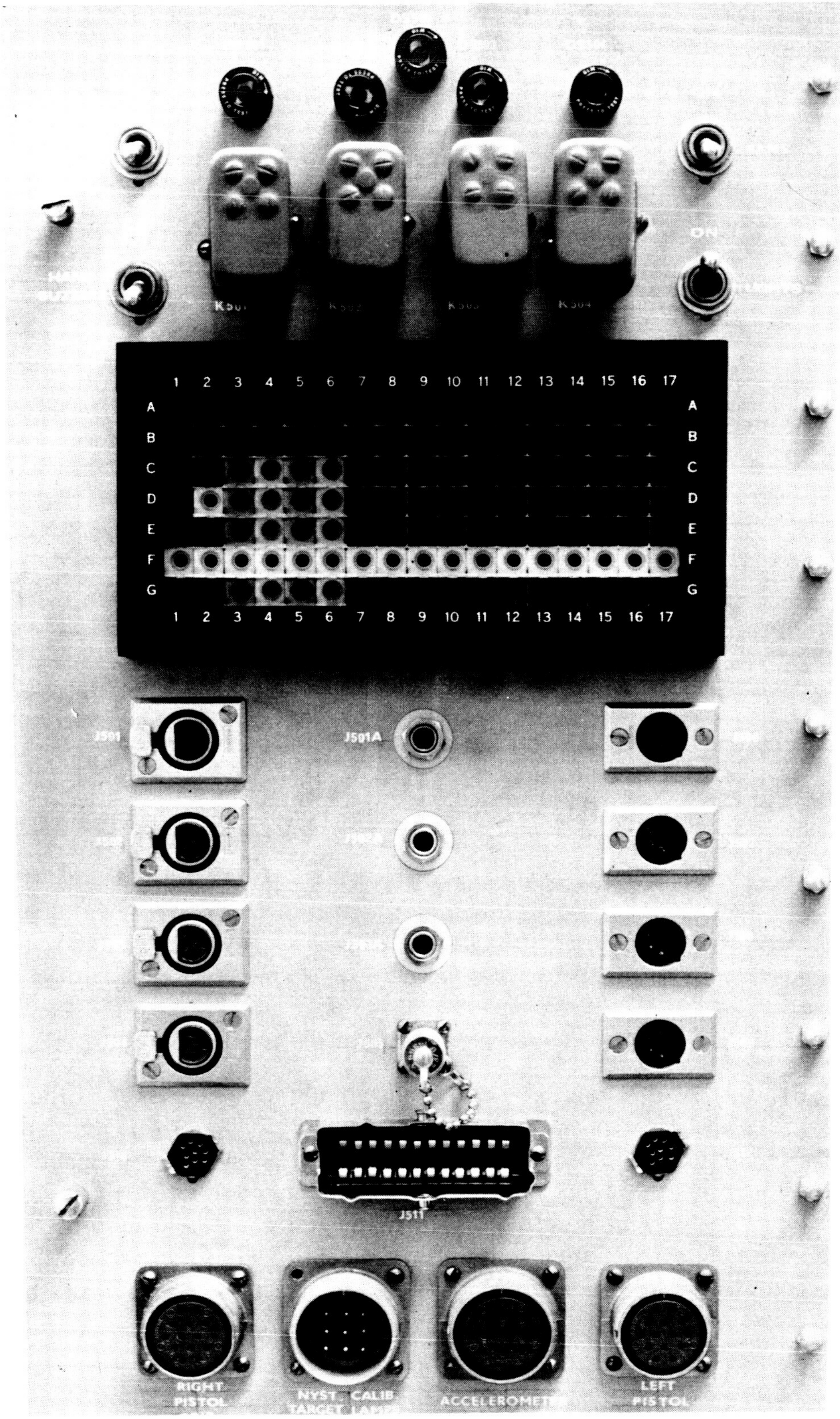

Figure 5

Close-up view of the PAR data patch-panel station attached to the rear of the chair.

The cells bounded by 01, 017, S1, and S17 are used chiefly to terminate the audio equipment used in the two-way voice communications system. Direct access to the differential-input preamplifiers of the eight-channel recorder is provided in the I1-I8, J1-J8, and K1-K8 rows; the single-ended output of these preamplifiers is made available in the H1-H8 row. Access to the record and reproduce amplifiers of a seven-channel magnetic-tape instrumentation recorder that may be connected by means of a rear-panel receptacle to the system is provided in the cells bounded by E1, E7, G1, and G7. Access to the command-signal input of the drive system and the output of various command signal sources is provided in the cell group bounded by D9, D17, G9, and G17.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
A	NYST. COM	PREAMP HORIZ.	OUTPUT VERT.	ACCELEROM. OUTPUT LO	HI	CAB BALANCED 50 Ω	MIKE	CAB HI	SPKR LO		DUAL 24 VDC SUPPLY PLUS	GND	MINUS	GENERAL 28VDC SUPPLY PLUS		GND		A
B							SLIP	RINGS	—TOP									B
C	HQ GND	HQ GND	SPDT— RELAY CONTACTS RY1 NO	RY2 NO	RY3 NO	RY4 NO	PILOT CONTROLLER HI	LO	XLR-3 JACKS J1 2	3	XLR-4 JACKS 2	J6 3	4	BLUE RIBBON CONNECTOR J11 1	2	3	4	C
D	SHIELD GND	TEST LAMP RETURN	C	C	C	C	TARGET LAMPS (VERTICAL) TOP	BOTTOM	J2 2	3	2	J7 3	4	5	6	7	8	D
E	PILOT LEFT THUMB	SWITCH RIGHT THUMB	NC	NC	NC	NC	TV CAMERA OUTPUT HI	LO	J3 2	3	2	J8 3	4	9	10	11	12	E
F							SLIP	RINGS	—BOTTOM									F
G	PILOT LEFT INDEX	SWITCH RIGHT INDEX	RY1 COIL LT. BUZZ.	RY2 COIL RT. BUZZ.	RY3 COIL OGI TST.	RY4 COIL CAB LITE	RY5 COIL AC JACKS	CAB INTER LOCKS	NYST. PREAMP RESET LINE	CAL LINE	TARGET LAMPS—HORIZONTAL CENTER	LEFT	RIGHT	10 VOLT FEED	COMMONING			G
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	

Figure 6

Layout drawing of the chair patch panel listing the circuits terminated at each patch-panel cell.

The H9, H17, K9, and K17 cell group terminates the output of the various system power supplies and also contains 12 circuits that interconnect this patch panel to a similar patch panel incorporated in the instrumentation system developed for an adjoining vestibular research device, the Coriolis Acceleration Platform (2). This latter feature allows the various recording systems and test equipment incorporated in each device's instrumentation system to be interchanged in the setup and calibration of either system. The circuits routinely interconnected to the subject's chair are terminated in the bottom two rows of cells.

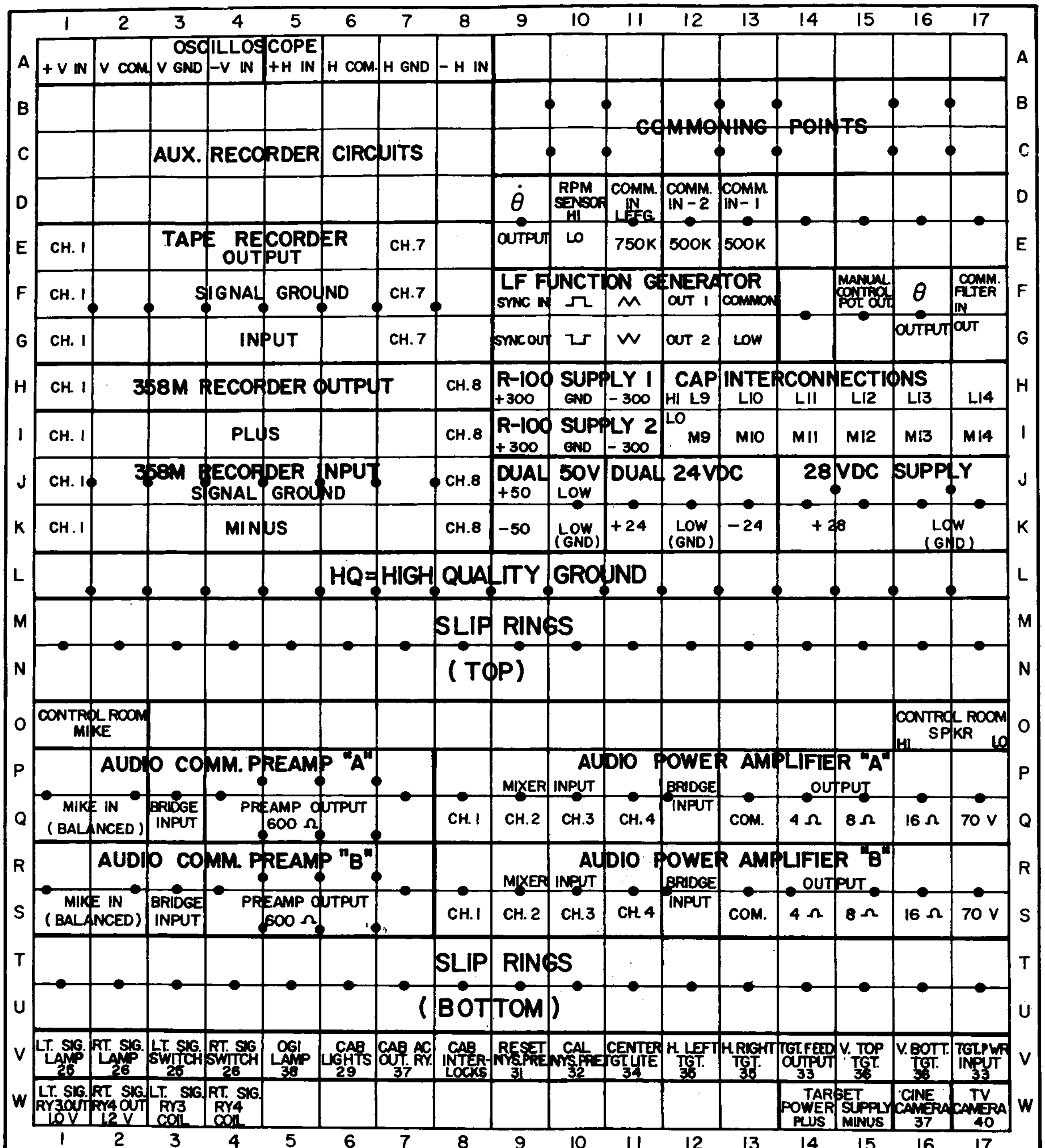

Figure 7

Layout drawing of the control room patch panel listing the circuits terminated at each patch-panel cell.

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13. ABSTRACT

The Periodic Angular Rotator is a novel servorotator designed for studies of the dynamic response of the oculovestibular system. It will rotate a single subject about an Earth-vertical axis in a wide variety of stimulus waveforms. Step function, ramp, and sinusoidal angular motions are generated precisely by a closed-loop power servomechamism drive system. The use of a low speed DC torque motor coupled directly to the payload resulted in a system with low acoustic noise and mechanical vibration properties, fast dynamic response characteristics, and a high degree of coupling stiffness. When operated in a velocity mode of control, the device is rated to produce a maximum angular velocity of 100 rpm either clockwise or counterclockwise at angular accelerations up to 100 deg/sec^2 and sinusoidal oscillation frequencies beyond 2.0 cps. When operated in the alternative displacement mode, similar ratings apply over a ± 150 degree excursion.

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14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.