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SUMMARY PAGE

THE PROBLEM

To develop an electronically controlled rotating device that can be installed on the radial arm of a centrifuge and programmed to precisely track the angular motions of the centrifuge so as to achieve the classical 1:1 counterrotation state of motion. With this capability, the device would facilitate the investigation of man's response to low-level dynamic linear acceleration stimuli without the complications of simultaneously occurring angular acceleration stimulation during transitions in centrifuge velocity.

FINDINGS

A small man-rated rotating device identified as the Counterrotator (CORO) was developed for installation aboard the radial track superstructure of the Coriolis Acceleration Platform (CAP), a centrifuge-like Earth-vertical rotator. The CORO device utilizes a DC torque drive motor to rotate a seated subject in the direction opposite to that of the CAP with precise 1:1 tracking achieved by operating the system as a closed-loop position servo. By this installation, the rotational center of CORO can be statically displaced between 0 and 19 ft from the rotational center of CAP and counterrotation can take place over the 0-to 100-deg/sec, clockwise or counterclockwise, velocity range at angular acceleration levels extending to 15 deg/sec^2. Accordingly, the device is rated for steady-state counterrotation in variable magnitude centripetal acceleration fields extending from 0 to 1.75 g nominal.

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INTRODUCTION

This report presents a brief description of the Counterrotator (CORO), a new man-rated motion device recently installed at the vestibular research facilities of this activity. The device proper is a small Earth-vertical rotator which utilizes a DC torque drive motor operated as a closed-loop position servo to turn a seated subject about his z (vertex-base) head axis. It was designed specifically for installation aboard the radial arm of the Coriolis Acceleration Platform (CAP), a centrifuge-like rotating structure which has been described in detail elsewhere (2). The function of the CORO drive system is to rotate a subject, fixed a known radius away from the center of CAP, in the direction opposite to that of CAP, so as to always maintain an exact 1:1 counterrotation ratio. As viewed by a fixed nonrotating observer, this state of motion results in translation without rotation since changes occur only in the spatial position, not the spatial orientation, of the CORO subject. Thus angular acceleration stimulation does not result when the angular velocity of CAP is changed.

PHYSICAL CONFIGURATION

The main elements of the CORO device are a rotating subject chair, a fixed drive pedestal, and a remotely located electronic control rack. The subject chair is fixed to and surrounded by a lightproof capsule that is supported at its center by the drive pedestal which houses all of the rotating components of the drive system. These include a DC torque drive motor which turns the capsule, a synchro control receiver which measures the angular position of the capsule relative to the pedestal, a torque type tachometer which determines the angular velocity of the capsule relative to the pedestal, and a slip-ring bank which provides electrical access to the instrumentation which may be installed within the capsule during experimentation. The CORO is remotely operated at a master control panel installed in the electronic rack which also houses the electronic amplifier and magnetic contactor circuitry associated with the drive system.

A photograph of the CORO capsule/subject-chair combination with an access door opened to show interior detail is presented in Figure 1. The cylindrically shaped capsule is approximately 5 1/2 ft in diameter and 6 ft in height. The outer wall is fabricated from sheet aluminum, with structural rigidity in the vertical dimension provided by four flanged channels which are equally spaced about the inner periphery and joined at the top and bottom by aluminum cross-frame members. These vertical channels also support two lightproof hinged doors which are flush mounted in the capsule wall at either side of the subject chair. The size of these doors provides ample room to attend to the subject and to set up the related instrumentation. The subject chair is supported by two centrally located aluminum channels fixed to the upper and lower cross-frame members.

Protective constraint for the subject is provided in the form of chest, lower torso, and leg harness assemblies. The particular head fixation apparatus shown in Figure 1 is a standard aviator crash helmet with custom-fitted head liners and an adjustable chin

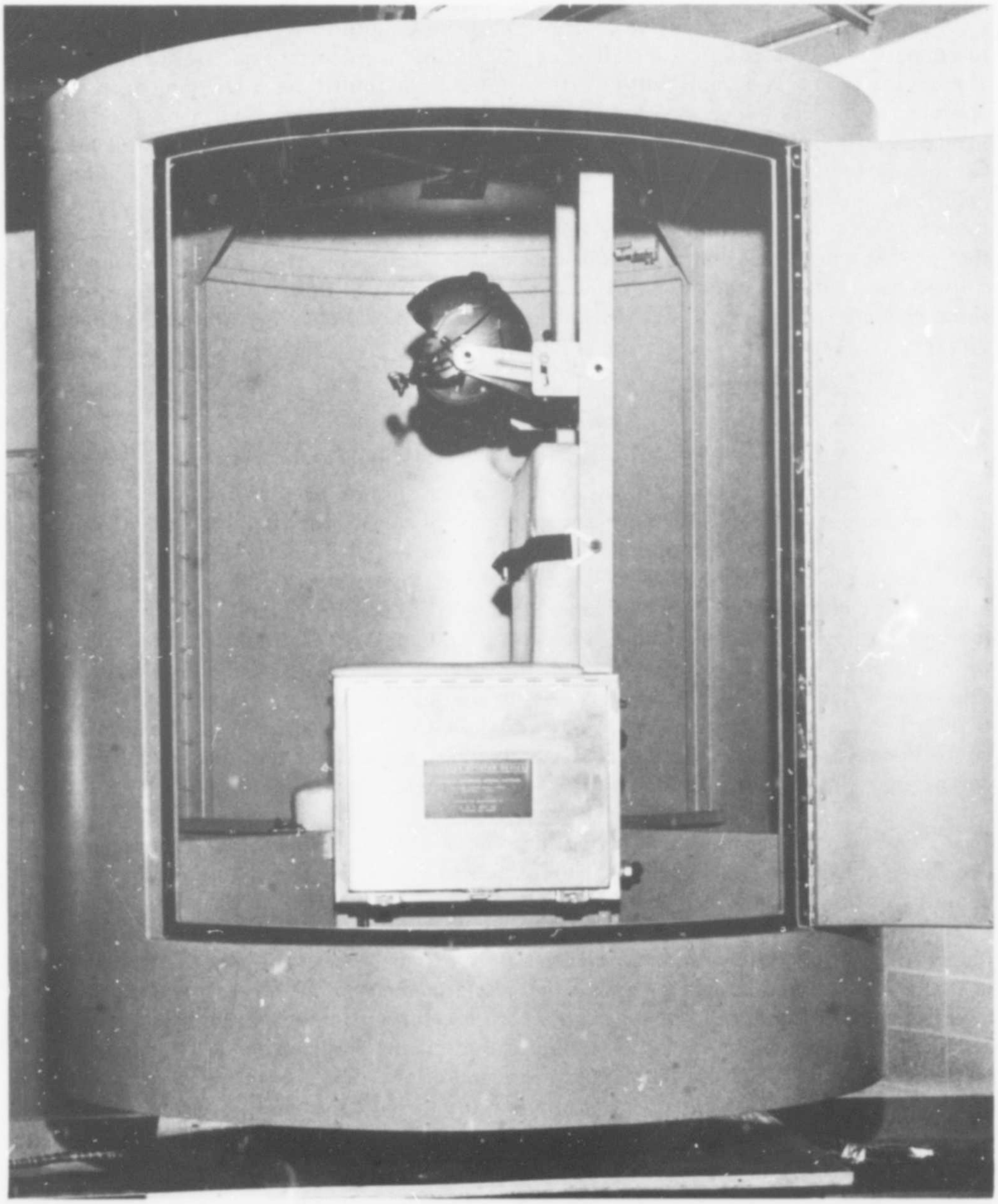


Figure 1

View of Counterrotator (CORO) Device with Access
Door Opened to Show Configu·ation of Subject Chair

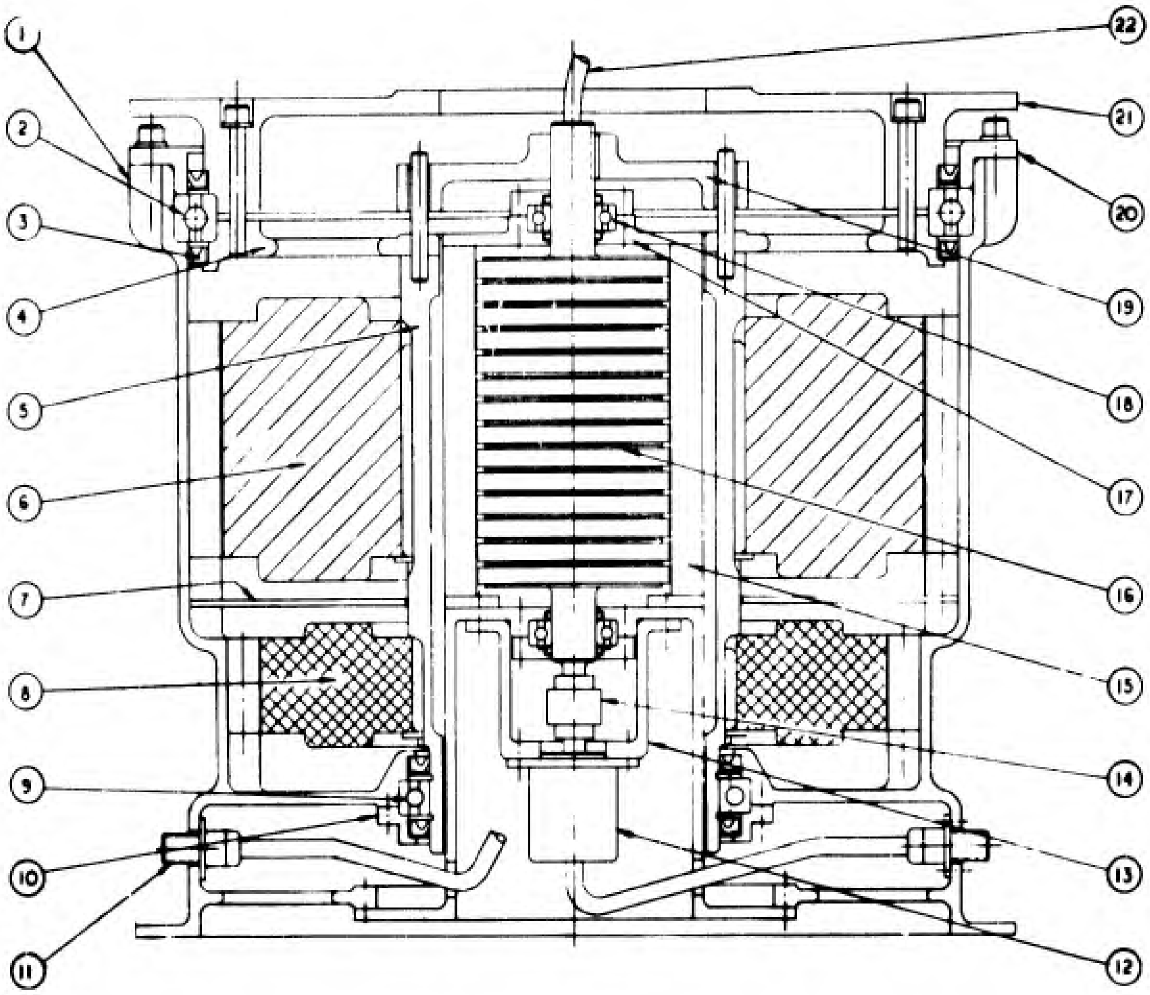
strap. The rectangular enclosure seen fixed to the left side of the chair is an electrical panel that terminates the electrophysiological slip-ring circuits routed through the drive pedestal; a similar panel located on the opposite side of the chair terminates the power and control slip-ring circuits. Lightproof ducts installed in the floor and two overhead blower fans provide forced-air ventilation of the capsule.

A simplified cross-section sketch of the CORO drive pedestal is presented in Figure 2 to illustrate the physical configuration of the interior components. The pedestal, of approximately 18-in. diameter and 20-in. height, is recessed into the base of the capsule immediately beneath the subject chair. The central element is a hollow torque tube, i.e., drive shaft, which is identified as Part #5 in Figure 2. The upper end of this shaft is attached to a cylindrical mounting plate (#21) which is bolt fastened to the base of the capsule and supported by a 4-point annual ball bearing (#2). The lower end of the drive shaft is held centered by a radial bearing (#9). The torus-shaped rotor of the DC torque drive motor (#6) is keyed to the drive shaft by means of a rotor adapter (#4); the permanent-magnet type stator is fixed directly to the pedestal housing. A torque type DC tachometer (#8), also having a torus-shaped rotor, is keyed to the drive shaft and magnetically isolated from the drive motor by means of a small magnetic shield (#7).

The angular position of the CORO drive shaft is measured by a small synchro (#12) which is in-line coupled to the base of a slip-ring stack (#16) that is installed inside the drive shaft at the level of the main torque motor. This slip-ring assembly (Breeze Corp. Dwg. No. D-BTD-261-503) provides 60 circuits to interconnect the capsule to the pedestal and utilizes coin silver slip ring and 75%-25% silver graphite brush materials. The circuits are subdivided into 2 video lines, 30 physiological rings application rated for a 28-VDC, 0.1-ampere resistive load, 22 control rings application rated for a 115-VDC, 5.0-ampere resistive load, and 6 ground return rings. The weight of the drive pedestal including all interior components is 320 lb. The total weight of the entire rotating system of CORO including the drive pedestal, capsule, and subject chair is 660 lb.

ELECTRICAL DRIVE SYSTEM

A simplified schematic block diagram of the CORO electrical drive system is presented in Figure 3. Since CORO drive system is operated as a position servo during counterrotation, the instantaneous angular displacement of the CAP rotating superstructure from an arbitrarily selected Earth-horizontal reference axis serves as the system command signal. This signal is derived from a 400-cps synchro transmitter (Type 23CX4) that is directly coupled to the CAP device. The stator output of this synchro is routed to the stator input of the synchro control transformer (23CT4) that is in-line coupled to the CORO drive shaft and measures the instantaneous angular displacement of the CORO capsule relative to its drive pedestal which, in turn, is fixed to the radial arm of CAP. The 400-cps output voltage from the synchro transformer is then passed through a two-stage demodulator to obtain a DC signal whose magnitude is proportional to the magnitude of the angular difference between the positions of CAP and CORO, and whose polarity corresponds to the direction of the angular difference. The first stage of the demodulator



1. Housing
2. 4 Point Ball Bearing
3. Bearing Seal
4. Rotor Adapter
5. Torque Tube
6. Torque Motor
7. Magnetic Shield
8. Tachometer
9. Radial Bearing
10. Bearing Retainer
11. AN Connectors with Cable
12. Synchro
13. Mounting, Synchro
14. Coupling, Flexible
15. Housing, Slip Ring
16. Slip Ring Stack
17. End Plate, Slip Ring Ass'y
18. Bearing, Slip Ring Ass'y
19. Driver, Slip Ring
20. Retainer, Bearing
21. Mounting Plate
22. Cable, with Connector

Figure 2

Cross-section Sketch of CORO Drive Pedestal

provides AC amplification and phase adjustment of the 400-cps error signal before rectification by the second stage.

The resulting position error signal is then directed to the input of a chopper-stabilized DC operational amplifier which sums this input with a DC feedback voltage derived from the torque tachometer (Inland Motor Corp. Model TG-10024A) coupled to the CORO drive shaft, thus providing servo loop rate compensation. The output of this amplifier is then passed to the input of a multi-stage, solid-state power amplifier (Inland Motor Corp., Model 655) which has a steady-state power rating of 1500 watts (75 volts at 20 amperes) and a peak rating of 2400 watts (80 volts at 30 amperes). This amplifier utilizes a proportional controller consisting of power transistors arranged in a four-arm bridge circuit with conduction of two arms resulting in motor rotation in one direction, and rotation in the opposite direction when energization is switched to the other two arms. A separate amplifier stage senses armature current developed by the power amplifier and routes this signal to limit circuitry which provides adjustable control of the maximum current that the power amplifier can deliver.

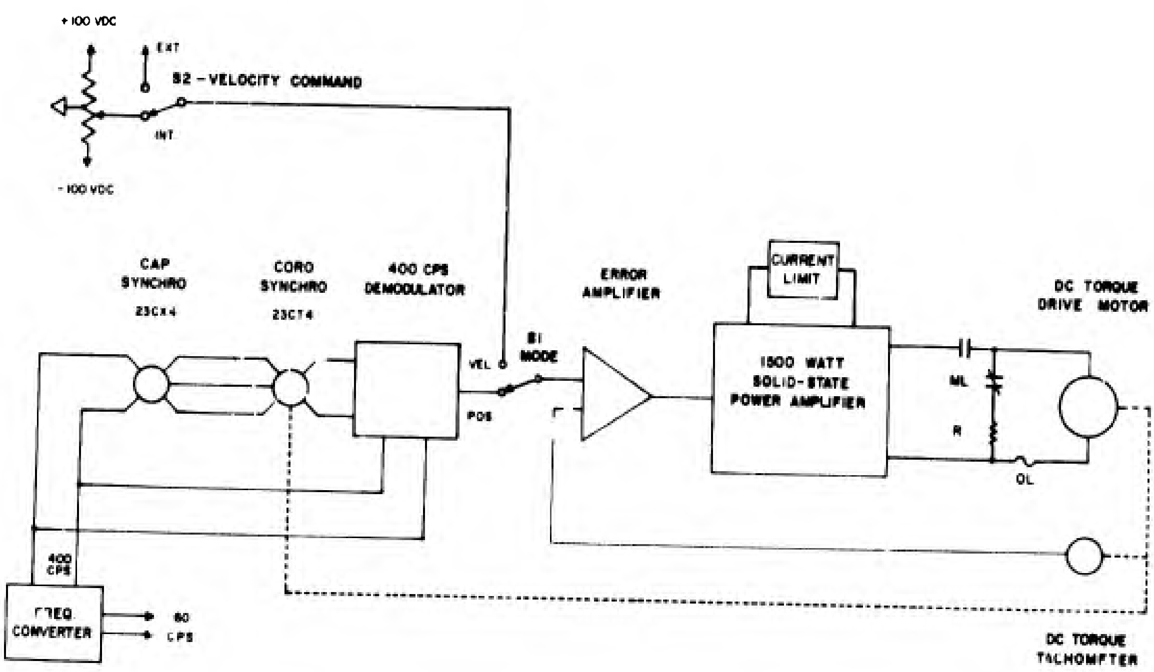


Figure 3

Simplified Electrical Diagram of CORO Drive System

The output of the power amplifier is connected to the armature of the torque drive motor (Inland Motor Corp., Model T-12009A) via a main loop contactor (ML). The DC torque motor is a gearless unit with permanent-magnet field excitation, has a maximum speed of 400 deg/sec (66.6 rpm), and is rated to deliver a peak torque of 135 lb-ft with an armature input of 80 volts and 30 amperes at any speed, including stall, within its operating range. The closed-loop configuration of the drive system, including rate feed-back to optimize system response time characteristics, then results in the torque motor rotating the CORO capsule in the direction opposite to the rotation of CAP so as to always minimize the angular position error signal, thus achieving the desired 1:1 counter-rotation. Since the majority of the test conditions to be encountered with CORO installed aboard CAP involve peak torque loads of less than 100 lb-ft, and since the torque constant of the motor/amplifier combination is approximately 4.5 lb-ft/ampere, current limiting is made to occur at about 22 to 23 amperes.

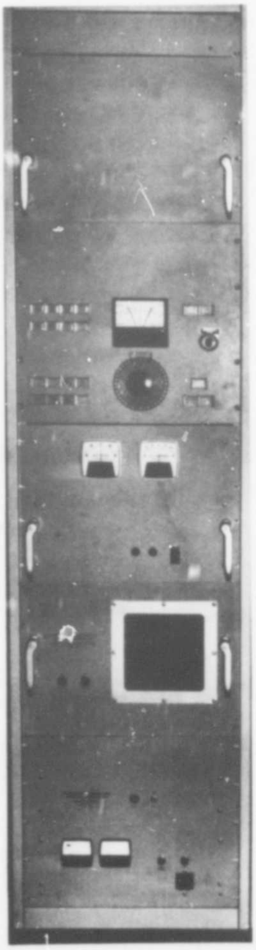


Figure 4

CORO Electronic Control Rack

Additional circuitry includes switch-volt protection to prevent starting the drive with a jolt in the event a command signal is present when the drive is first energized; overcurrent interlocking of the drive motor which, in conjunction with the power amplifier current limit circuitry, protects the equipment in the event of a component failure and also limits the maximum angular acceleration a subject may experience; and interlock circuits to sense motor overspeed, motor overheating, loss of electronic rack cooling air, and power amplifier overheating. In the event of an emergency, the drive system can be brought to a complete stop from top speed within 6 sec. This operation is brought about by closed-loop servo control to power the motor to a halt through regenerative braking. In the event of a power failure or loss of control power, a dynamic braking circuit (resistor R in Figure 3) will automatically bring the drive system to rest within 12 sec.

The CORO can also be used as a conventional Earth-vertical rotator since provisions have been made for velocity control of the drive system. In this mode, velocity and acceleration profiles can be programmed with greater fidelity due to the increase in closed-loop frequency bandwidth. Velocity control is symbolized in Figure 3 by placement of switch S1 in its upper position; this connects the input of the error amplifier to a DC control signal made proportional to the desired instantaneous angular velocity of CORO. This signal can be derived from a manually operated, multi-turn, center-tapped potentiometer installed on the CORO master control panel; or it can be derived from some external source such as a low-frequency function generator, an analog computer, or a tape storage medium. When operated in this mode, CORO has a full scale angular velocity of 400 deg/sec, a maximum angular acceleration capability of 30 deg/sec^2, an over-all frequency bandwidth of 5.5 cps, and an over-all velocity accuracy of ± 0.5 per cent. Since the torque motor is direct coupled to the rotating payload, the drive system has a high degree of stiffness and fast response time characteristics. The torque motor approach has also been used in the previous development of rotary drive systems for CAP (2) and the Periodic Angular Rotator (1).

All control circuitry and components external to the CORO device are housed in one electronic control rack, shown in Figure 4, which is installed inside the CAP control room. The components are installed on five rack-mounted panel assemblies and one rear-mounted chassis. The top panel assembly contains all relay circuitry used in the drive-control and interlock systems. Below the relay panel is the master control panel which provides the operator with all control functions required in starting, controlling, and stopping the CORO drive. The third panel from the top contains the wire terminations of all control circuitry. This panel provides easy access to the control wiring for maintenance, calibration, or trouble-shooting. The fourth panel houses the servo amplifier and the lowest panel contains all power supplies and reference voltage supplies used in the CORO drive control. Magnetic contactors are mounted on the fixed vertical chassis at the rear of the rack. The total weight of the 19-in. by 79-in. rack is 600 lb.

A close-up photograph of the CORO master control panel is shown in Figure 5. The combination indicator lamp-switch unit assemblies seen at the upper right of the panel are used to apply and remove 208-VAC, 3-phase input power to the system with actual start and stop operations controlled by the assemblies at the lower right. The indicator

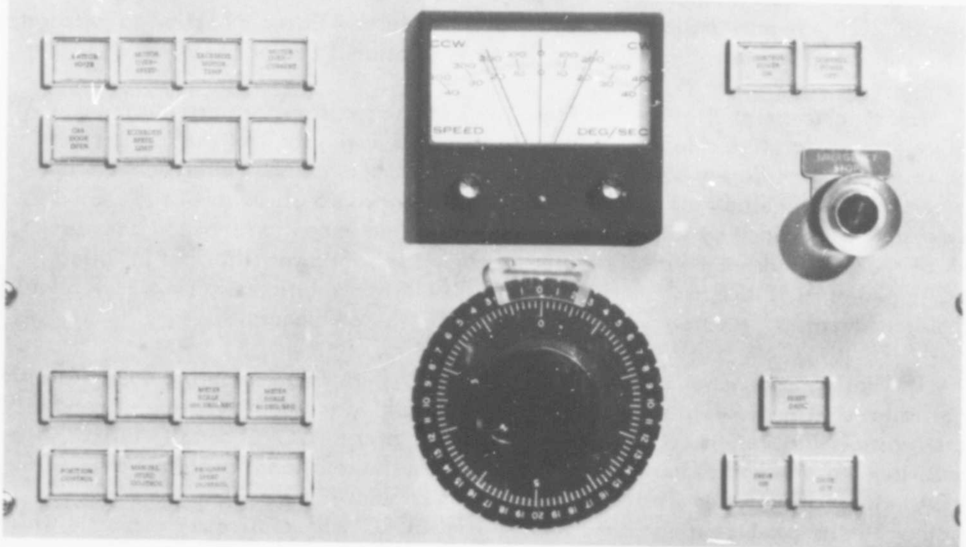


Figure 5

CORO Master Control Panel

lamps at the upper left monitor the status of the key safety interlock and motor protection circuits of the system and are illuminated only when a malfunction occurs in the related circuit. Selection of the position mode for counterrotation, the velocity mode with an external command signal source, or the velocity mode with manual adjustment of velocity derived from the centrally located potentiometer is made by means of the switch assemblies located at the lower left of the panel. Visual readout of the magnitude and direction of the instantaneous angular velocity of CORO is provided for by the zero-center panel meter which contains two adjustable sensing pointers that can be preset by the operator to some selected upper speed limit for each direction of rotation. If the actual velocity of the device exceeds these limits as a result of either a programming error or a system malfunction, this limit circuitry automatically brings the CORO device to a stop

THE COUNTERROTATION CAPABILITY

A photograph of the CORO device installed aboard the radial arm of the CAP is shown in Figure 6. The rotating element of CAP is a 40-ft long track superstructure which supports a 20-ft diameter capsule at its center; the superstructure, in turn, is supported by a conically shaped pedestal assembly which houses a DC torque motor, operated as a closed-loop velocity servo, which rotates the entire device about an Earth-vertical axis. CORO is installed on a 4-ft by 4-ft track platform that is wheel supported on two "Vee" rails which extend over the full length of the CAP track superstructure. The base of the track platform is coupled via wire rope to the shaft of a second drive motor, installed in the superstructure proper immediately beneath the center of the capsule, which is operated as a closed-loop position servo. This drive system allows CORO to be moved along the track superstructure in either direction so as to effect precise control of its static displacement from the rotational center of CAP.

The synchro transmitter used to sense the instantaneous angular orientation of CAP relative to a nonrotating reference is directly coupled to the shaft of the upper-slip-ring stack installed immediately above the ceiling of the CAP capsule. Interconnection between the CORO electronic control rack and the on-board elements of the CORO drive system is provided by this slip-ring stack, with the exception that the armature leads of the CORO drive motor are routed through a set of power slip rings installed in the CAP pedestal. Electrical access to the CORO instrumentation slip rings is available at a shielded-cell-type patch panel installed inside the CAP capsule.

The basic performance ratings of the CORO/CAP installation during counterrotation are as follows: The absolute maximum payload of CORO, including the subject and all related instrumentation, is 300 lb. The rotational center of CORO can be statically prepositioned at any radius between 0 and 19 ft from the rotational center of CAP. When the CAP rotary drive system, rated for a maximum angular acceleration of 15 deg/sec^2, is programmed to produce a given motion profile, CORO will duplicate the profile while undergoing 1:1 counterrotation with 100 deg/sec (16.6 rpm) serving as the upper angular velocity limit. Accordingly, the system can effect steady-state counterrotation in centripetal acceleration fields extending from 0 to 1.75 g nominal. The over-all design bandwidth of the CORO drive system is 0.5 cps with the static tracking error rated not to exceed ±0.15 deg.

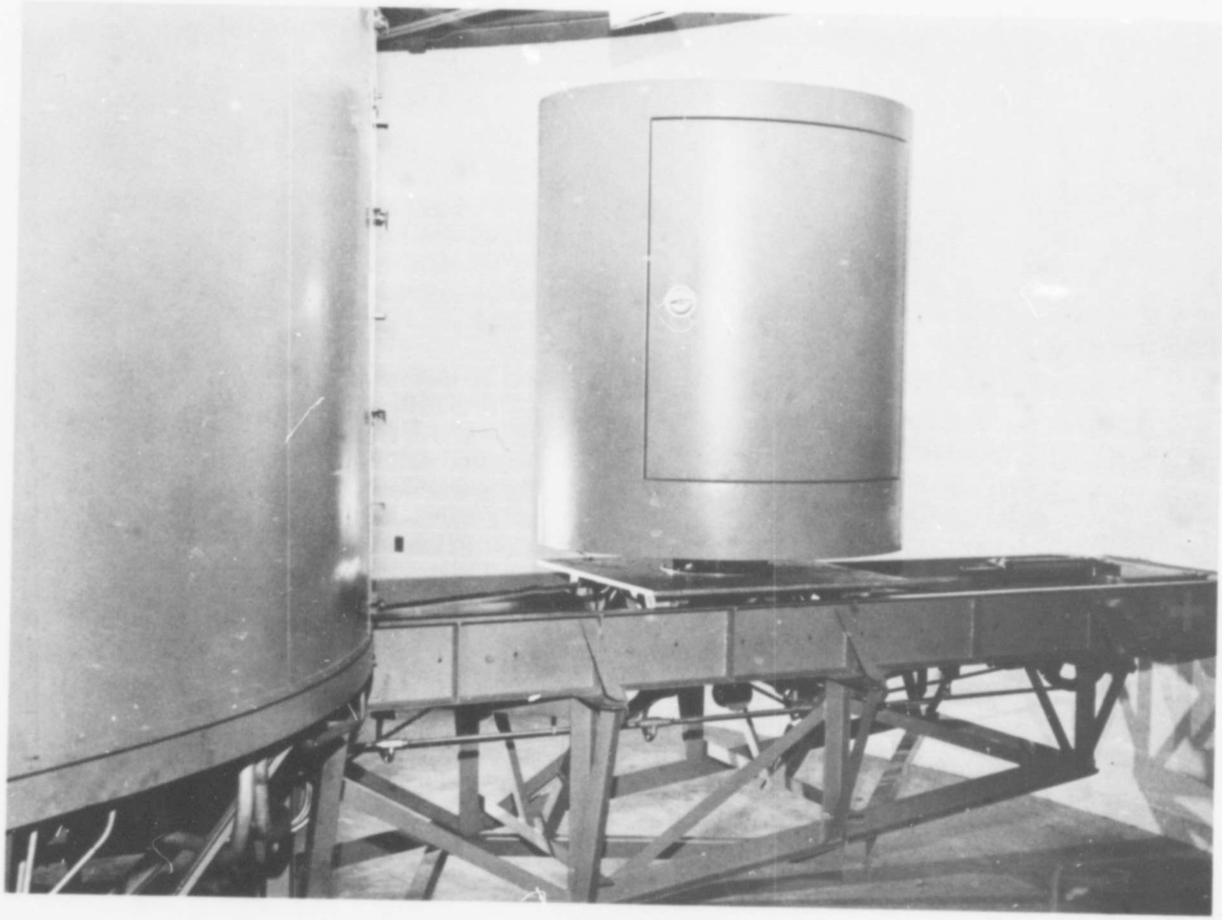


Figure 6

View of CORO Installation on the Radial Track
Superstructure of the Coriolis Acceleration Platform

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13. ABSTRACT

A new man-rated vestibular research device, identified as the Counterrotator (CORO), has been developed to investigate man's response to the dynamic linear acceleration environment afforded by counterrotation aboard a centrifuge. The device proper is a small Earth-vertical rotator which utilizes a DC torque motor operated as a closed-loop position servo to turn a seated subject about his z head axis. When installed aboard the radial arm of the Coriolis Acceleration Platform (CAP), a centrifuge-like rotator, the CORO drive system will track the angular motions of CAP over the 0- to 100-deg/sec velocity range at angular accelerations extending to 15 deg/sec². The device is rated to achieve this 1:1 counterrotation capability in low-level, variable magnitude, centripetal acceleration fields extending from 0 to 1.75 g nominal.

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Rotation devices						
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