NASA Technical Memorandum 108804

IN-51
208998
13P

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(NASA-TM-108804) AN AUTOMATIC 14-DAY PASTE DIET FEEDER FOR ANIMALS (NASA) 13 p

N94-26086

Unclas

G3/51 0208998

January 1994

National Aeronautics and Space Administration

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An Automatic 14-Day Paste Diet Feeder for Animals

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Summary

During a centrifuge experiment, any interruption that requires stopping the centrifuge may influence the results. Centrifuges often must be stopped for animal maintenance (food, water, and waste removal), especially in cases of timed feedings. To eliminate the need for stopping the centrifuge while still providing timed feeding, an automatic paste diet feeder was developed. The feeder is based on a constant volume concept and can deliver a predetermined amount of paste diet at specified time intervals. This unit was supported by water delivery and waste collection systems. The entire system performed reliably and maintained the animals well for a continuous centrifugation experiment of 14 days.

Introduction

Studies involving chronic exposure of animals to unique environments are often compromised by the need for human intervention to provide cage/habitat maintenance (e.g., replenish food and water and remove waste). This is a particular problem during hypergravity experiments because the centrifuge must be stopped intermittently. To eliminate this problem an automatic feeder was developed, with supporting water and waste systems that allowed a cage containing small rodents (rats, mice, etc.) to be maintained on a centrifuge run continuously for 14 days.

The feeding system had to meet three criteria. First, it had to deliver 140 g to a rodent cage at specified time intervals four times/day. Second, the delivery system had to be fully automated because the cages and feeders would be inaccessible during an experiment. Since the paste diet was 60% water (similar to oatmeal) with an initial consistency that can change over time, the final requirement was to deliver a measured mass of food regardless of consistency.

Feeder Design

The feeder design is shown in figure 1. A photograph is shown in figure 2. The parts of the feeder are identified numerically in the following text. A cutaway of the cage is shown in figure 3. The outer plastic cage, 100 × 56 × 61 cm, was attached directly to the swing arm of the centrifuge. The 65 × 20 × 16 cm Plexiglas™ animal cage (12) was placed inside (figs. 1 and 2). The feeder included a pressurized food (paste) reservoir, delivery system (associated plumbing and valves), and an electronic control system.

The reservoir (1) was a 7.6 liter stainless steel cylinder 22.9 cm in diameter and 27.9 cm high, attached at its base to an 11.4 cm high funnel that reduced the 22.9 cm cylinder diameter to a 2.5 cm diameter at the first valve.

The delivery system consisted of 2.5 cm diameter stainless steel tubing, two 2.5 cm motorized ball valves, (2, 3), and a motor driven Teflon™ piston (4). Delivery operation was controlled by an electronic relay chassis (5) mounted on the centrifuge cage, and connected through slip rings (17) to a programmable timer outside the centrifuge rotunda (18). The number of feedings and times of operation were preset using the programmable timer. The feeder was mounted in the outer cage (11) of both centrifuge and stationary control cages, and the paste was delivered into a food tray inside the animal cage (12). Metal cross hairs were attached to the end of the delivery tube to prevent the animals from eating the paste in the tube that had not yet been presented.

The entire system was flushed with 70% alcohol prior to use to eliminate bacteria. The radiation-sterilized food (0.5 mrad at Nutek Corp., Palo Alto, CA 94303) was placed into the reservoir and a leveling plate (6) placed on top of the paste so it would pack evenly. The reservoir top was then sealed with an airtight lid and the space between the lid and leveling plate was purged and filled with nitrogen (7) to create a constant pressure of 5 psi to force the paste down into the funnel. A video camera (16) recorded three feedings/day; the fourth feeding took place in the dark and was not recorded on video. G-force was confirmed with an accelerometer mounted at the level of the cage bottom (15).

The water system was a 12 liter carboy (13) placed near the center of the centrifuge. Tubing was routed from the carboy down the centrifuge arm and into the cages, and water was provided (by gravity feed and G force)

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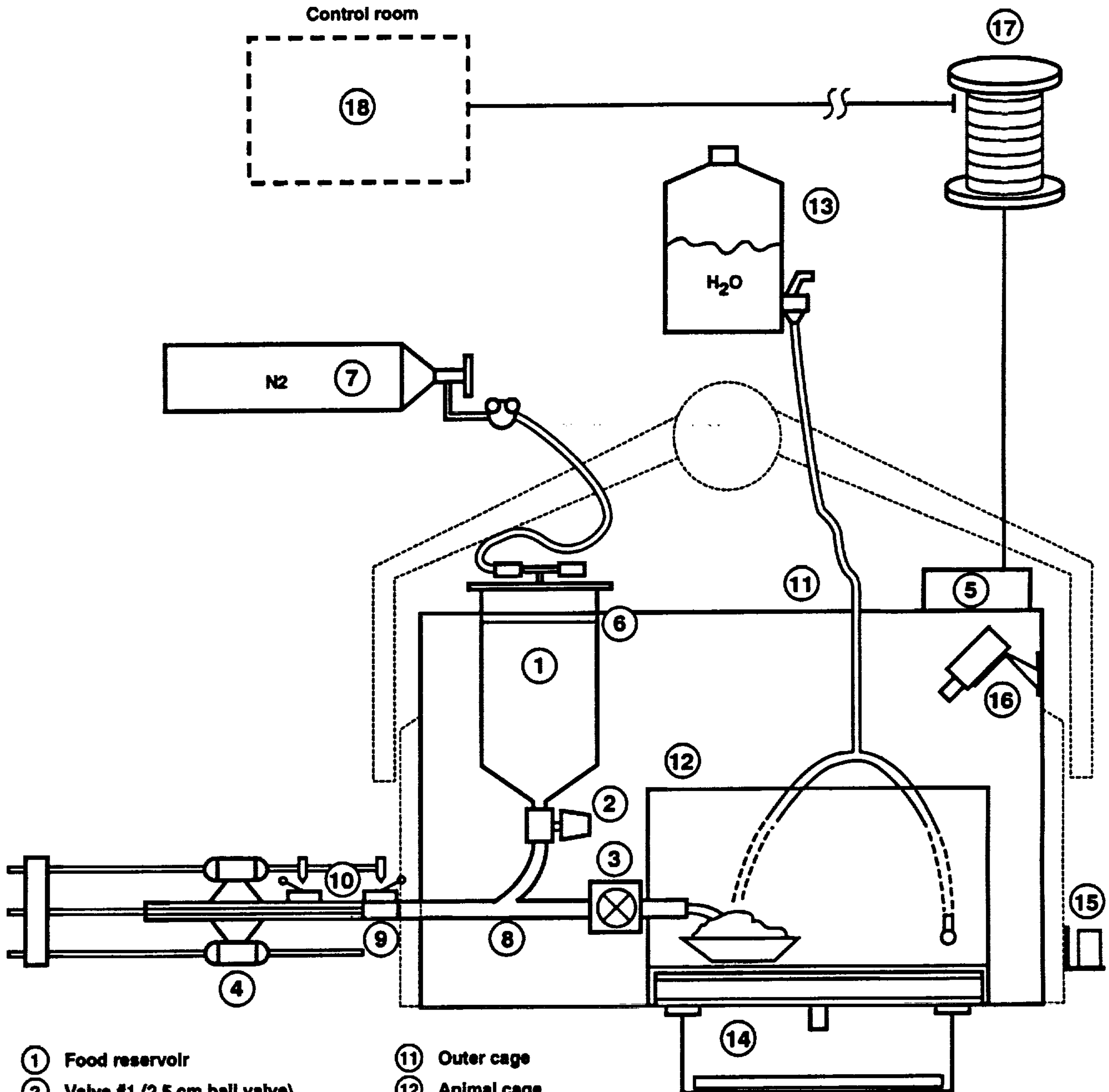

1. Food reservoir
2. Valve #1 (2.5 cm ball valve)
3. Valve #2 (2.5 cm ball valve)
4. Piston drive motor
5. Relay board/timing system
6. Leveling plate
7. Nitrogen tank
8. Delivery tube (2.5 cm stainless steel)
9. Teflon piston
10. Limit switches
11. Outer cage
12. Animal cage
13. Water delivery system
14. Waste collection system
15. Accelerometer
16. Video camera
17. Slip rings
18. Timer (in control room)

Figure 1. The feeder system.

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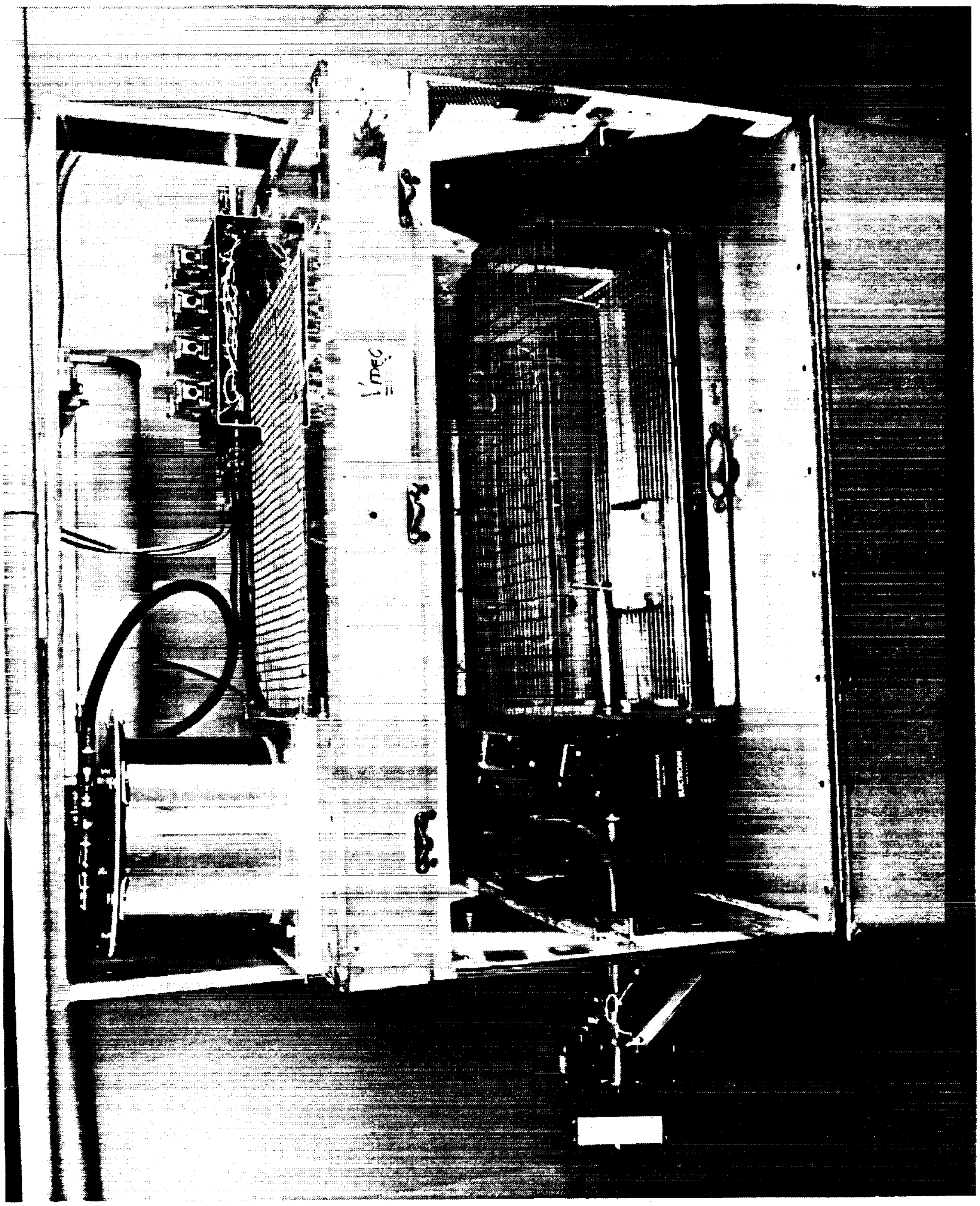


Figure 2. The actual feeder/cage setup.

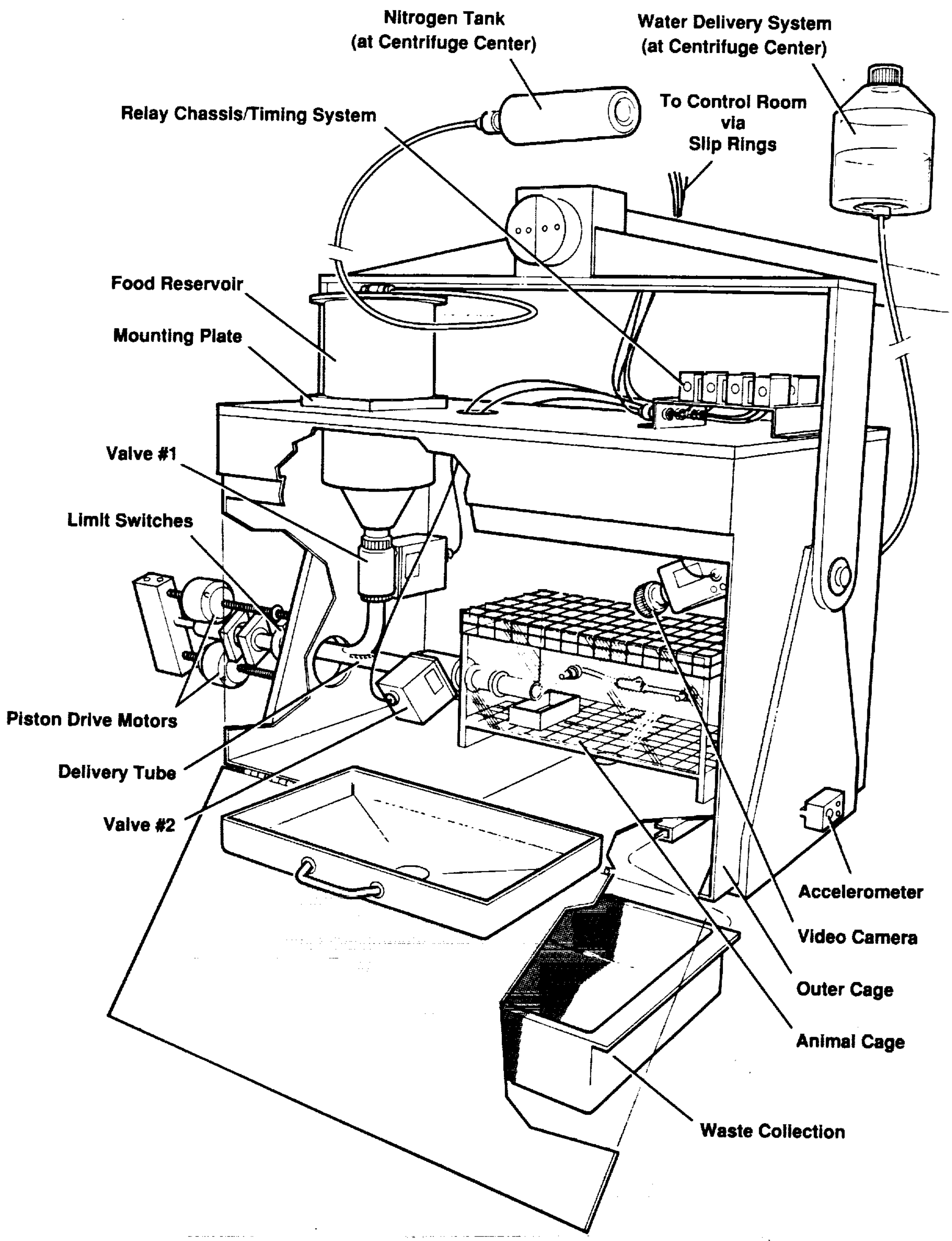


Figure 3. Cage cutaway.

ad libitum through two lixit valves. The waste collection system was a metal tray, placed under the bottom of the wire cage, which had a drain hole that allowed waste to flow into a collection bucket (14). The collection bucket was lined with phosphoric acid treated pads to neutralize the ammonia in the waste (100 ml/pad of 0.1 m H_3PO_4 dried before use). The entire support system was mounted on the centrifuge arm (see fig. 3).

The feeding system was tested on the Ames 3.7 meter radius centrifuge at 2 G for 14 days. A second feeding system was mounted on a stationary control cage inside the centrifuge room.

Feeder Operation

When the first valve is opened, nitrogen pressure forces the paste into the curved tube as the piston (9) retracts along the delivery tube (8). After a 30 sec delay, the first valve closes and the second valve opens. The piston forces the paste down the delivery tube, past the second valve, and into the food (paste) tray in the cage. The distance the piston moves along the tube is adjusted/calibrated by measuring the weight of food delivered per piston stroke and adjusting limit switches (10) at each end of piston travel until the desired amount is delivered. This calibration is performed both with the centrifuge stopped and with the centrifuge running at 2 G for 2 hr to ensure the amount of paste delivered does not change during hypergravity. The specifications and final calibration was for 140 ± 2 g/feeding.

Video recordings of three feedings/day confirmed that both feeders functioned properly for 14 days. The actual paste delivered was 138.5 g/feeding for the stationary cage (within specifications) and 154.0 g/feeding for the centrifuge cage, which may have been due to the increased G forces assisting the flow of food, change in consistency of the food, or some combination of these two.

Electrical Operation

An electronic system block design is shown in figure 4. Figure 5 shows the ladder logic schematic for the relay control chassis. Photographs are shown in figures 6 and 7. The 2 G feeder uses the following electrical equipment to deliver a set quantity of rat food four times/day: a timer, time delay relays, electromechanical relays, electromechanical valves, limit switches, and a motor driven linear actuator. The following is a description of how these devices interact to deliver a given quantity of food.

Sequence of Operations

The delivery sequence begins (see figs. 4 and 5) with the opening of valve 20R (reservoir) directly below the food reservoir. The command for opening this valve comes from the timer and time delay relay inside the centrifuge control room. Once the command to open the valve has taken place, the rest of the feeding sequence is controlled by the relay control chassis on board the centrifuge (see fig. 6).

Opening of Reservoir Valve 20R

An eight-channel timer is used in the centrifuge control room to initiate four feeding sequences/day. Timer relay contacts are used to activate relay 2TDO6. Time delay open relay 2TDO6 completes a path to neutral, through contacts 1 and 3, to open an electromechanical 2.5 cm valve 20R located at the bottom of the food reservoir. The other valve, 20E (empty valve), must be closed before 20R can be opened. This is assured by contacts 9 and 11 of 20EC (empty closed). Valve 20R is kept open for 38.4 sec to allow the compressed nitrogen to push the food against the piston. There is a 5 sec cycle time for the electromechanical valves to open or close. Therefore, 38.4 sec would give at least 30 sec of pressure prior to piston retraction.

Piston Retraction

The piston begins to retract when 2TDO6 reaches the end of its time delay and provides a path to neutral for 5ME (motor enable) through contacts 8 and 11. To activate 5ME, the 20RO (reservoir open) is picked up (when valve 20R is completely open) and 33RX (retract auxiliary) contacts are closed. Relay 5ME supplies power to the motors through normally closed contacts of 46MR (motor reverse).

Closing of Reservoir Valve 20R

Valve 20R does not close until 2TDM (time delay motor) contacts 1 and 3 make contact. Motor 2TDM is activated by normally closed contacts 5 and 6 of 33RX. These contacts close when the piston reaches the end of its travel. The 12 sec delay allows the compressed nitrogen to push down on the food ensuring that the food fills the cylinder before 20R closes.

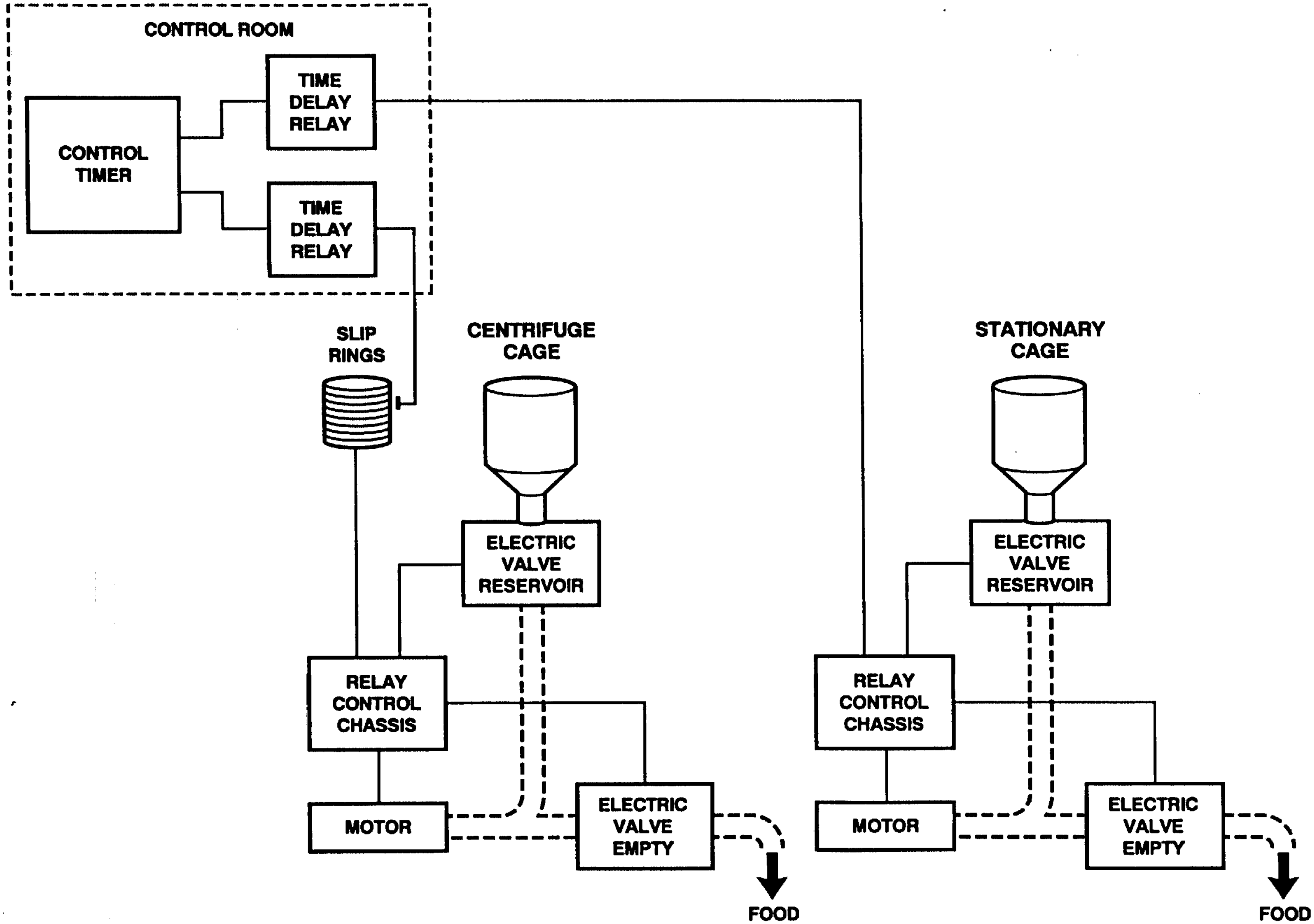
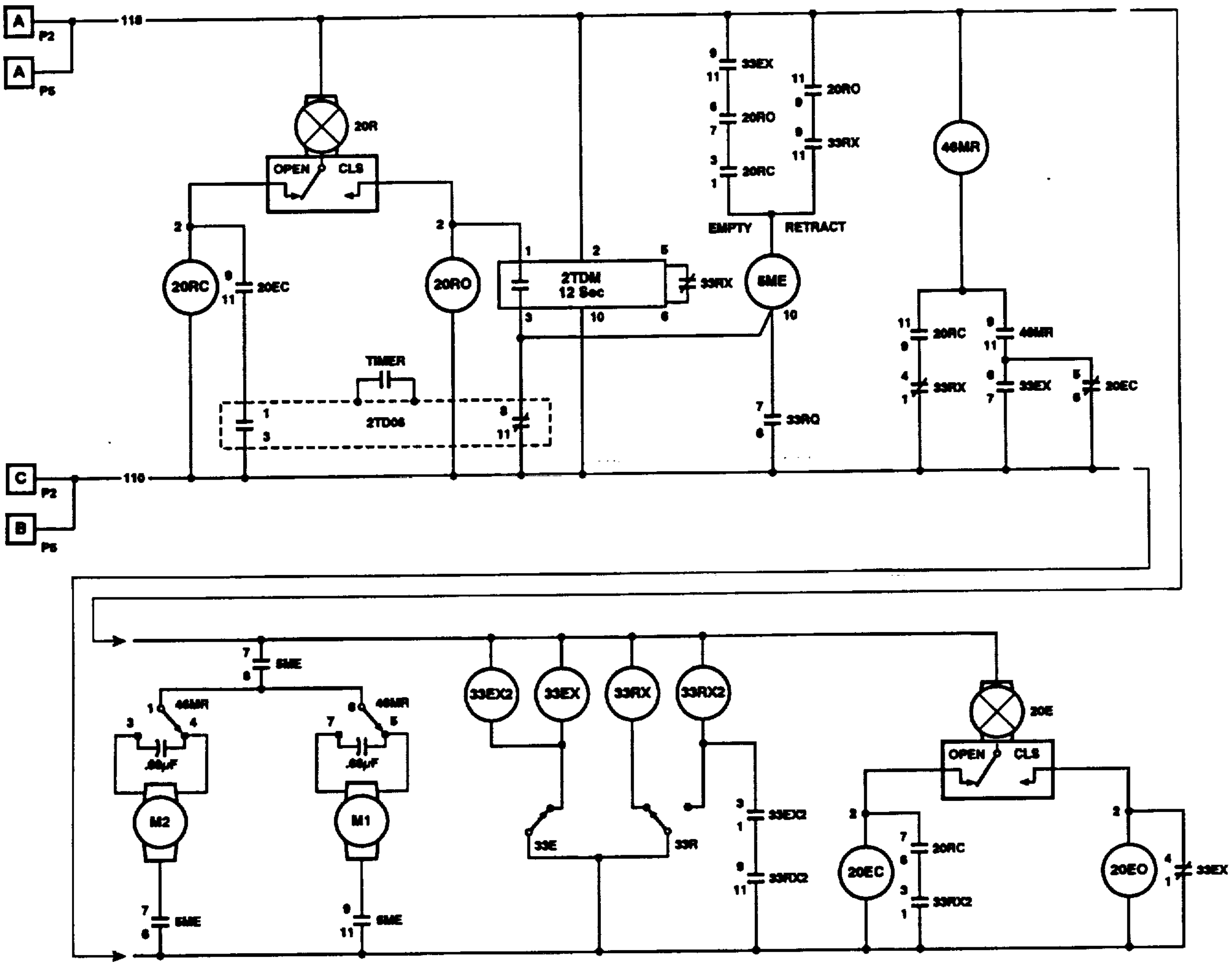


Figure 4. Electronic system block diagram.



KEY: ANSI relay names

2TDO6	Time delay on open relay 6
2TDM	Time delay motor
5ME	Motor enable relay
20E	Electrically operated empty valve
20EC	Empty valve closed
20EO	Empty valve open
20R	Electrically operated reservoir valve
20RC	Reservoir valve closed
20RO	Reservoir valve open
33E	Position switch extended position
33EX	Extend auxiliary relay
33EX2	Extend second auxiliary relay
33R	Position switch retracted position
33RX	Retracted auxiliary relay
33RX2	Retracted second auxiliary relay
46MR	Motor reverse relay

Figure 5. Relay control chassis—ladder logic schematic.

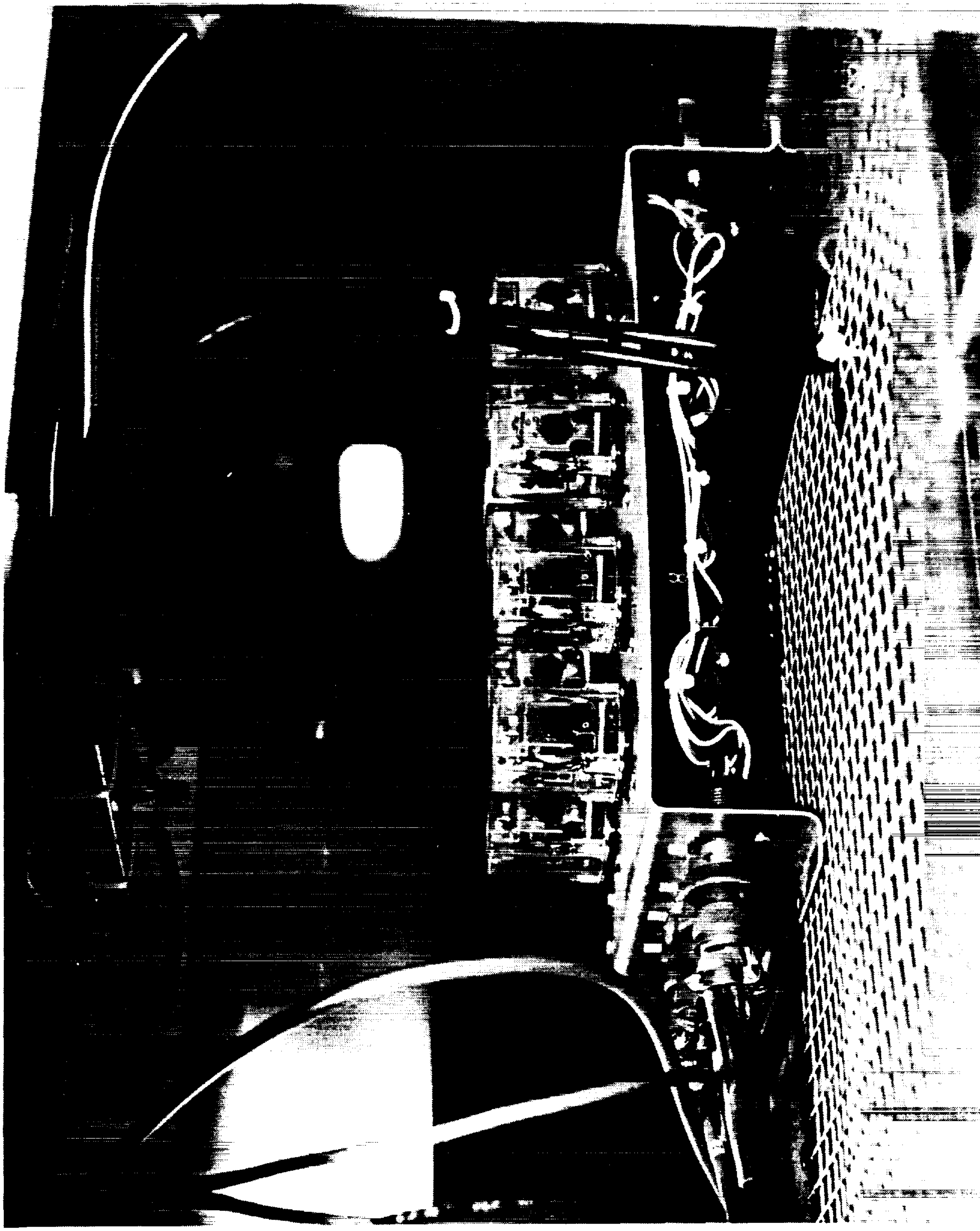


Figure 6. Electronic relay control chassis.

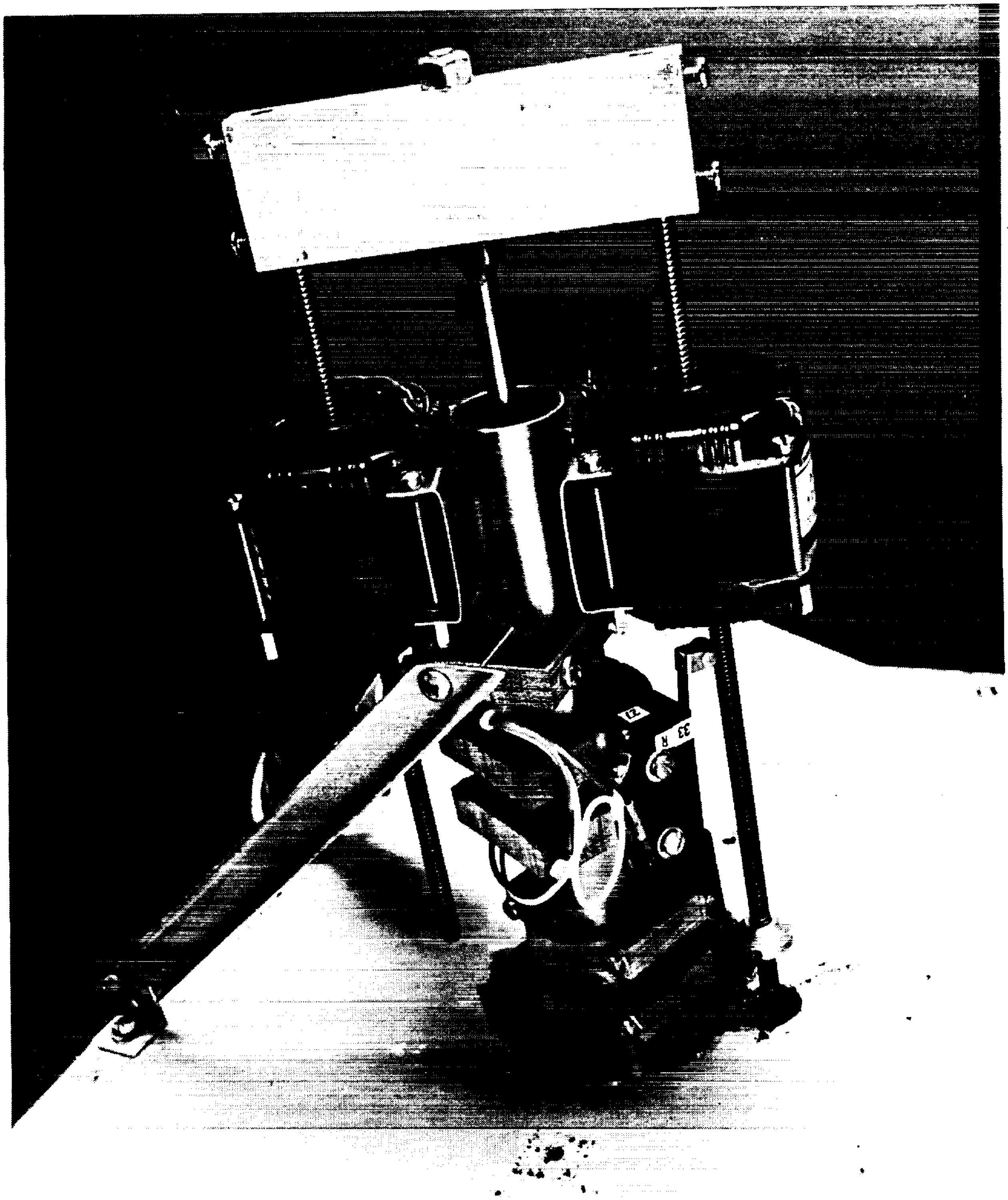


Figure 7. Motor drive assembly.

Reversing Motors

Once 20R is closed, it is necessary to reverse the linear actuator motors. This is the function of 46MR. Relay 20RC (reservoir closed) contacts 9 and 11 are closed when 20R valve is closed. Relay 33RX (retract auxiliary) normally closed contacts 4 and 1 are closed when the piston is fully retracted. Relay 46MR is latched closed through contacts 9 and 11 and through 33EX (extend auxiliary) contacts 6 and 7. The normally closed contacts of 20EC (empty closed) were added to prevent a relay race.

Relay 20E Opening and Food Delivery

The piston will pause at its fully retracted position to allow closing of 20R and opening of 20E (empty valve) before the empty stroke begins. Valve 20E cannot be opened until contacts 7 and 6 of 20RC are closed. This is an interlock to eliminate the possibility of having both valves open at the same time. The 5ME relay prevents the piston from moving until 20E is fully open. When 20EO (empty open) is active, it closes contacts 6 and 7. Relay 20RC is not active until 20R is fully closed. At that time contacts 3 and 1 of 20RC will close. Relay 33EX has been active since the piston left its fully extended position and began its retract cycle. With 46MR and 5ME active, the linear actuator motors (see fig. 7) will push the food through valve 20E, down the dispensing tube, and into the cage.

Relay 20E Closing and End of Feeding Cycle

When the piston is fully extended, limit switch 33E is contacted, dropping out 33EX and 33EX2. Relay 5ME is de-activated, stopping the motors, by contacts 9 and 11 of 33EX. Valve 20E is closed by the normally closed contacts 4 and 1 of 33EX. When 20E is fully closed, normally closed contacts 5 and 6 of 20EC (empty closed) open, dropping out 46MR. The system is now ready for the next feeding sequence command from the control room timer (see appendix for parts information).

Discussion

After the experiment, the paste delivered per feeding was 120 g/feeding in both feeders. The approximately 15% reduction in food delivered could be due to the change in consistency of the food or the capacity of the food reservoir. The feeder system measures volume so if the consistency of the food changed significantly it may have affected the weight of the volume fed. It is also possible that the feeders were nearing capacity of delivery. They were loaded with 12 kg of food each and had delivered approximately 8 kg by the final feeding. Since at least 2 kg are needed to fill the tubing and valves, the 2 kg remaining may not have been enough to keep it working properly. Further testing and a more extensive calibration with the centrifuge running will enhance the accuracy of the system.

Water and waste systems worked well. Water was used at a higher rate than expected in the centrifuge cage (74.2 ml/rat/day) compared with control (16.6 ml/rat/day). Although there was no evidence of leakage, because of the increased forces on the lixits, more water may have been released when activated than the animals consumed. The drain on the centrifuge cage waste system became blocked by hair and bits of the food paste, so the waste overflowed the collection tray. A larger drainage hole will prevent such blockage in the future. The overflow did not come in contact with the animals and leaked out of the outer cage. The ammonia levels, measured with a passive detector (Gastec Dositube Corp., Ayase City, Japan), were below detectable limits (measuring range and calibration scale for 1 hr test time is 25–500 ppm) for both centrifuge and stationary cages. Water and waste systems functioned as expected in the stationary cage.

The entire system functioned within desired specifications and maintained the animals well for the 14 day experiment.

Appendix

Electronic parts list

Quantity	Description
2	ASAHI America Electromni 2.54 cm valves
1	ESE 8 channel timer ES-720
2	Linear actuator motor 3601-001 from Minarik
2	30.48 cm linear actuator screws
4	SSAC TDMB 422D time delay relays
5	MS3470W12-3P connector receptacle
1	MS347OW12-10S connector receptacle
1	MS3470W12-10P connector receptacle
1	MS3470W14-19S connector receptacle
1	MS3476W14-19P connector plug
5	MS3476W12-3S connector plug
1	MS3476W12-10S connector plug
1	MS3476W12-10P connector plug
10	120VAC electromagnetic relay
14	Relay sockets

Mechanical parts list

Quantity	Description
1	Cover, food reservoir; aluminum plate 29.85 cm diameter, 4.8 mm thick
6	Clips, reservoir cover; 25.4 × 6.4 mm bolts
1	Reservoir; stainless steel stock pot 7.57 liter, 22 ga, Polarware Co. 8Y-0
1	Funnel; stainless steel 22.86 cm major diameter, 11.43 cm high
4	Fitting; stainless steel 25.4 mm
1	Tube; stainless steel, internal diameter 28.6 mm, wall 1.5 mm
1	Piston; 27.8 mm diameter, Teflon™, dual "O" rings
1	Food tray; stainless steel 0.8 mm thick, dimensions 15.24 × 10.16 × 1.27 cm
1	Cage; Plexiglas™ 6.4 mm thick
1	Floor screen; stainless steel, hole size 12.7 mm^2
2	Lixits
1	Tygon tubing; internal diameter 6.4 mm
1	Waste tray; stainless steel 0.8 mm thick

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
January 1994

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
An Automatic 14-Day Paste Diet Feeder for Animals

5. FUNDING NUMBERS
199-08-12-06

6. AUTHOR(S)
Marilyn Vasques, Jerry Mulenburg, Dan Gundo, and Jon Griffith*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ames Research Center
Moffett Field, CA 94035-1000

8. PERFORMING ORGANIZATION REPORT NUMBER
A-94037

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-108804

11. SUPPLEMENTARY NOTES
Point of Contact: Marilyn Vasques, Ames Research Center, MS 239-11, Moffett Field, CA 94035-1000; (415) 604-6120
*Bionetics Corporation

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified — Unlimited
Subject Category 51

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

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14. SUBJECT TERMS
Automatic feeder, Animal feeding, Cages

15. NUMBER OF PAGES
14

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		