50cy.

Atomic Energy of Canada Limited

PERFORMANCE OF THE NRX SHUT-OFF RODS

101-296

by

R.E. MANSON

Chalk River, Ontario
August, 1965

AECL-2299

PERFORMANCE OF THE NRX SHUT-OFF RODS

IOI-296

by

R. E. MANSON

SYNOPSIS

A new type of shut-off rod of electro-mechanical design was developed by the American Machine and Foundry Company for use in the NRX reactor following the accident of 1952. The new rods were installed in May, 1956, as part of the control system conversion program which was completed in 1958.

Some problems were encountered with limit switch adjustment but minor modifications in design led to much improved operation. The performance of the rods also improved as more experience was gained in the maintenance and adjustment of the various headgear components. Each headgear is now overhauled once a year on a routine basis.

The present design of shut-off rod is considered to be very satisfactory. There has only been one occasion when a shut-off rod has failed to come fully down on a trip. Rods have failed to operate correctly on five other occasions but these occurred during shutdown periods or when the reactor was being shutdown manually.

AECL-2299

Atomic Energy of Canada Limited

PERFORMANCE OF THE NRX SHUT-OFF RODS

IOI-296

by

R. E. MANSON

Chalk River, Ontario
August, 1965

AECL-2299

TABLE OF CONTENTS

ILLUSTRATIONS

PERFORMANCE OF THE NRX SHUT-OFF RODS (AMF TYPE)

HISTORY

The first shut-off rods designed for the NRX reactor were air-operated. They were raised by air pressure and were fired into the reactor on a trip by 100 lb/in^2 air, using a piston operating in a steel cylinder in the headgear of each rod. This design was intended to meet the specification that the reaction must be stopped in ½ second. In order to do this, the shut-off rods had to be halfway into the reactor (a travel of 5 feet) within 0.3 seconds, the aim being to shut down the reactor under all possible conditions that could arise.

The pneumatic shut-off rods proved to be unreliable because of the very close tolerances required for the piston. Any slight misalignment or small amount of rust or dirt caused the rods to stick or jam, and this occurred on numerous occasions.

After the NRX accident in 1952, the safety and reliability of the control system was examined by AECL personnel as well as by an outside engineering firm. Two major recommendations were made at that time.

1. A better design of shut-off rods should be devised.

2. There should be automatic back-up protection for the shut-off rods such as an automatic heavy water dump on a trip.

The American Machine and Foundry Company was given a contract to design and fabricate a new type of shut-off rod. As it was obvious that no practical system could be found that would stop all accidents, the specifications were relaxed and AMF came up with a rod of an electro-mechanical design that would drop halfway into the reactor in 0.7 seconds, a spring being used to give the initial acceleration. There was little possibility of sticking as no close tolerances were required.

To implement the second recommendation, a partial heavy water dump was incorporated in the system and it was also decided to have the reactor power controlled by means of heavy water

level variation rather than by a control rod. With the more dependable shut-off rods plus the back-up protection of the heavy water dump it was possible to reduce the number of shut-off rods from 18 to 6. The six shut-off rods are located in the reactor in such a way that the milli-k value is one-half that of the original eighteen rods.

The new shut-off rods were installed in the spring of 1956. The conversion of the control system was made in two stages over a two-year period and the system was carefully checked out. The program was completed in April, 1958, but the control rod and other obsolete equipment were not removed until July, 1958.

The new control system has worked very well and the performance of the AMF-type of shut-off rods has been very good. As would be expected, a number of revisions were required in the design of the shut-off rods during the early months of operation, chiefly to improve the operation and adjustment of the limit switches. In addition to these improvements, annual preventive maintenance on the shut-off rod headgears has led to a remarkably trouble-free performance.

DESCRIPTION OF THE AMF TYPE SHUT-OFF RODS

The absorber section of the AMF shut-off rod is suspended from a steel cable which winds around a drum in the rod headgear located in the upper header room. The absorber is a molybdenum steel tube filled with boron carbide slugs.

The absorber is raised or lowered in an outer assembly by a two-phase motor which drives the drum through a worm gear and a magnetic disc clutch (see Figures 1 and 2). The rod is raised by energizing the clutch and driving the motor to turn the drum. To release the rod, the clutch is de-energized and the rod falls by gravity, a compression spring in the headgear giving the initial acceleration from the top position.

A rotary hydraulic pump acts as a snubber during the bottom third of the rod's travel. A stack of twelve pick-up rings ride on the drum shaft. As the rod falls, the rings pick up each other in sequence, the last ring engaging a

positive stop which prevents backlash of the cable by arresting the motion of the drum after the rod reaches the bottom.

Attached to the ninth ring is a spur gear which couples the shaft to the hydraulic snubber when the rod is less than 4 feet from the bottom. The snubber consists of a spur gear reducer driving a rotary vane which operates past a metering groove thus limiting the amount of hydraulic fluid which may pass the vane. At high speeds, such as when a rod is dropped, the metering action offers a large resistance to the rod during its last 4 feet of travel. The resistance is a function of the speed and the vane position. Maximum resistance is offered shortly after the snubber is picked up. The effect of the decreasing rod speed is counteracted by the decrease in the depth of the metering groove resulting in an essentially linear rod deceleration until the rod is almost down. Thus the velocity of the rod is smoothly reduced to practically zero and the rod strikes the lower mechanical stop with no appreciable impact.

Also geared to the drum is a shaft on which are mounted three cams for operating limit switches, and a potentiometer for position indication. The neck of the headgear originally contained four limit switches actuated by two flat finger-type cams at the top of the rod. These four switches proved difficult to synchronize and were replaced in 1957 by one switch having four contacts. Difficulty was also encountered with bending of the neck limit switches due to misalignment of the cams. To solve this problem, the two original cams were replaced by one simple circular cam (see Figure 3) and the limit switches in the neck were moved to the outside with actuation by a single pin passing through the neck. This eliminated all wiring and limit switches inside the neck and resulted in much improved operation.

The original rod had an actuating rod assembly which actuated the down limit switch when the rod was at its lower limit, but much difficulty was encountered in obtaining proper indication. The actuating rod was too flexible and bent under stress and there were also electrical faults due to the wet conditions at the switches. Several modifications were tried without much success. The lower limit switch assemblies and the bottom sections of the push rods were finally removed from all the rods in 1958. "Rod down" indication is now provided by a

cam in the headgear operating a switch. This has proved satisfactory except that a hazard exists should a sorber section break during a trip and the upper part be later raised to actuate the upper limit switch. Further development work was done to devise a suitable lower limit switch but no satisfactory solution was found.

There are thus four limit switches at the present time:

a) 3 limit switches, cam operated by the drum. Two of these control the operation of the motor. The third provides indication when the rod has reached its lower limit, operates contacts in the drop time circuit, and operates interlock contacts in the control system.

b) 1 limit switch, double throw, double pole type actuated by the top section of the absorber, which actuates the rod sequence control circuit and provides an indication when the shut-off rod has reached its upper limit.

A general data sheet for the NRX shut-off rods is included in this report (page 6). For a more detailed description of the rods and of the control circuit, reference should be made to the NRX Design Manuals A-15-1 to A-15-4, to the AMF Operation and Maintenance Manual ER-6936, and to the NRX Reactor Handbook, IOI-225.

ROD PERFORMANCE

The information required for assessing the performance of the NRX shut-off rods was obtained from the NRX Rod Office records, from the files of correspondence, and from the service record for the headgears as given in the Instrument Shop log. Discussions were held with several persons who have had experience with the testing, operation and maintenance of the rods.

For the purpose of the operating records, the NRX shut-off rod is considered as having two main sections:

1) the headgear, and

2) the barrel, which includes the sorber and the outer shell.

The barrels were changed fairly frequently when the rods were first placed in use, chiefly because of faulty push-rod operation and trouble with the lower limit switches. Since the lower limit switches were removed in 1958, there has seldom been any reason for changing a barrel except for two occasions of a stuck absorber and another incident when the cable broke. Practically all of the shut-off rod problems are related to the operation of the headgear and the balance of this report will deal only with the headgear problems.

GENERAL DATA

NRX Shut-off Rods

Total height	34 ft 1½ in.
Total weight	240 lb
Weight of headgear	91 lb
Weight of absorber	19.45 lb with cable
Dimensions of assembled headgear	
Height	24½ in.
Width	9⅞ in.
Depth	11 in.

Motor 100 Watt, 2 phase, 2 pole, low inertia servo motor with a synchronous speed of 3600 rev/min max. Diehl Manufacturing Co., Finderene, New Jersey

Drum Speed 20 rev/min

Maximum speed rod can be driven by motor 20 ft/min

Drop Time 0.7 second maximum to pass mid position

Full insertion drop time	1 to 1.35 seconds
Removal time	25 seconds minimum per rod
Removal rate	0.3 mk/sec
Total load (6 shut-off rods)	50 mk
Shutdown rate	34 mk/sec

Clutch Warner Electric Brake and Clutch Co., Beloit, Wis. Rated at 90 V DC and 0.10 amp

Potentiometer 5000 ohm resistance
Beckman Helipot Corporation, Toronto, Ont.

Sorber Section Tube length 10 ft 8.31 in.
1¼ in. OD x 0.49 in. wall

Boron carbide, Norbide B_4C, Norton Company
Hot pressed discs, 1½ in. long, Sp.G. 2.2
Weight of boron carbide 11.4 lb (8.9 lb boron)

Cable Assembly

Cable 3/32 in., 7 x 7 strand
Type 304 stainless steel
Length, 12 ft 9¾ in. under 100 lb tension
American Machine and Foundry Co., Greenwich, Conn.

HEADGEAR PERFORMANCE

The headgear are numbered from 1 to 10, six being in use at any time and four are spares. The shut-off rods are located at the following reactor positions:

Sequence	Reactor Position
1	M8
2	D14
3	L23
4	F22
5	G7
6	P16

The headgear removals and installations, as recorded in the Rod Office records, have been plotted in the form of bar charts, Figures 5 and 6. Figure 5 gives the operating history of headgear Nos. 1 to 10 for the period 1960 to 1965. The reactor position for each installation is indicated and the reason for each removal is given. In Figure 6, the same records are used to indicate the successive and continuing occupancy of the sequence positions Nos. 1 to 6 by the various headgear. In this case, the number in each box represents the particular headgear occupying the reactor position during the period indicated. Only the long-term installations have been plotted.

The reasons for removal are not always given in the rod records. They are usually listed as "for repairs", "routine maintenance", "modifications", "faulty operation" etc. The reasons for malfunction of a rod may not be known at the time of removal and sometimes cannot even be determined when the headgear is later inspected and tested. The following is a list of some of the faults that have been recorded, and some of the possible causes:

Limit switch trouble (by far the greatest number)
Ground fault (Failure of insulation, wire cut, wet conditions)
Noisy operation (Worn gears or bearings, clutch maladjustments, lubricant needed)
Drop time too fast or slow (Snubber adjustment, change of snubber oil)
Absorber sticking (screw fallen into barrel, cable broken)
Cable broke (faulty limit switch operation)
Clutch trouble (clutch needs re-facing).

The headgear are removed once a year for general overhaul and preventive maintenance, most of the removals shown in the chart being for this reason. The headgear service record, as summarized from the Instrument Shop log book, is shown in Appendix "A" of this report. During the annual overhaul, the following maintenance is done as required.

Replace all bearings, motor pinion and associated brass gear
Rewire completely
Inspect tabs and shaft
Inspect drum, shaft and associated gear
Inspect gear on snubber assembly
Lubricate
Adjust tension on spring
Adjust cams and limit switches
Check clutch assembly, reface clutch
Change snubber oil. Put orifice in vane if required.
Test for drop-time.

The excellent operating record for the NRX shut-off rods over the last few years is largely due to the annual preventive maintenance program. Other factors that have led to relatively trouble-free operation are the modifications and improvements that have been made in the arrangement of the limit switches and actuators, and greater experience in the adjustment of the switches and of the snubber.

REVIEW OF SHUT-OFF ROD OPERATING PROBLEMS

LIMIT SWITCHES

The original specifications for position indication called for a device on the sorber section of each rod for "rod down" indication. Considerable trouble was experienced with the operation of these lower limit switches during the first two years of operation. The switch assembly was located at the bottom of each rod in the lower header room and was actuated by a push rod which moved down as the sorber section reached its lower limit.

On many occasions, the lower limit switches were not actuated when the sorber fell on a trip or would not clear when the rod was lifted. Investigation usually showed that the sorber had fallen when required to do so, the trouble generally

being due to malfunction of the switch or sticking of the push-rod. The trouble with the switches was due, in large part, to the wet conditions in the lower header room causing ground faults. Of a total of 64 faults between January and October, 1957, 51 were traced directly to lower limit switch malfunction. Shut-off rod failures other than those caused by the lower limit switches numbered 13.

In order to obtain more reliable indication, it was proposed in January, 1958, to dispense with the lower limit switches and obtain the rod down signal by means of the cam limit switch driven by the cable drum in the headgear. As this was a policy change, approval was sought and obtained from the Pile Operating Committee, and the changeover was made in July, 1958, the switch assemblies being removed. Satisfactory 'rod down" indication has been obtained since that time.

An analysis was made of possible shut-off rod failures to determine the protection afforded by the new cam operated lower limit switch. The following conditions were considered.

1. Reactor Operating. Cable breaks, rod drops to the bottom The cam operated switch will not be actuated. Rod actuated upper limit switch will indicate rod no longer at the top and will trip the reactor.

2. Reactor Trips. Rod sticks part way down. Cam operated switch will not be actuated as snubber stops cable from unwinding. The rod actuated upper limit switches will indicate rod has left the top.

3. On raising, the cable breaks. Rod remains at the bottom. Drum keeps turning and thus cam switches will be operated, indicating that rod has left the bottom. The rod actuated upper limit switches will not be operated, preventing further raising of the rods. If the last rod in sequence remains at the bottom, the "all up" lights will not be energized.

4. Clutch sticks. Motor keeps driving until last cam limit switches are actuated. Rod actuated upper limit switches indicate that the rod has left the top. Alarm and/or trip indicated by rod monitoring circuit.

5. Rod breaks and part of rod remains at the bottom. The upper part of the rod will be raised to the top and will actuate the upper limit switches. Normal conditions will be indicated by the instrumentation. The broken section remaining in the reactor will overheat with no indication of the situation being apparent.

This last condition represents a real hazard. It was accepted at the time although a considerable amount of development work was subsequently done to devise an acceptable lower limit switch assembly. A mock-up of a proposed unit was tried in the NRX test station but was not found entirely satisfactory. No development work is being done at the present time.

As would be expected, the performance of the headgear improved as more experience was gained in the maintenance of the various components particularly in the adjustments required for the limit switches and the snubber. On several occasions, it was found that headgear which checked out at the test station would not function properly when installed in the reactor. The difficulty was eventually traced to the ball at the top end of the cable not seating properly in the slot on the drum, the shoulder of the ball shank hanging up on the edge of the slot. This had the effect of shortening the cable by about ¼ inch and thus invalidating all the fine adjustments that had been made. Special care is now taken to see that the ball is always seated properly in the socket on the drum.

As mentioned previously, the operation of the neck limit switches was considerably improved by changing from a double prong type cam to a single circular cam actuating a single pin passing through the neck. There has been some wear of the pin but this is a minor problem.

SNUBBER ADJUSTMENT

The snubber must be adjusted periodically in order to meet drop-time specifications. Considerable difficulty was experienced with this adjustment until a back-log of experience was built up by the maintenance personnel.

The specification for full rod insertion time is 1 to 1.35 seconds, based on half-way (5 foot) rod insertion time of

0.7 second maximum. In practice, the full drop-time is adjusted between 1.10 and 1.35 seconds.

The hydraulic fluid originally specified for the snubber was Esso "Univis J-43". No. 47 oil or mixtures of No. 43 and No. 47 are now also used to obtain the required drop time. Further adjustment may be obtained by changing the tension on the take-up spring, or by changing the size of the orifice hole.

CLUTCH

Some clutch slippage has occurred. The clutch is not considered to be strong enough as presently designed. Although this is a safe fault, it can interfere with the continuous operation of the reactor.

The clutch plate was originally composed of two concentric steel rings separated by a composition material. The composition material was intended to act as a bearing surface but was found to give insufficient lift and was machined down leaving a narrow metal bearing surface.

The clutch plates have been found to wear considerably over a period of one year so that it is now the practice to have them refaced during the annual overhaul.

Headgear have been removed from the reactor on three or four occasions because of noisy operation. This fault is usually due to maladjustment of the clutch and is corrected by dismantling and servicing the clutch assembly.

MOTOR

The motor in the headgear has given no trouble. There have been occasions where the motor has stalled and cut out on overload but this has been due to improper cam setting.

CABLE

There was one case of a broken cable in the reactor (HG No. 4, 1961), the drum also being damaged at that time. On

another occasion (HG No. 8, 1962) a cable was broken at the test stand. The reasons for these incidents have not been definitely established. Limit switch maladjustment may have been the cause.

The cable length is specified at 12 ft 9¾ in. and this length must be held if the headgears are to be interchangeable.

WIRING

Some initial difficulty was encountered with the wiring being bared and broken by the gear train and cable. The wiring was rerouted and guards were installed. When the limit switches in the neck were later moved to the outside, all wiring inside the neck was eliminated. This led to much improved operation.

On one occasion when a headgear was removed because of a ground fault (HG No. 6, 1961) a wire was found caught between the top cover and the case.

The wiring is inspected during the annual overhaul of each headgear and is completely changed if this is indicated.

GENERAL PERFORMANCE

During the period of May 5, 1956 to June 30, 1965, the shut-off rods were called upon to shutdown the reactor a total of 1624 times (1016 trips, 608 shutdowns). There have been 6 occasions in this time when a shut-off rod failed to operate correctly and 3 of these occurred during shutdown periods when the reactor was not operating. On two occasions, the reactor was being shutdown manually. There has only been one occasion during normal operation when a shut-off rod has failed to come fully down after a trip.

The following is the history of the failures that have occurred:

Jan.22, 1958 Sorber stuck ⅔ of the way down during a manual shutdown. Examination revealed a star washer lodged in the barrel.

Feb. 27, 1958 During a manual shutdown, the sorber stuck 100 cm from the bottom. The fault appeared to be due to an unidentified metal fragment.

April 11, 1961 During testing on a scheduled shutdown, the sorber was found stuck in the "up" position. After the headgear was changed, the lifting cable broke during a drop test (the sorber completed its fall). The cause of the fault was not definitely established but there is a possibility that the cable had not been properly installed on the headgear.

Nov. 23, 1961 During a shutdown period, a sorber stuck approximately one foot from the bottom during a routine check. Investigation revealed that the fault was due to a headgear. The trouble was believed due to a small set screw which loosened and bound on the cable drum housing.

Mar. 19, 1963 During shutdown period, a sorber failed to go fully down. A borescope examination revealed no foreign objects. The tip of the neck limit switch plunger on the headgear was found broken off, which could have been the cause of the sticking.

May 16, 1965 During operation of the reactor, the reactor tripped and a sorber failed to go fully down. The rod freed itself when lifted manually and dropped the remaining 6 inches. A boroscope examination revealed a bolt jammed in a joint in the wall of the barrel.

This last incident is the only failure to date of an AMF shut-off rod on a trip.

Both the operations and the maintenance groups are very well satisfied with the present design of the NRX shut-off rods and consider the performance to be exceptionally good.

A P P E N D I X A

NRX SHUT-OFF RODS

SUMMARY OF HEADGEAR SERVICE RECORD 1960 to 1965

(from Instrument Shop Log Book)

HG No. 1

28. 4.61	Readjusted cams and put orifice in snubber with No. 47 oil.
26.11.62	Completely overhauled. Changed wiring and plug. New brass worm wheel gear. A lot of snubber difficulty.
20. 9.63	Completely overhauled. Changed brass gear and worm wheel - clutch assembly.
28. 9.64	Completely overhauled. Replaced all bearings. Faced clutch. Assembled lubricated and tested. Snubber oil No. 43 used.
29. 6.65	Rewired completely. Attached new 37 pin connector. Adjusted cams and limit switches.

HG No. 2

28. 9.60	Completely overhauled. Replaced worm bearings and gears. Lubricated. Replaced tabs and drum shaft with new ones from AMF for testing. Snubber oil No. 47 used. Removed orifice.
8.12.60	Removed tabs and shaft for inspection. Replaced with new shaft and old tabs. Reassembled and tested. Made orifice in snubber with No. 65 drill. Used No. 47 oil.
6. 1.61	Found ground fault when installed in the reactor. Ground fault found at solder terminal on lower rod limit switch.
10. 4.61	Rod upper limit switch set for maximum rod travel.

3. 1.62 Completely overhauled. Replaced all bearings, motor pinion and associated brass gear. Rewired limit switches. Snubber oil mixture of No. 43 and No. 47 oil used. Tested.

30. 4.62 Fabricated worm gear and motor take-off gear. Adjusted tension on spring, checked limit switches. Tested.

6. 8.63 Completely overhauled. Complete wiring change.

12. 5.64 Completely overhauled. Bearings changed. Changed two gears on snubber assembly.

HG No. 3

11. 8.60 Completely overhauled. Lubricated. Mixture of No. 43 and No. 47 snubber oil used.

10. 1.61 Replaced motor pinion and worm shaft gear to eliminate noise. Rod upper limits did not come in. Installed longer actuating pin. Changed snubber oil. Changed drainage bearing. Increased tension on spring one notch.

15.11.61 Completely overhauled. Replaced bearing and rewired switches. Replaced complete clutch assembly. Replaced motor pinion and worm shaft gear. Used mixture of No. 43 and No. 47 snubber oil.

31. 8.62 Rod lower limit switch coming in too soon. Adjusted. Changed oil in snubber (no. 43 and No. 47). Tested.

13. 4.64 Completely overhauled. Changed ratio gear box on switch assembly. Completely rewired.

29. 7.65 Completely overhauled. Replaced bearings and "O" rings. Adjusted cams for proper sequencing.

HG No. 4

29. 9.60 Completely overhauled. Replaced all worn bearings and gears. Lubricated. Drop time checked.

5. 1.61 Rod upper limit switch did not come in. Installed longer actuator and adjusted cam upper limit switch. Checked drop time. Adjusted take-up spring one notch.

10. 4.61 Checked upper limit switch operation. Adjusted.

12. 4.61 Cable broke in reactor. Replaced. Checked out O.K. at test station. Drum was damaged by broken cable. Replaced drum and shaft and associated gear. Re-faced clutch. Put orifice in snubber vane. Checked drop time.

9. 6.61 Replaced broken drum shaft and broken upper rod limit switch actuating pin. Relubricated and tested.

4.12.61 Lower limit switch not operating properly. Repaired snubber bearings found to be worn. Replaced No. 43 and No. 47 snubber oil used. Drop time checked.

26. 2.62 Installed longer plunger on rod upper limit switch. Reset cams and checked. Drop time checked.

10. 7.62 Installed shorter plunger on rod upper limit switch. Lubricated worm gear and take-off gear. Reset cam upper limit switch.

4.12.62 Completely overhauled. Complete wiring change. Clutch plate refaced.

28. 1.63 Inspected. No fault found.

19. 3.63 Replaced broken upper rod switch actuator.

21. 4.63 Headgear would not drive up or down. Trouble not found.

5.11.63 Replaced broken rod upper limit switch. Reset upper limit cam. Lubricated.

24. 1.64 Completely overhauled. New clutch plate.

6. 5.65 Completely overhauled. Replaced lower cam switch and neck switch actuator. Refaced clutch plate.

HG No. 5

15. 8.60	Completely overhauled. Bearings replaced. Lubricated. Drop time tested.
15.10.61	Completely overhauled. Replaced bearings. Switches rewired. Replaced cable drum. Machined clutch plate. Lubricated. Tested.
2. 5.62	Checked headgear. Lubricated with Molykote. No changes made. Tested.
6. 9.62	Checked headgear. Lubricated tabs and pinions.
30. 5.63	Reported unsatisfactory. Checked limit switches. Changed oil in snubber.
7.11.63	Completely overhauled. Complete wire change. Headgear had finished a cycle test of 1500 drops. Changed brass worm wheel gear and clutch plate. Tested.
2. 2.65	Completely overhauled. Lubricated. Changed motor pinion and pinion gear. Changed snubber oil. Tested.

HG No. 6

22. 6.61	Completely overhauled. Rewired limit switches. Replaced bearings, motor pinion and worm shaft gear. Changed snubber oil. Tested.
31. 8.61	Removed from reactor because of ground fault. Wire found caught between top cover and case. Repaired.
16. 2.62	Completely overhauled. Installed new 37-pin cannon connector. Rewired completely. Replaced bearings and brass take-off gear from motor. Made smaller orifice hole in snubber. Changed snubber oil. Tested.
4. 4.62	Installed new neck piece and new type of rod upper limit switch. Tested.

23. 5.62 Headgear motor found to be cutting out on overload when rod near upper end, probably when rod lifting rod actuator. Checked, but trouble had cleared.

30. 5.62 Motor cutting out on overload. Found cam setting too close to top, causing motor to stall. Lowered cam upper limit. Tested O.K.

15. 9.62 Modified rod upper limit neck switch to allow more adjustment. Mounted a pin connector plug and receptacle on cover box and moved air connection.

25.10.62 Modified neck switch would not clear. Raised switch. Checked O.K.

21.12.62 Headgear removed to reset upper limit switches.

31. 5.63 Headgear reported unsatisfactory. Bench check O.K.

23.12.63 Completely overhauled. Replaced all bearings and brass worm gear. Found noisy. Replaced worm gear as keyway was too large. Changed snubber oil. Tested.

21. 1.64 Neck switch trouble in reactor, not resetting when rod driven down. Fault cleared on testing.

3. 2.65 Completely overhauled. Lubricated. Snubber oil changed. Tested.

HG No. 7

2. 2.61 Completely overhauled. Worn bearings changed. Lubricated. Snubber oil changed. Tested.

5.12.61 Headgear jamming and would not drive up or down. It was found that a set screw in the drum assembly had loosened and was catching on the casting. Headgear appeared to be generally in bad shape and was completely overhauled. Bearings and worn gears were replaced. Switches rewired. Tested.

20. 3.63 Completely overhauled and rewired. Refaced the clutch plate. Tested.

15. 4.64 Completely overhauled. Snubber dismantled and serviced. Motor pinion and brass gear changed. Motor bearings changed. Tested.

15. 7.65 Completely overhauled. Snubber dismantled and serviced, No. 60 Univis oil used. Cams adjusted for proper sequence of contacting switches. Tested.

HG No. 8

6. 2.61 Completely overhauled and lubricated. Changed all bearings. Tested.

7. 4.61 Removed from reactor with faulty cam lower limit switch. Switch replaced, cams adjusted. Tested.

10. 7.61 Rod lower limit switch and rod upper limit switch not coming in. Noisy on down drive clutch dismantled and serviced. Switches adjusted. Tested.

14. 3.62 Completely overhauled. Limit switches rewired. Bearings replaced. Motor pinion gear replaced. Tested.

4. 7.62 Cable broken on test stand. Clutch was found off-set. Reset clutch and switches. Tested.

10. 4.63 Completely overhauled. Wiring changed. Clutch re-faced. Cam and rod limit switches reset. Tested.

31. 8.64 Completely overhauled. Clutch refaced. Switches reset. Tested.

HG No. 9

1. 9.61 Completely overhauled. Switches rewired. Bearings replaced. Motor worm and pinion gears replaced. Cam lower limit switch reset. Clutch refaced. Tested.

13. 2.63 Completely overhauled and rewired. A knock developed on testing. Changed reduction motor on switch assembly but knock still present. Changed complete clutch assembly and knock cleared. Tested.

16. 3.64 Completely overhauled. Tested.

29. 6.65 Completely overhauled. Switches reset. Tested.

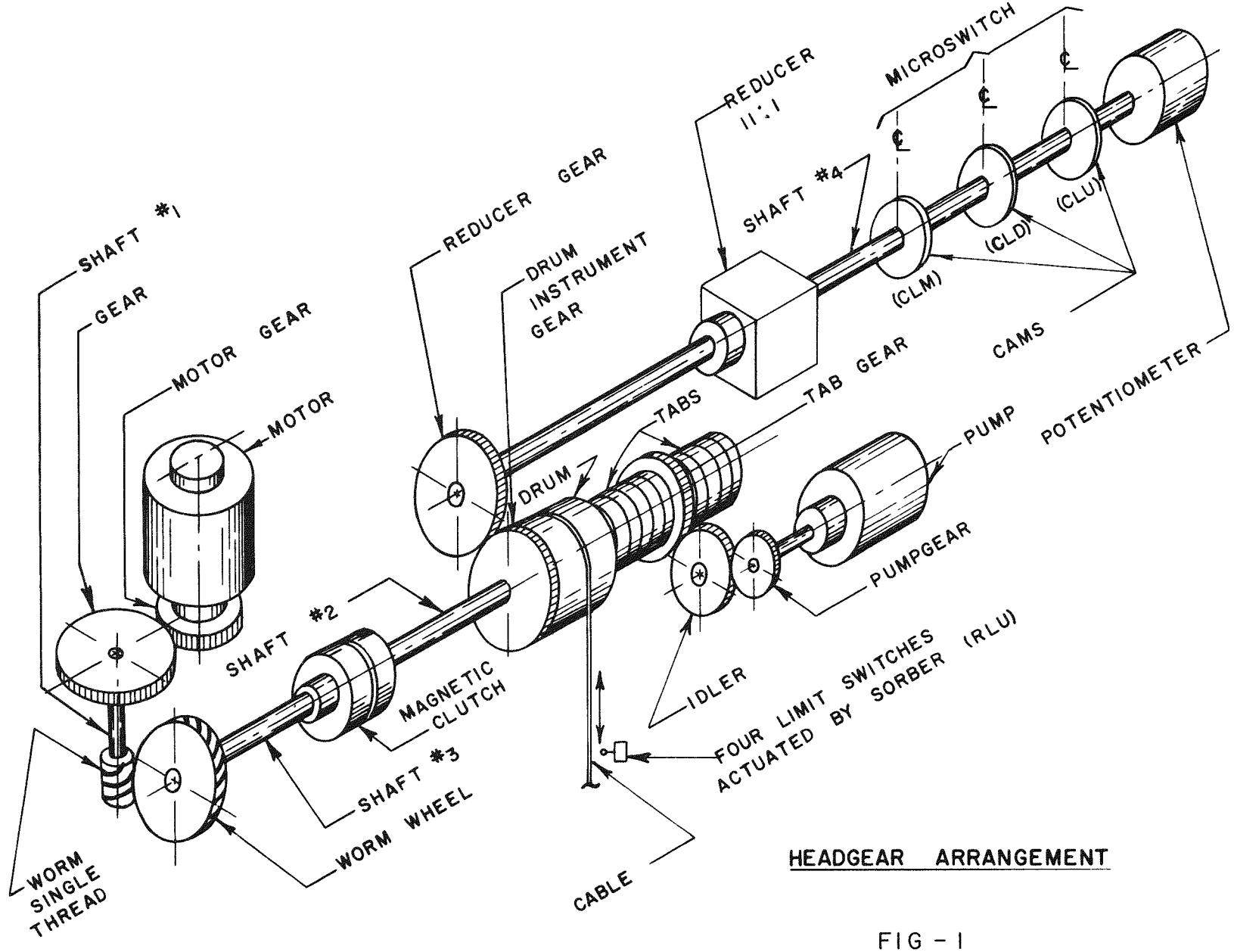
HG No. 10

3. 5.61 Completely overhauled. Bearings replaced. Lubricated. Snubber serviced. Oil changed. Tested.

10. 1.63 Completely overhauled. Bearings replaced where necessary. Lubricated. Completely rewired. Fitted new cannon connector. Clutch plate refaced. Tested.

19.12.63 Completely overhauled. Bearings replaced. Lubricated gears and tabs. Replaced cam lower limit switch. Snubber oil changed. Tested.

2. 2.65 Completely overhauled. Lubricated. Snubber oil changed. Tested.



HEADGEAR ARRANGEMENT

FIG - 1

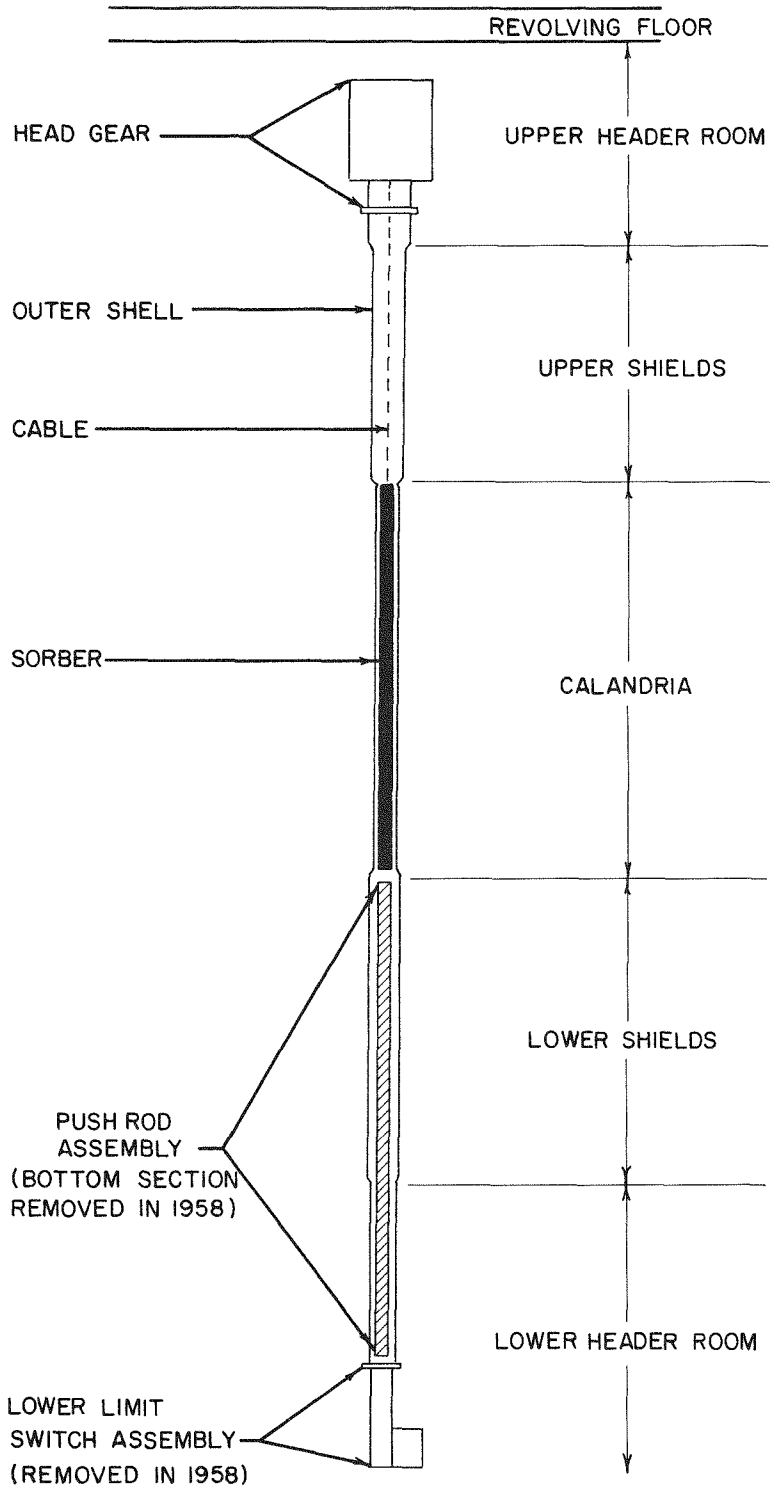


FIG. 2

A.M.F. SHUT-OFF ROD

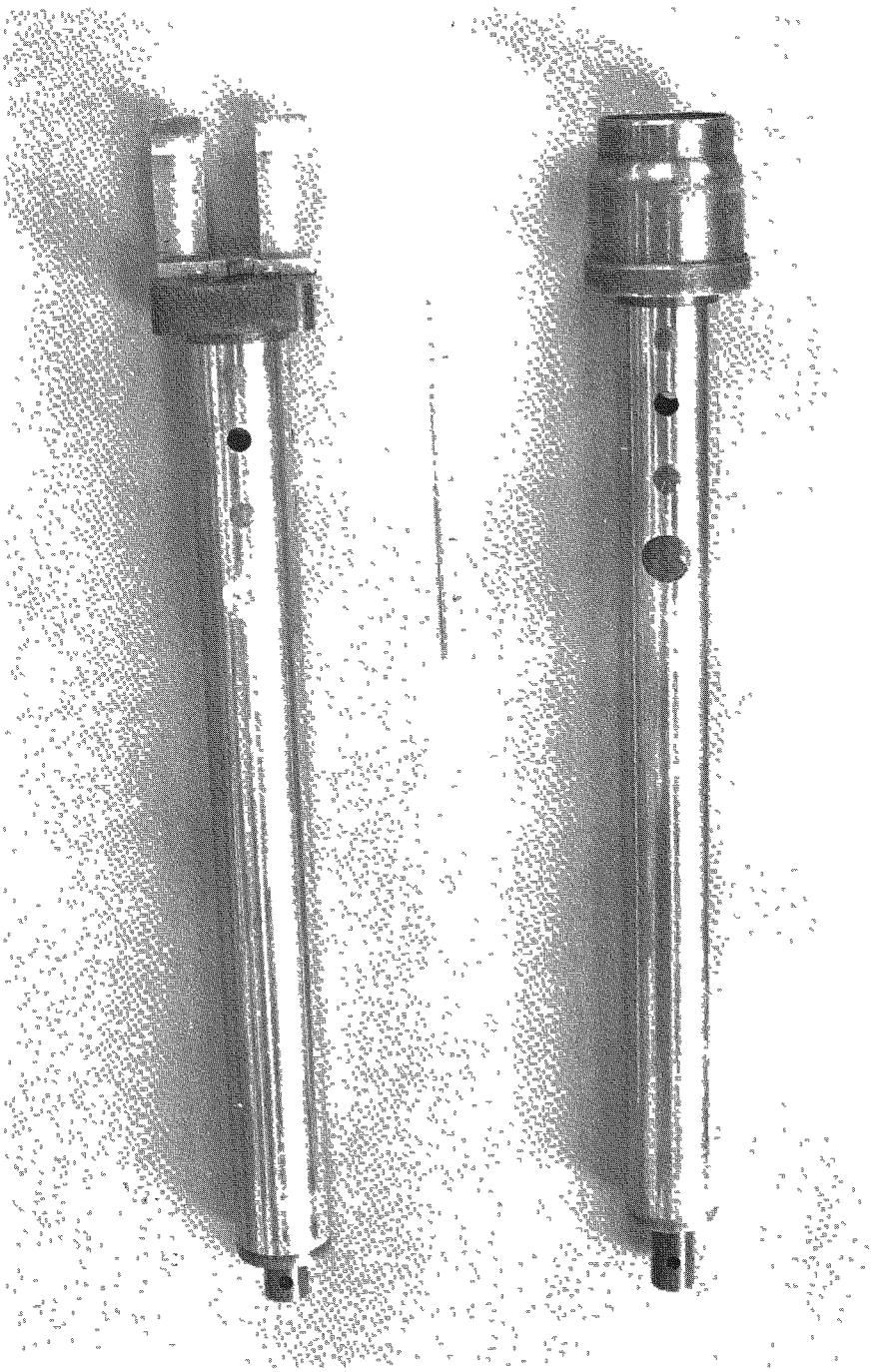
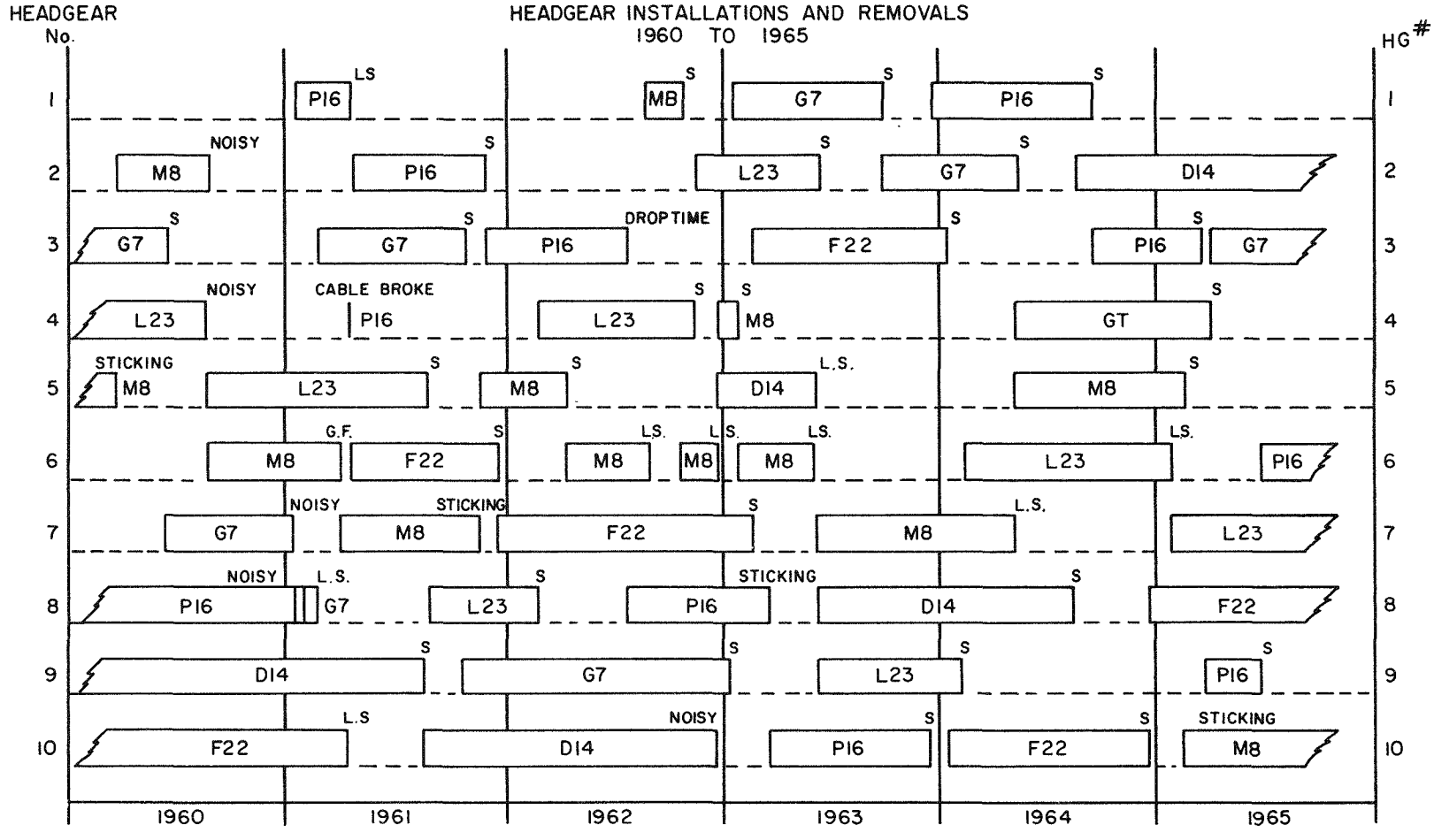


FIGURE 3
Top Section of Absorber CAM Actuators

FIGURE 4
Headgear Assembly NRX Shut-Off Rod

PERFORMANCE OF NRX SHUT-OFF RODS



LEGEND

L.S. LIMIT SWITCH TROUBLE
S ROUTINE SERVICE CHECK
G.F. GROUND FAULT

FIG. 5

PERFORMANCE OF NRX SHUT-OFF RODS

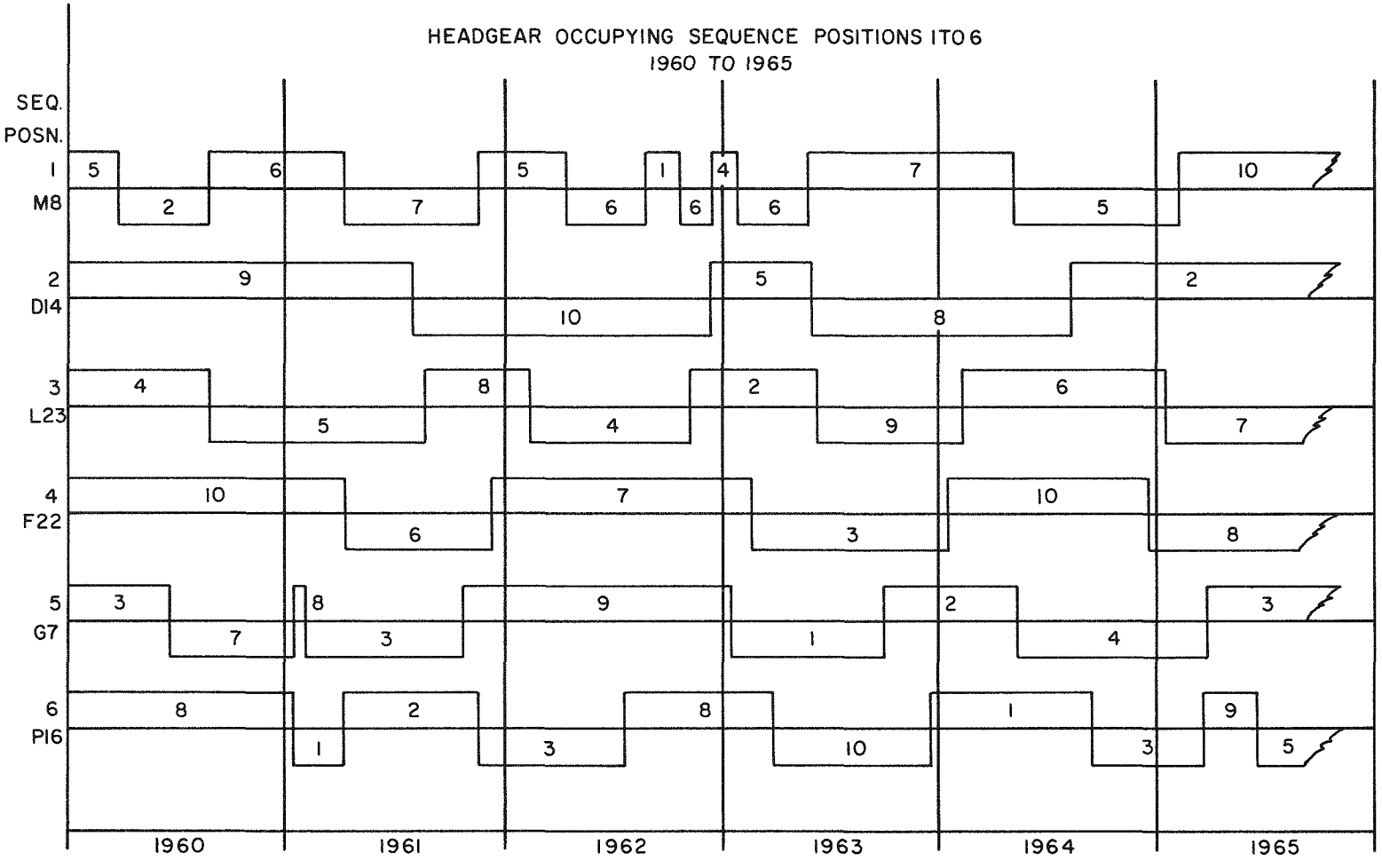


FIG.6