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Aging and Service Wear of Multistage Switches Used in Safety Systems of Nuclear Power Plants

Volume 1. Operating Experience and Failure Identification

G. C. Roberts
V. P. Bacanskas
G. J. Toman

Work Performed for
U.S. Nuclear Regulatory Commission
under
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AGING AND SERVICE WEAR OF MULTISTAGE SWITCHES USED IN SAFETY SYSTEMS OF NUCLEAR POWER PLANTS

VOLUME 1. OPERATING EXPERIENCE AND FAILURE IDENTIFICATION

FRC Report 5384-13-4

G. C. Roberts V. P. Bacanskas
G. J. Toman

In Support of
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Mr. Len Scharf, General Electric Company
Ms. Marilyn E. Smit, Microswitch Division of Honeywell
Mr. Bill Hass, Westinghouse Corporation

EXECUTIVE SUMMARY

The purpose of this report is to provide an assessment that characterizes the aging mechanisms of multistage switches, as well as the nuclear power plant experience with failures of multistage switches in safety-related service. Under the guidelines of the intermediate objectives of the Nuclear Plant Aging Research (NPAR) Program, this study is directed toward identifying the specific degradation mechanisms present in multistage switches and correlating these mechanisms to the potential for detection using currently available inspection, surveillance, and maintenance techniques. An ultimate goal of the program is to identify methods of inspection and surveillance of components that are effective in detecting significant aging and service-wear effects before loss of safety function so that maintenance can be performed in a timely manner to restore the component's functional capabilities.

Section 1 describes the objectives of the NPAR Program. Section 2 describes the principal types and uses of multistage switches in safety-related systems of nuclear power plants and discusses the generic features of these devices. Section 3 provides a detailed description of the components, materials of construction, and operation of each of the multistage switches included in the assessment. Section 4 discusses the stressors and aging mechanisms for multistage switches, and Sect. 5 provides an analysis of failure data from the Licensee Event Report (LER) system. Section 6 provides an analysis of the various failure modes of multistage rotary switches and their related causes. Section 7 investigates the existing recommended and required maintenance and surveillance practices. In Section 8 several techniques with a potential for assessing the condition of switch components and possibly predicting age-related failures are identified. Section 9 concludes that the frequency of failures for multistage rotary switches is very low with only 109 failures reported over a 13-year period in the LER data base. In Sect. 10 a recommendation has been made to eliminate multistage rotary switches from further consideration under the NPAR Program because the cost of implementing a comprehensive surveillance and monitoring program will outweigh the potential benefits. However, it is recommended that in-service failures be analyzed to determine whether the failures are due to random defects or are the result of generic deficiencies, which would require corrective action.

AGING AND SERVICE WEAR OF MULTISTAGE SWITCHES USED IN SAFETY SYSTEMS OF NUCLEAR POWER PLANTS

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ABSTRACT

An assessment of the types and uses of multistage switches in nuclear power plant safety-related service is provided. Through a description of the operation of each type of switch, combined with knowledge of nuclear power plant applications and operational occurrences, the significant stressors responsible for multistage switch deterioration are identified. A review of operating experience (failure data) leads to identification of potential monitoring techniques for early detection of incipient failures. Although the operating experience does not justify extensive deterioration monitoring of multistage switches, nondestructive testing methods that could be used to evaluate the condition of switches are identified.

1. INTRODUCTION

This report provides an assessment of the aging mechanisms of multistage rotary switches and of nuclear power plant experience with failures of multistage switches in safety-related service. The report was prepared under contract to Martin Marietta Energy Systems, Inc., operator of Oak Ridge National Laboratory (ORNL), for the Nuclear Plant Aging Research (NPAR) Program, which is sponsored by the Office of Nuclear Regulatory Research (RES) of the U.S. Nuclear Regulatory Commission (NRC). The NPAR Program Plan is detailed in NUREG-1144.

The NPAR Program has the following objectives:

1. to identify and characterize aging and service-wear effects that, if unchecked, could cause degradation of structures, components, and systems and thereby impair plant safety;
2. to identify methods of inspection, surveillance, and monitoring or of evaluating residual life of structures, components, and systems that will ensure timely detection of significant aging effects before loss of safety function; and
3. to evaluate the effectiveness of storage, maintenance, repair, and replacement practices in mitigating the rate and extent of degradation caused by service wear.

Figure 1 shows the overall strategy of the NPAR Program. This report addresses Phase 1 of the NPAR Program and emphasizes collection of information pertaining to the uses and configurations of multistage rotary switches, identification of significant stressors and aging mechanisms, and review of pertinent failure data and operating experience. It concludes with an interim assessment of potential condition monitoring techniques.

Although there are several manufacturers of multistage rotary switches, models from four manufacturers were chosen for evaluation because of their similarity — in design, applications, and materials of construction — to most of the switch styles used in control and safety system service in nuclear power plants. The manufacturers selected were General Electric (GE) Company, Westinghouse Electric Corporation, Electroswitch Corporation, and the Microswitch Division of Honeywell Corporation.

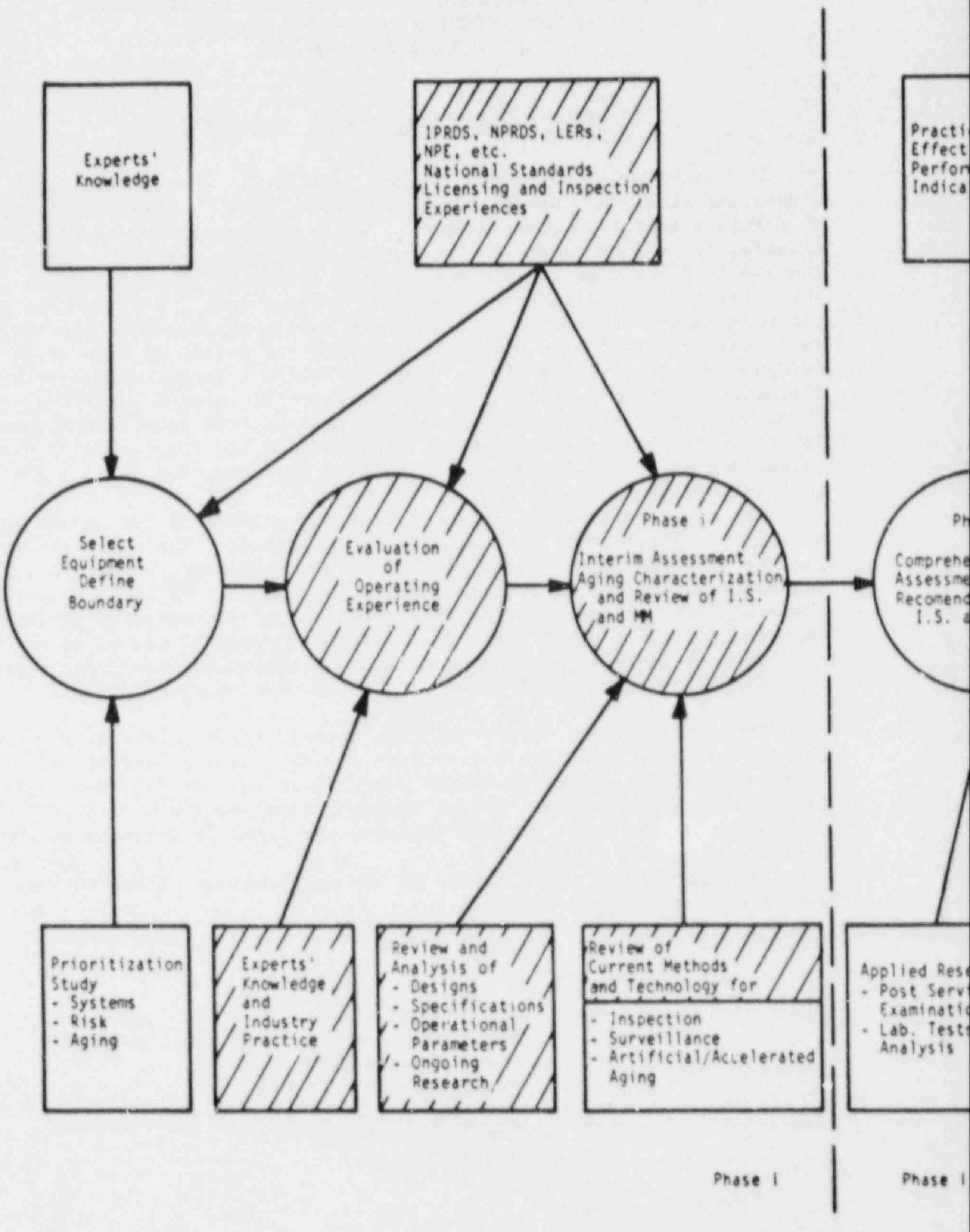
Experts' Knowledge
IPRDS, NPRDS, LERs, NPE, etc. National Standards Licensing and Inspection Experiences
Select Equipment Define Boundary
Evaluation of Operating Experience
Phase I
Interim Assessment Aging Characterization and Review of I.S. and MM
Prioritization Study - Systems - Risk - Aging
Experts' Knowledge and Industry Practice
Review and Analysis of - Designs - Specifications - Operational Parameters - Ongoing Research
Review of Current Methods and Technology for
- Inspection - Surveillance - Artificial/Accelerated Aging
Phase I
Phase I

Fig. 1. NPAR

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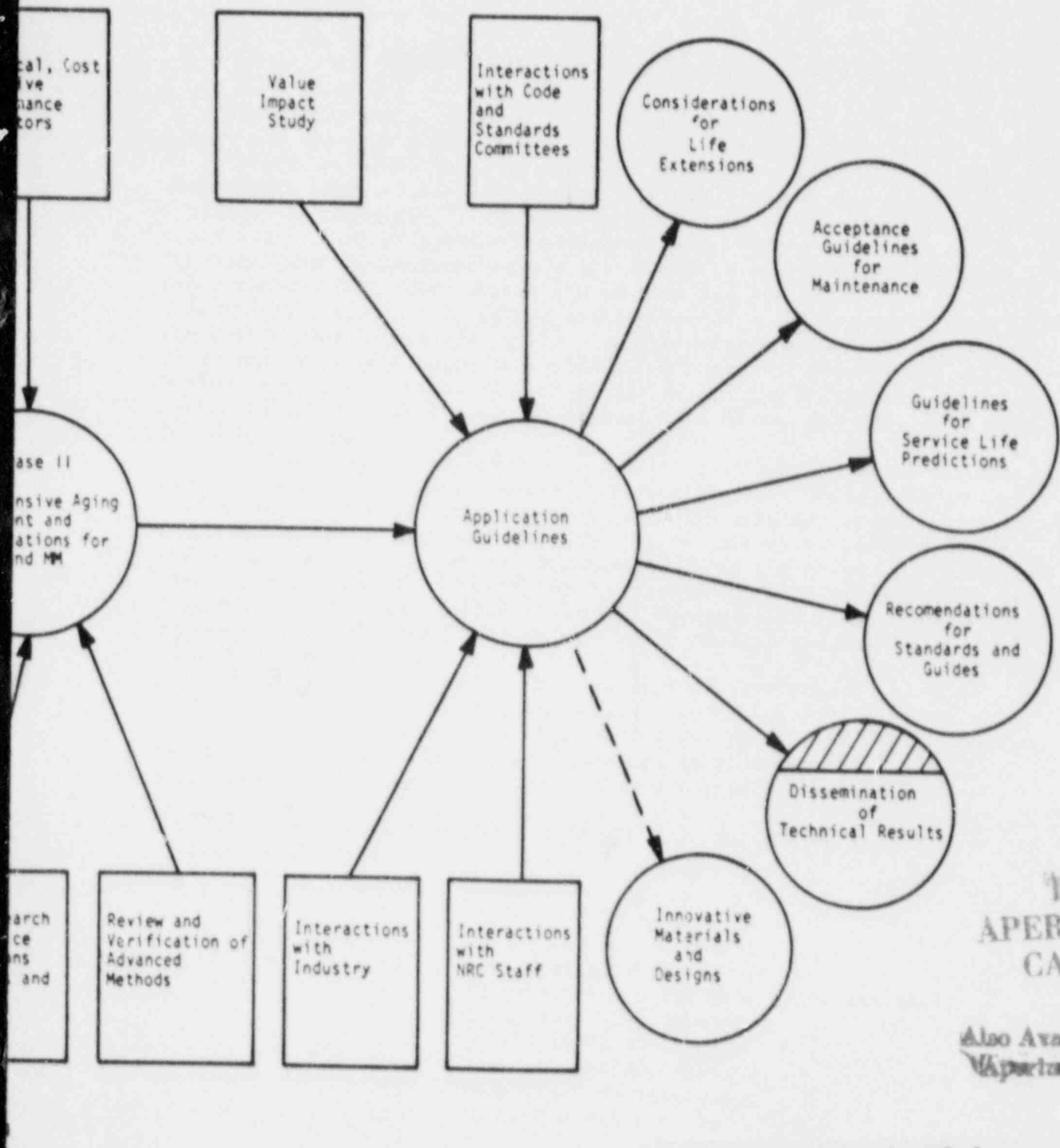

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Program Strategy.

2. PRINCIPAL APPLICATIONS AND FEATURES OF MULTISTAGE ROTARY SWITCHES IN CONTROL SYSTEMS OF NUCLEAR POWER PLANTS

2.1 Principal Applications of Rotary Switches

The rotary switch is used in many applications in nuclear power generating stations. One of the most complex and important applications of a rotary switch in power stations is the reactor mode switch, which is principally used to select the operating mode (run, start-up, refuel, or shutdown) of the plant.[1] The mode switch is one of the few devices in which the control circuits of redundant systems meet. Although the reactor mode switch represents only a single switch application, the boiling water reactor (BWR) mode switch may contain and switch as many as 24 independent circuits. A similar application of a large control switch is the switch used to transfer control of essential reactor control systems to an emergency control room should the main control room become uninhabitable for any reason. The GE SB series and the Electroswitch Corporation Series 20 and 24 switches discussed in Sects. 3.1 and 3.3 are used for such applications.

The more common application of control switches is for on-off control or energization of automatic control circuits. These applications include pump and motor control circuits, valve control, circuit breaker control, and control of dampers. The rotary control switches used for these applications may provide direct control of the actuated devices, that is, switching 120-V power for a solenoid-operated valve, or may be used with an auxiliary device to control an electrical load, for example, switching 125-V dc control power to a motor starter to energize a 480-V ac three-phase motor.

The population of rotary switches varies significantly by plant design; however, when considering both the various applications of control switches throughout a nuclear power plant and the numerous locations (main control room, motor control centers, local equipment control), a population on the order of 1500 switches per plant is a conservative estimate.

The approximate distribution of the applications of the 1500 control switches is as follows:

	Quantity	Location
	500	Main Control Room
	300	Instrumentation Cabinets (test switches)
	100	Electrical Switchboards
	200	Remote Shutdown Panels
	100	Radwaste Control Panels
	100	Local Control Stations
	200	Miscellaneous
Total	1500	

2.2 Features of Multistage Rotary Switches

The multistage rotary switch contains a number of individual switch circuits that change state when the handle is turned. Each switch circuit contains one moving contact and one stationary contact as the basic electrical elements. The basic switch has a handle, shaft, detent or position segment, and one or more contact segments. The design is such that contact segments can be added to the basic switch configuration to increase the number of circuits that can be made or broken. Each segment contains a stationary contact, a moving contact, and an insulated cam that is connected to the handle. The cam will either directly force the moving contact against a stationary contact to complete a circuit or cause a spring to force the moving contact onto the stationary contact. The cam is shaped so that opening and closing of the contact occur suddenly. Figures 2 and 3 show common cam and contact arrangements, respectively. Figure 2 shows two stationary contacts that interface with two moving contacts connected to a shorting bar. Figure 3 shows a switch

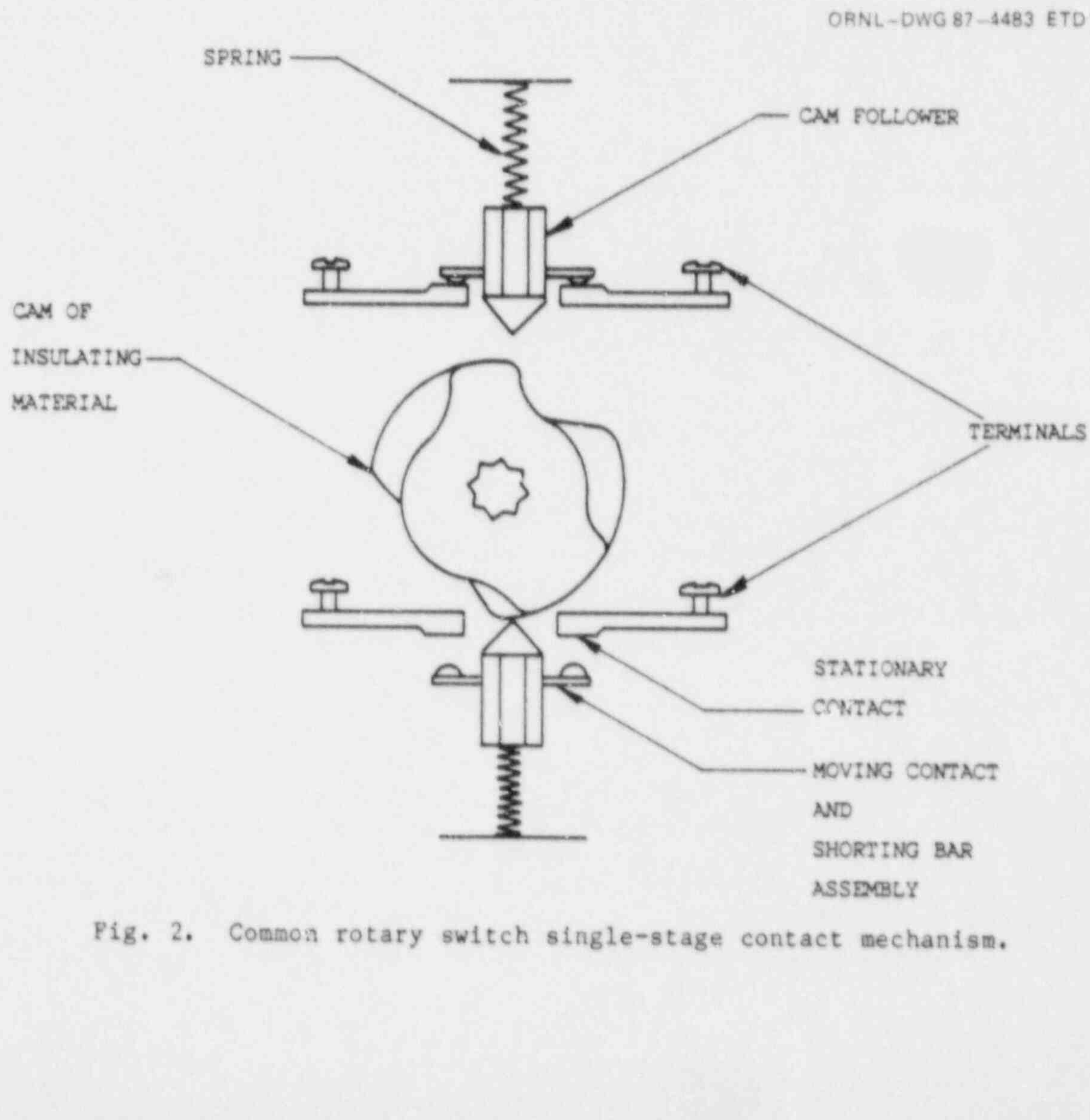

Fig. 2. Common rotary switch single-stage contact mechanism.

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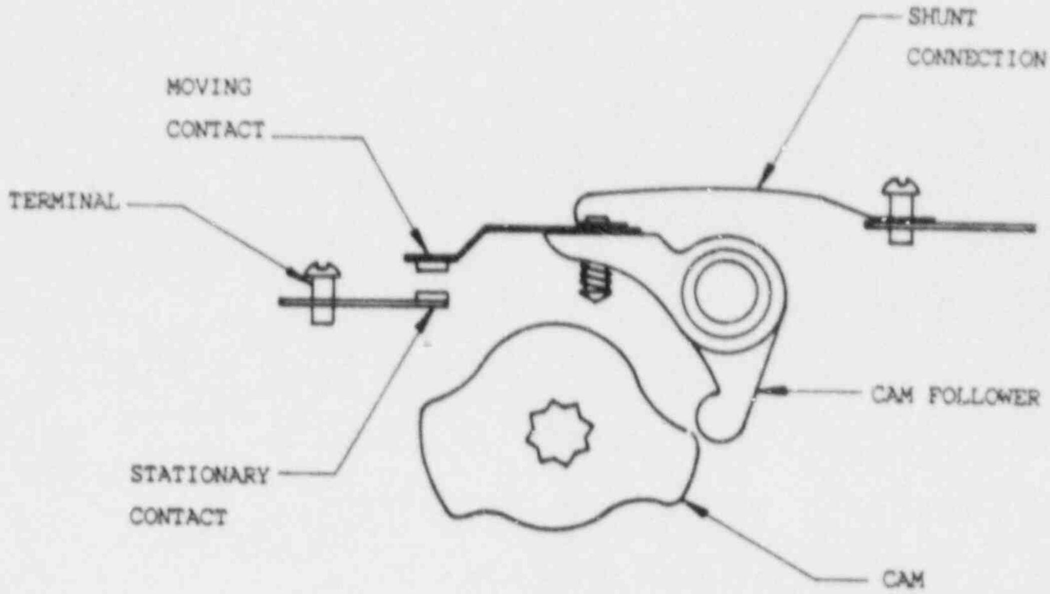

Fig. 3. Cam-operated control switch.

with one stationary contact and one moving contact. The moving contact is connected to a second stationary terminal by means of a flexible metallic strip.

Different manufacturers identify switch segments by different terms. Common terms are segment, block, and gang, which are functionally interchangeable. The term "gang" was commonly used to describe the older switch designs, which generally consisted of ceramic segments with a stator and rotor mechanism providing the switching action. Newer designs use a structural frame made of phenolic or molded plastic, which is held together by segmented or full-length bolts.

Rotary switches may have 2 to 12 positions, depending on the manufacturer and the application.

Switches, whether multiposition with detent or spring return, may be designed with a geared coupling of shafts that permits the rotation of two or more shafts in tandem by the action of a single handle. The geared coupling arrangement (Fig. 4) uses a gear on each camshaft with the gears meshing in such a way as to form a gear train. This switch arrangement is used where the depth of the control panel limits the number of stages that can be assembled onto a single camshaft.

Knife-edge moving contacts are a feature of some switch designs. The moving contact passes between the two halves of a stationary contact causing them to move outwards and, at the same time, provides a wiping action as a result of the friction between the surfaces of the contacts. The wiping action tends to clean the contacts on each closure. The cams that open and close the switch contacts can be contoured and arranged on the shaft so as to provide two distinct switching actions. In one switch action option, as the switch handle is turned from one position to an

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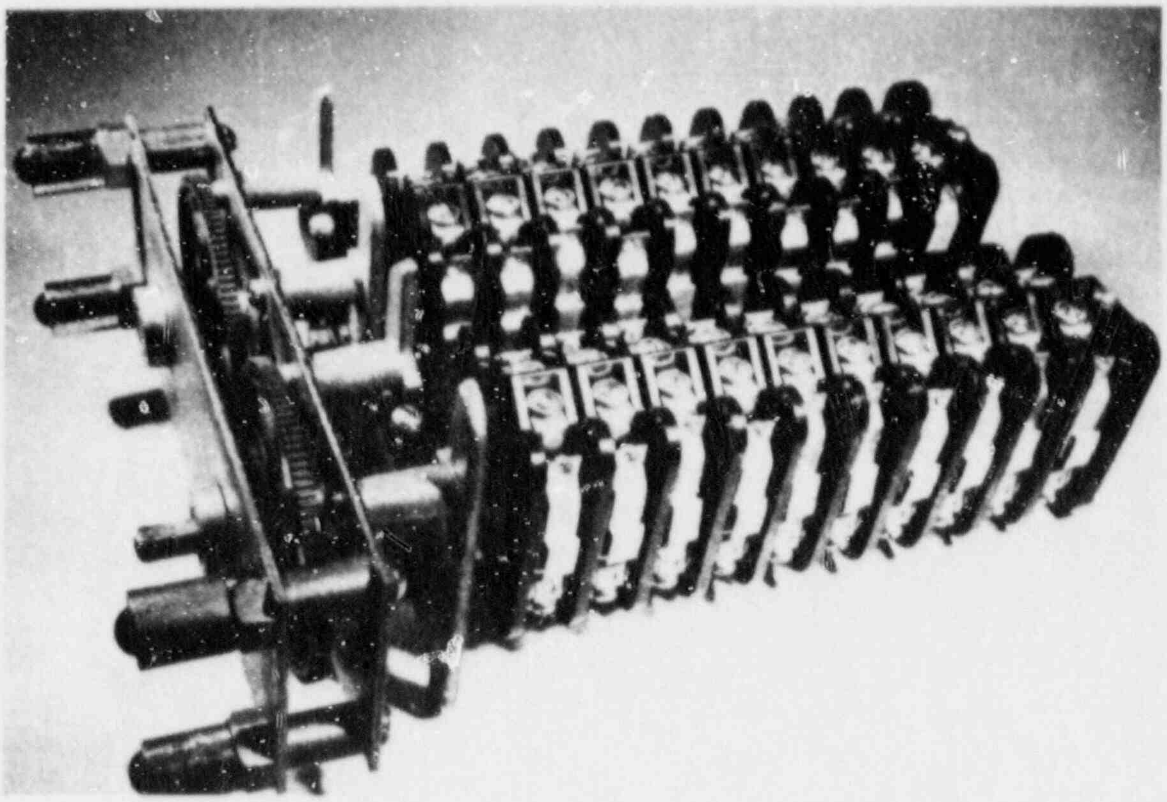

Fig. 4. Rotary switch with geared coupling of multiple shafts.

adjacent position, all of the contacts that close in the new position complete their action before any of the closed contacts in the original position open. This action is known as make-before-break. Conversely, in a break-before-make configuration, the contacts that were closed in the original switch position and that will open in the adjacent position complete their switching action before any of the previously open contacts that will close in the new position complete their action.

A cam may be designed to provide either contact-opening or contact-closing action or both. In some designs, one cam provides the means for advancing the moving contact toward the stationary contact, and another cam acts to cause the moving contact to retreat from the stationary contact. In other designs, the cam surface is contoured so that it provides both the opening and the closing actions.

Most of the switch models are available in two basic operating handle configurations, that is, multiposition with a detent selector or a spring-return selector.

The detent selector mechanism exists in more than one style. In one model, a ball bearing is moved out of one machined slot on an indexer into an adjacent slot when the switch handle is rotated to the next position. Figure 5 shows the basic components of this style. Another model uses a star wheel that engages a spring-loaded stop roller to provide positive position detent (Fig. 6).

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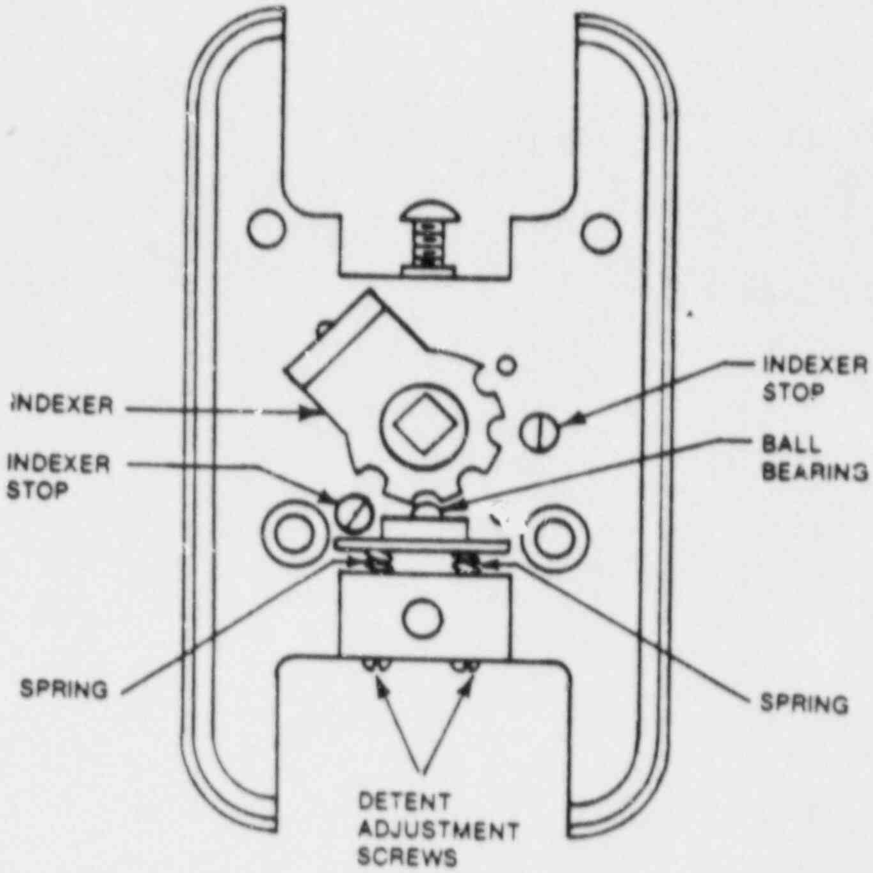

Fig. 5. One style of switch detent selector mechanism.

The spring-return switch configuration is characterized by spring return of the switch handle to a control-neutral position after having performed its function. The operator starts a control function by turning the switch handle either clockwise or counterclockwise, depending on switch application, and holding it temporarily. After release, the switch handle returns to a central position. When the selector is held in its temporary position, certain contacts close; after the spring return, another set of contacts closes. Turning the switch handle clockwise causes a final setup of contacts different from that obtained by turning the handle counterclockwise. The keyway of the cams in this configuration is designed with a special slip action. When the switch handle is turned either clockwise or counterclockwise from the central position, the shaft immediately engages the cam, enabling it to open and close a set of contacts. On releasing the handle, the shaft does not engage the cam as the handle returns to the central position, leaving the contacts in the closed position.

Switch handles are generally available in several styles. The common shapes include round, knurled, oval, and pistol-grip. Many are interchangeable. As another option, key lock handles are available so

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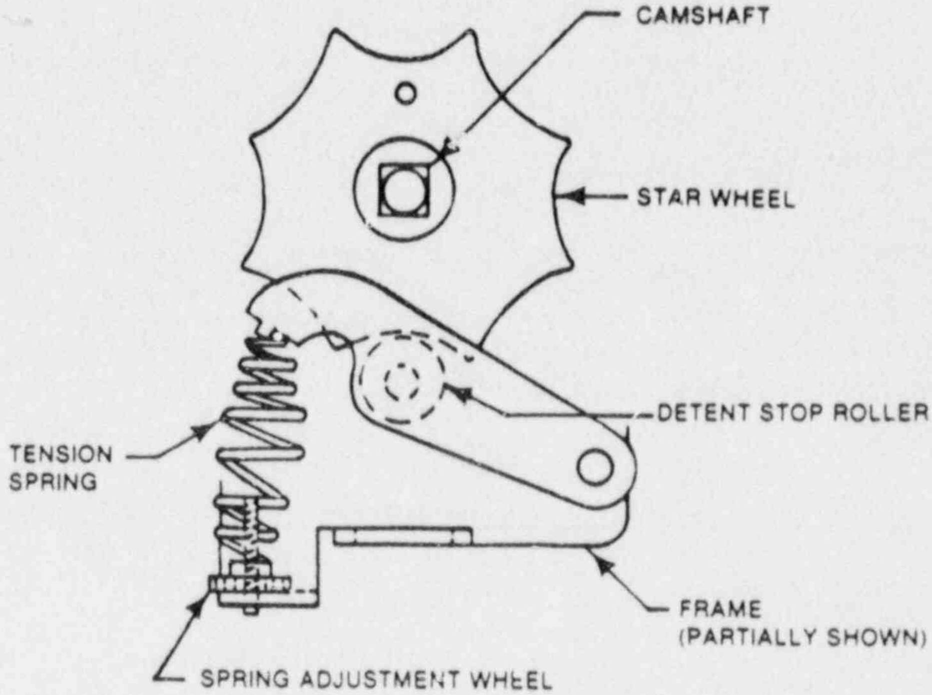

Fig. 6. Second style of switch detent selector mechanism.

that it is possible to lock the switch in only one handle position. Another common handle design, the pull-to-lock, allows the handle to be pulled out in a position that is usually beyond the "off" position. Pulling the handle out engages a different set of switch contacts or, in some cases, disengages the handle from the shaft. A pull-to-lock switch is desirable to prevent inadvertent operation of equipment during maintenance activities. Rotary control switches are provided with escutcheon plates that indicate the current switch position and may have indicating lamps showing the status of the equipment being controlled.

The multistage rotary switch provides the means to switch several independent circuits simultaneously. Each independent circuit is isolated by means of a nonconducting barrier located between adjacent circuits. In such an application, each set of moving and stationary contacts may be used to provide interruption of the current in a single circuit and to isolate the power from the device being controlled. For better dc breaking capability, series contacts are generally used. In one switch handle position, several separate circuits may be energized while the remaining circuits are interrupted. By turning the switch handle to an adjacent position, one or more of the energized circuits may be interrupted while one or more of the formerly interrupted circuits are made up. Some circuits may not change state from one switch handle position to another.

3. DESCRIPTION OF MULTISTAGE ROTARY SWITCHES

Among the rotary switches that are commonly employed in nuclear power plant applications are the General Electric SB-1, SB-9, and SBM models; the Electroswitch Series 24 and 20 rotary switches; the Microswitch CMC 920/921 and PT series; the GE CR 2940 model; and the Westinghouse W-2, PB1 and PB2, and OT2 models.

The switches that are available from the various manufacturers are similar in design and often employ the same materials of construction. For example, the GE SBM and the Electroswitch Series 24 both have contacts made of silver and contact blocks made of phenolic.

The GE SB-1 and the Westinghouse W-2 switches are older designs that are relatively bulky compared with newer switch designs with the same number of stages. Many of the newer switch designs use injection molded parts.

3.1 General Electric Company Multistage Rotary Switches

3.1.1 General Electric SB-1 and SB-9 models

The GE SB-1 switch (Fig. 7) is a cam-operated device that has three molded cams assembled on a square shaft to prevent slipping. Each of the two closing cams advances one of the moving contacts toward the mating stationary contact while the third cam opens both contacts. Rotation of the shaft causes the closing cam to push against the contact carrier arm at the lower end of the carrier, causing it to rotate so that the moving contact attached to the other end of the carrier moves to the closed position. The opening cam, on the other hand, pushes against a spring-loaded pin (cam follower) at the upper end of the contact carrier (Fig. 8), causing the moving contact to retreat from the stationary contact. The spring-loaded pin that attaches the moving contact to the contact carrier allows the opening cam to open a set of contacts even though the closing cam is in the "close" position. A triple layer of flexible conductor provides the electrical path between the moving contact and stationary terminal that is attached to the same support as the moving contact carrier. The positive pressure at the silver-to-silver contacts results in a wiping action and positive contact opening and closing action. Insulating barriers between adjacent contacts prevent arcing between circuits.

The GE Type SB-9 switch is similar to the SB-1 in functional design. The major difference is that the SB-9 is more sturdily built to withstand the rigors of frequent operation. The detent positioning device of the SB-9 requires a greater actuating force to move the switch handle out of one position to another and is located at the rear of the switch as opposed to the front as in the SB-1. This switch also has wear-resistant bearings and better insulation to ground to withstand high inductive switching transients. The SB-9 switch is designed for heavy-duty service and repetitive operations.

The GE SB-1 and SB-9 switches contain two single-pole switches per stage. Each switch consists of four contacts (two per switch circuit)

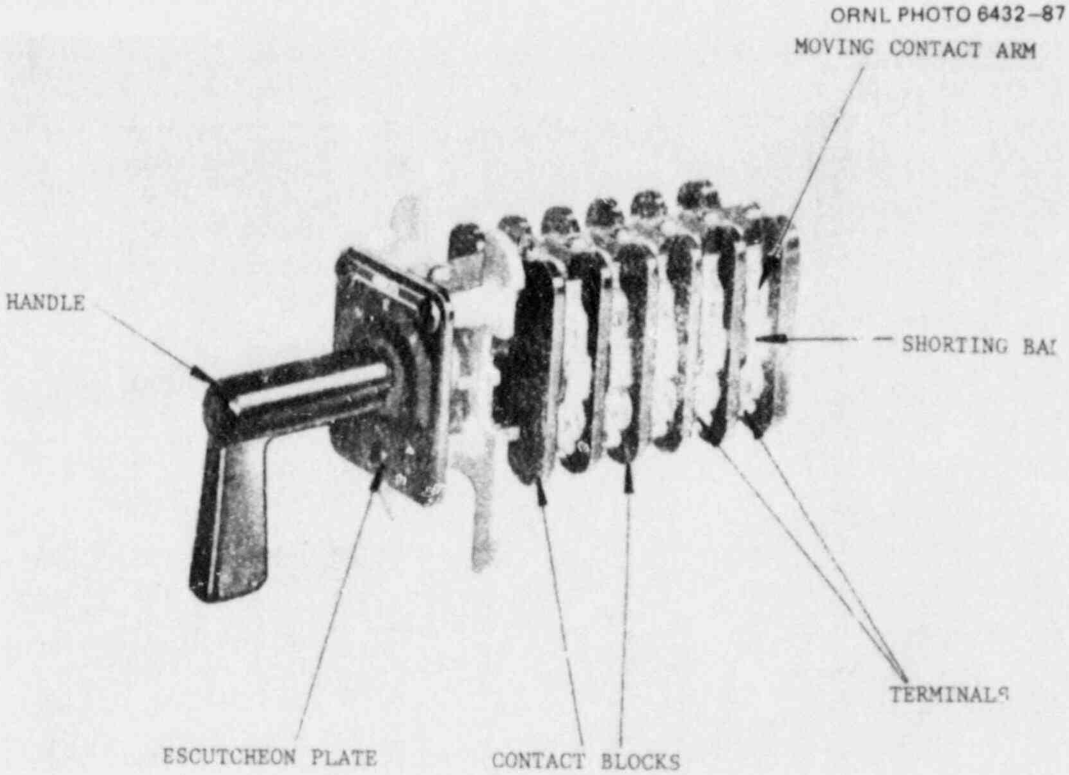

Fig. 7. General Electric type SB-1 switch with cover removed.

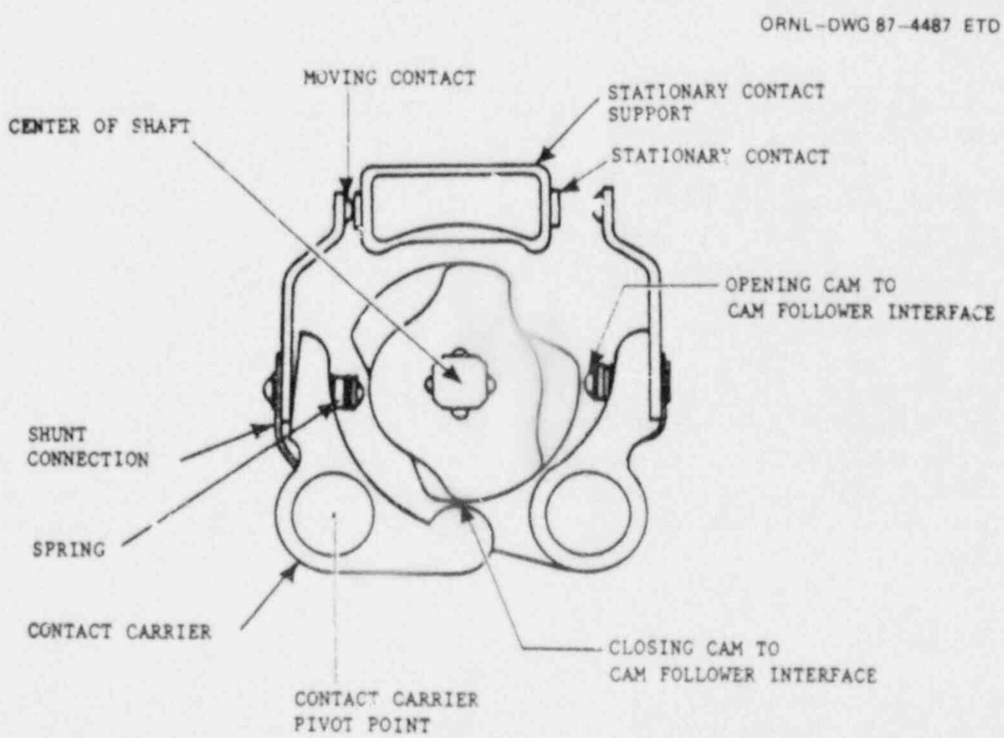

Fig. 8. General Electric type SB-1 cam-operated contacts.

(Fig. 8). Both switches are rated at 600 V, 20 A continuous or 250 A for 3 s. In trip circuit applications, the current interrupting ratings depend on the voltage, on the nature of the load (inductive or noninductive), and the number of contacts connected in series (Table 1).[2]

Table 1. Circuit interrupting ratings of GE SB-1 and SB-9 rotary control switches[2]

Circuit (V)	Interrupting rating (A)					
	Noninductive circuit			Inductive circuit		
	Number of contacts					
	1	2 in series	4 in series	1	2 in series	4 in series
24 dc	6	30		4	20	30
48 dc	5	25	40	3	15	25
125 dc	2.5	11	25	2	6.25	9.5
250 dc	0.75	2	8	0.7	1.75	6.5
600 dc	0.25	0.45	1.35	0.15	0.35	1.25
115 ac	40	75		24	50	
220 ac	25	50		12	25	40
440 ac	12	25		5	12	20
550 ac	6	12		4	10	15

The switch contacts have a higher current rating for load breaking when used with an inductive load in an ac circuit than in a dc circuit. In an ac circuit, arcing between contacts is suppressed when the current goes to zero during the current cycle. As the voltage between the contacts increases again, clean air moves in to replace the ionized arc plasma, effectively preventing an arc from being reestablished. In a dc circuit, on the other hand, there is no current zero to assist in suppressing the inductive surge associated with dc inductive load breaking. Thus, arcing persists for a longer time after load breaking than in an ac circuit. Because arcing causes damage to the contacts (vaporization), a dc circuit requires less current flow than a comparable ac circuit to produce the same wear on the contacts. The current rating of switch contacts in a dc circuit can be increased by using contacts in series because the energy absorbed by the contacts in breaking the load is thereby distributed over several contacts.

3.1.2 GE SBM model

The GE SBM switch is a cam-operated device having two mechanically and electrically separate sets of contacts per stage.[3] Opening of contacts is accomplished by means of two cams and two cam followers that are connected to moving contacts. The SBM switch can be obtained with up to ten stages or decks of contacts on a single shaft. The SBM switch is compact compared with the SB-1. A ten-stage SB-9 (Fig. 9) has dimensions of 2 1/2 × 2 15/16 × 19 7/16 in. with standard cover, while a ten-stage SBM has dimensions of ~2 5/8 × 2 5/16 × 9 1/8 in. Figures 10 and 11 give pictorial and diagrammatic views of the switch and major SBM switch components.

Each cam for the SBM switch operates one set of contacts and is constructed with two operating surfaces. These surfaces operate on the cam

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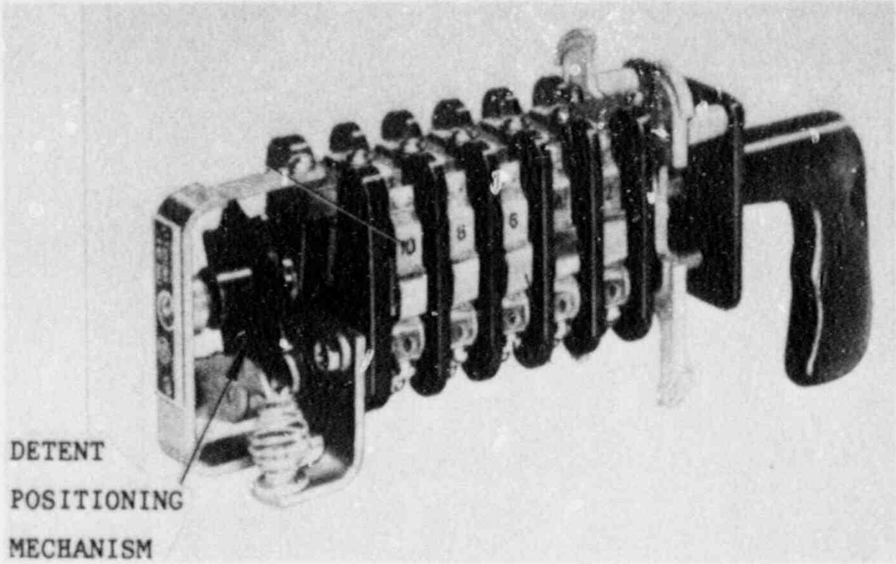

Fig. 9. General Electric type SB-9 switch with cover removed.

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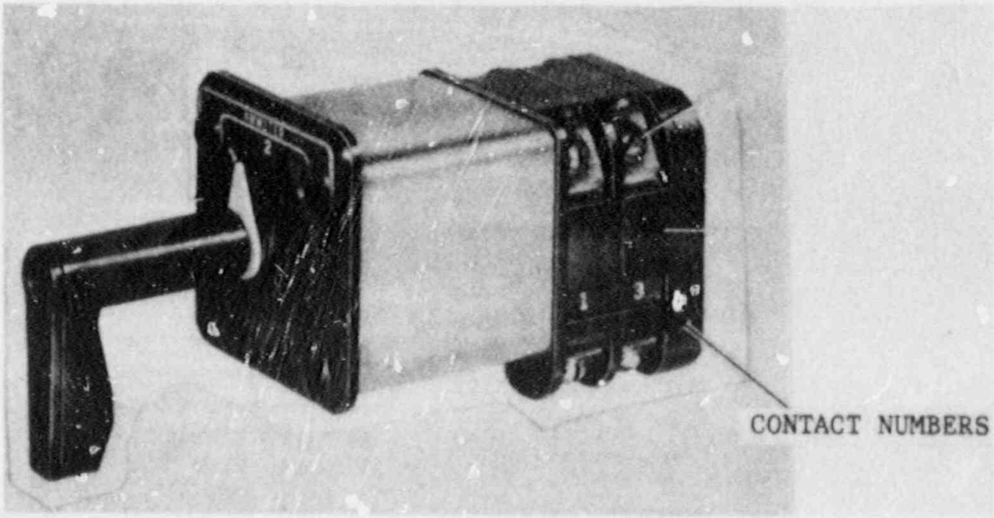

Fig. 10. General Electric SBM rotary cam-operated control switch.

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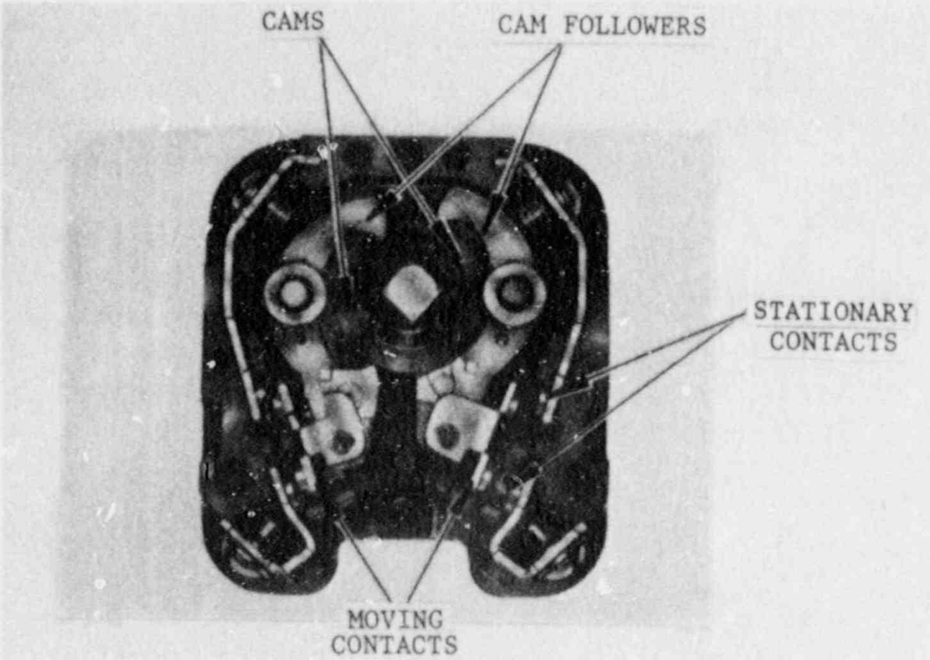

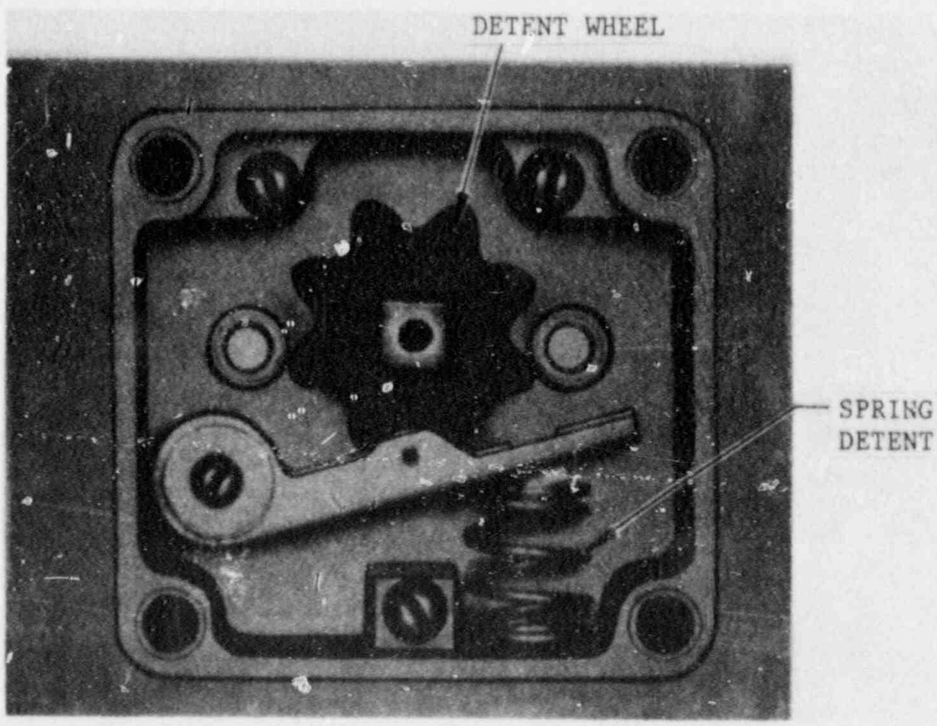

Fig. 11. Contact segment and detent mechanism of the GE SBM switch.

follower, which has two tips — a closing tip and an opening tip — located in offset horizontal planes and lining up with the two cam operating surfaces (Fig. 11). As the cam is rotated, one surface pushes against the closing tip of the cam follower while the opening tip is relieved. Both tips of the cam follower are always in contact with the cam surfaces, allowing a positive closing and opening action not dependent on springs.

Each cam follower has a spring-loaded moving contact attached to it.[3] A compression spring acts to give adequate pressure when a contact is closed. The moving contact is held to the cam follower by a pin passing through a hole in the cam follower and through an angled slot in the moving contact. As the contacts close, the moving contact slides along this slot while compressing the spring, thus causing relative motion or "wipe" between moving and stationary contacts.

Momentary contact switches have a torsion spring on the shaft that returns the switch to a central or neutral position when the handle is released after operation to a clockwise or counterclockwise side position. This torsion spring is designed for maximum 90° clockwise or counterclockwise rotation to either side of the central position. The torsion spring may be designed in such a manner as to be effective on only one side of the central position. That is, the switch may have momentary contact to one side of the central position and maintaining contacts on the other side.

Some applications of the SBM switch, particularly the momentary contact variety that has a torsion spring on the shaft to return the switch to a neutral position, require a contact action that lags behind the switch handle motion (lost motion or slip contacts). Such action is used where it is desirable to have alarm or indicator lamps stay on to indicate the last active position of the switch. Slip contacts use cams with a special loose fit on the shaft. When the shaft has turned far enough to close or open these contacts, it can be rotated 45° in the reverse direction without moving the cams, but beyond this point, the cam moves with the shaft and the contacts either open or close.

The SBM switch is also available with a pull-to-lock capability for safety lockout for activities such as system maintenance.

The SBM is rated for a mechanical life of 500,000 (unloaded condition) operations. The electrical ratings are 600 V ac or dc, 20 A continuous or 250 A for 3 s. The interrupting rating depends upon the voltage and character of the circuit. Table 2 illustrates the interrupting duty of a single contact and contacts in series when various conditions exist on a circuit.

3.1.3 GE CR 2940 model

The General Electric CR 2940 switch model offers double-break silver contacts with positive make-and-break action. Two types of heavy-duty oil-tight contact blocks are available. The single-circuit design provides the basic single-contact block with one normally open set of contacts and one normally closed contact block. Double-contact blocks contain two normally open sets of contacts and two normally closed sets of contacts. Switch units, with blocks in tandem, are available with up to four normally open sets and four normally closed sets of contact

Table 2. Circuit interrupting ratings for GE SBM rotary switch[2]

Circuit (V)	Interrupting rating (A)			
	Noninductive		Inductive	
	Number of contacts			
	1	2 in series	1	2 in series
24 dc	10	30	8	25
48 dc	8	25	6	18
125 dc	5	15	4	10
250 dc	1	3	1	2.5
600 dc	0.4	0.8	0.3	0.7
115 ac	40	75	24	50
230 ac	25	50	12	25
460 ac	20	30	10	20
600 ac	15	25	8	12

arrangements. The GE CR 2940 is available as a two- or three-position configuration that can operate under severe industrial conditions where oil, water coolant, and/or other contaminants may be present. Typical applications of the switch, shown in Fig. 12, are with magnetic contactors and starters.

The principle of operation of the CR 2940 rotary switch is similar to that of the Westinghouse PB series described in Sect. 3.2.2.

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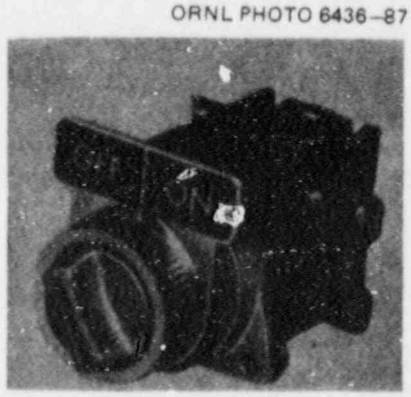

Fig. 12. General Electric CR 2940 rotary control switch.

3.2 Westinghouse Electric Corporation Multistage Rotary Switches

3.2.1 Westinghouse Type W-2 model

The Westinghouse Type W-2 switch is designed for use as an instrument, control, or general purpose switch. It is a relatively compact switch; a ten-stage unit with pull-to-lock option, it has approximate dimensions of 2 1/4 × 3 × 17 1/4 in. Design flexibility of internal parts and contacting, plus external jumpering of the contact terminals, affords a vast number of switch contact arrangements.

General construction. The W-2 switch consists essentially of an operating handle, face plate, control housing, contact frame assembly, and rotor assembly.[4] It can be built with one to nine stages, all clamped together to the control housing by two tie bolts. A steel operating shaft ties the contact rotors together. A metal cover on the rear of the switch holds the position stop pins, retains the shaft, and provides switch identification. For push or pull switches, the metal cover is replaced by a polycarbonate cover that houses the pullout mechanism.

Switch positions. The Type W-2 switch has a minimum of 2 and a maximum of 12 rotary positions with a 30° throw between positions, irrespective of the number of positions. Each rotary position coincides with the nameplate markings. The number of positions of each switch can be altered by removing the rear cover and changing the position of the "stop" pin or pins located in the rear housing spacer.

In addition to rotary motion, the W-2 switch can be provided with a lateral movement (push-pull) of the handle and shaft. Spring-loaded roller contacts are housed in a pull rotor fastened onto the shaft by E-rings (retaining rings) (Fig. 13). The roller contacts, which are connected by a shorting bar, span two adjacent terminals and move back and forth laterally between the two adjacent terminals in one row of one stage and the two adjacent terminals in a similar rotary position but in the other row of the same stage. The mechanism allowing the lateral movement is assembled at the rear of the switch in a clear polycarbonate cover. The cover (Fig. 13) has a guide piece in which a slot (or slots) receives the arm on the end of the shaft. Lateral movement can occur only when the arm and slot match.

Contact frames. Two contact frame sizes are available. The half frame has six sets of contacts: three sets on the top at 11, 12, and 1 o'clock positions and three sets on the bottom at 5, 6, and 7 o'clock positions. The full frame has 12 sets of contacts. each set located at 30° intervals around its perimeter, as are the numbers on a clock. The contact frames are made of glass polyester insulating material.

Stationary contacts. Around the circumference of the stage frame, two rows of contact terminal studs are arranged at equal angular intervals (Fig. 14). The terminal studs are made of silver-plated bronze alloy and are positioned such that there are two studs in line (a set) per stage. The head of the terminal screw is the stationary contact face.

A circuit is made up when two in-line studs (a set) are shorted by two rolling contacts connected by a shorting bar.

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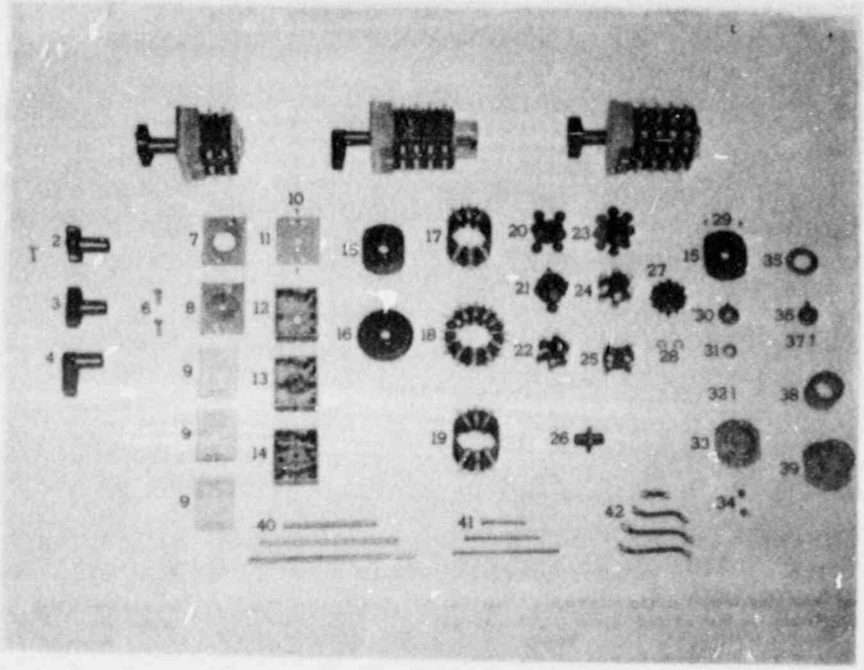

Fig. 13. Westinghouse W-2 control switch components.

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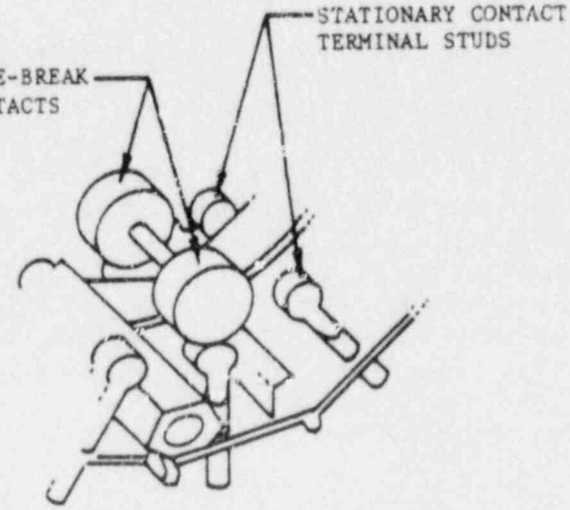

Fig. 14. Contact mechanism and stage frame assembly of W-2 switch.

Rotors. The rotors hold the roller contacts. Each rotor, made of glass polyester insulating material, rotates independently between the stage spacer plates. The rotor assembly is equipped with one to six dumbbell rollers (as determined by the required circuitry), which are made up of two rolling contacts connected by a shorting bar. The rotor assembly makes contact with two adjacent stationary terminal studs to complete a circuit, thus affording a double, series break contact. The silver-plated bronze alloy roller contacts provide a rolling, wiping action; are self-aligning on assembly; and require no adjustment of contact pressure for the life of the switch. Contact springs do not carry current.

Contact arrangement. Although the internal contacting is standardized for each basic type of switch — such as ammeter, voltmeter, and circuit breaker — by using available insulated jumpers, connections between external switch terminals can be made to obtain the desired circuitry for a specific application.

Handles. Handles for the Type W-2 switch are made of phenolic insulating material. Each handle has a recessed arrow molded into it to serve as a visual aid in positioning. The handles are made in six shapes, including oval, round, pistol grip, large pistol grip, and fingertip. Handles can also be obtained with fixed or removable keys. All handles are fastened to the shaft by a screw through the front of the handle.

Operation. The Type W-2 switch is a rotary-roller action switch. Rotation of the shaft causes the rotor rollers to roll from one set of stationary contacts to another. The number of roller contacts can vary from one to six, depending on the number of rotary positions required for the switch application. Each roller contact, moving radially, is held in and guided by a slot in the rotor arm. The rollers are pushed outward from the shaft by spring pressure. Between the roller and spring there is an insulated spring seat to reduce friction and wear. On standard potential contacts, an insulated wheel is used on both ends of the roller contact. These wheels roll inside the switch stator frame (Fig. 14). This arrangement reduces the friction of the spring-loaded roller in riding onto the stationary contact during closing and also results in an increased air gap and faster contact separation upon opening.

Overlapping contacts are obtained by increasing the diameter of the contact rollers of the shorting bar. At midposition the roller spans the space between the stationary contacts. Such rollers provide a make-before-break contact in going from one position to an adjacent position.

The Type W-2 switch is available in both the maintained and the spring return types. Both types use a common detent housing that is 7/8 in. deep, located between the back surface of the dial plate and the frame-rotor unit. This feature permits conversion from one type to another with a minimum of effort.

The current interrupting ratings of the W-2 switch are given in Table 3.

Table 3. Circuit ratings of Westinghouse W-2 switch[4]

Circuit (V)	Rating[a] (A)			
	General purpose	Normal	Inrush	Two contacts in series general purpose
	Standard contact[b]			
600	8	2.4	12	20
240	20	6	30	40
110	30	10	60	60
250	1.65	1.1		9.5
125	5	2.2		20
	Slip contacts[c]			
600	8	2.4	12	
240	20	6	30	
110	30	10	60	
250	1	0.55		
125	3.5	1.1		

[a]Ammeter contacts and contacts housed in the pull rotor are not given ratings because they do not interrupt loads. Normally closed ammeter contact has a continuous rating of 10 A.

[b]Adjacent poles (contacts in same chamber) must be connected to same polarity.

[c]Two adjacent, side-pole, double-throw contacts (in same chamber or stage) must be connected at same polarity.

For current circuits an assembly with normally closed contacts between front and rear terminals at each position on a stage is used. The assembly consists of a shorting bar across the two terminals that is held closed by spring pressure. Turning the switch handle causes a cam to push the shorting bar away from the two terminals. Operating simultaneously in a different stage with this contact assembly are regular rollers designed and arranged so that they make a parallel circuit just before the opening of the normally closed contact. This arrangement permits overlapping transition (make-before-break) in current metering of circuits.

On three-position switches, slip contacts are available. These contacts close when the switch operating handle is turned to the clockwise position and remain closed after the operating handle has returned to the center position. The contacts open when the operating handle is turned to the counterclockwise position and remain open upon return of the handle to the center position.

Spring-actuated roller contacts are mounted in a wafer housing fastened to the operating shaft by retaining rings. The wafer housing can only be moved by a push or pull movement. The roller contact spans two adjacent terminals on a band, and it moves back and forth between two bands in a stage.

3.2.2 Westinghouse PB1, PB2, and OT2 models

The Westinghouse PB1 selector switch is designed for National Electrical Manufacturers Association (NEMA) 13 applications (oil-tight and dust-tight construction for indoor use) and is suitable for many industrial and commercial uses.[5] It is available with five different types of polycarbonate operating knobs, including rotary and key operated.

The PB2 selector switch is similar in design to the PB1 switch but is made from plastic for either NEMA 13 applications or applications requiring corrosion resistance as defined by the NEMA standards ICS 6-110-58 Corrosion Test.[5]

The Westinghouse PB1 and PB2 selector switches are supplied with a choice of two, three, or four operating positions. If required, detent maintained switches can be field converted from two to three to four positions by changing the location of the operating knob in relation to the tube inside the housing. With the operating knob removed, numbered slots are visible in the tube (Fig. 15). The numerals 2, 3, and 4 correspond to the number of selector switch positions. On installation, the selector switch handles' key is matched to the appropriate numbered slot. Knobs for two- and three-position operation are interchangeable and can be modified for four-position operation by removal of the stop extension.

The PB series switches are of modular design with the basic unit being the contact block with one pair of stationary contacts and one pair of moving contacts. Contact blocks may be stacked up to four deep.

The possible contact sequences of the two- and three-position selector switches are achieved with the use of one cam. The cam mounts on the rear of the housing and is held in place by the adapter plate. The cam is located in different radial locations to achieve the various contact sequences.

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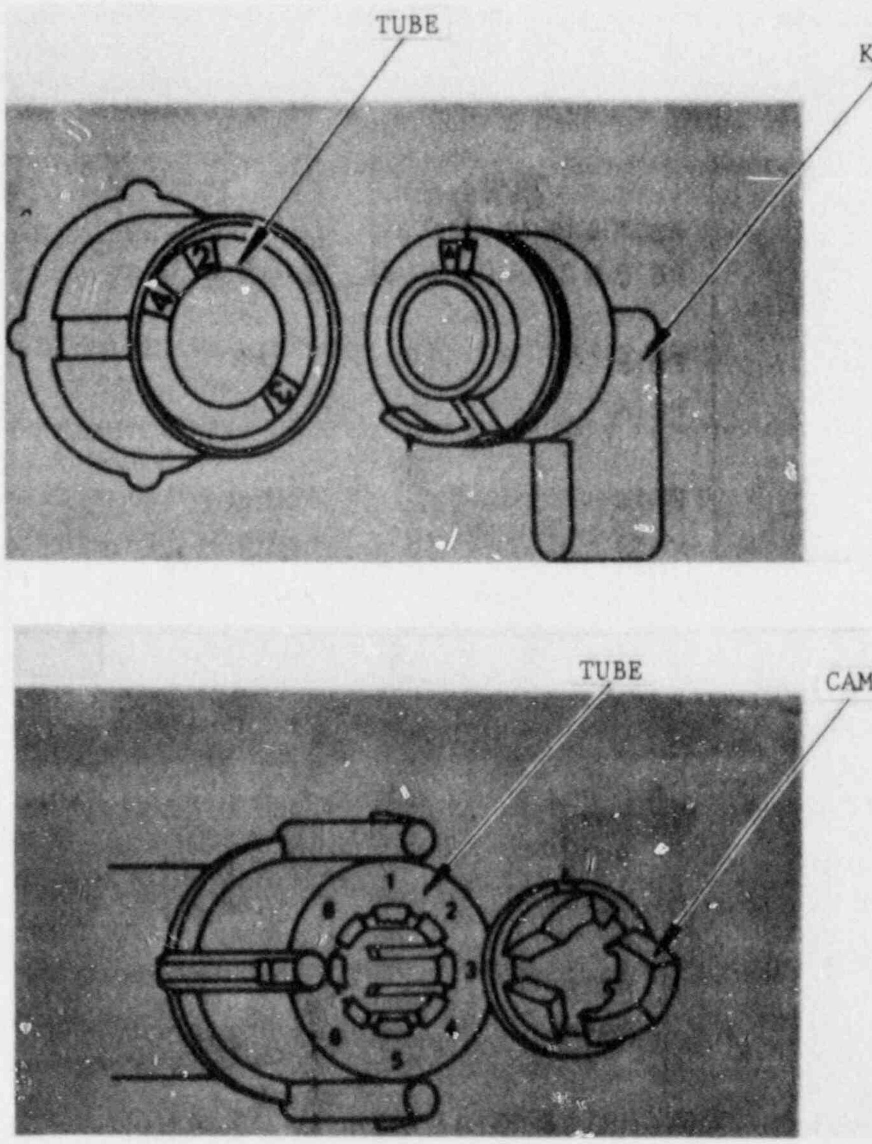

Fig. 15. Westinghouse PB1 and PB2 selector mechanism.

Operation. Opening and closing of the contacts in the PB series switches is accomplished by the axial-face cam operating against a spring-loaded pin that carries the moving contacts (Fig. 16). The surfaces of the cam that face the back of the switch are contoured so as to produce the required switching action (closing or opening of the contacts) for a specific switch handle position. To permit stacking of contact blocks for operation by one handle, the contact-carrying pin is slotted at the back end to accept the front end of the add-on contact block pin.

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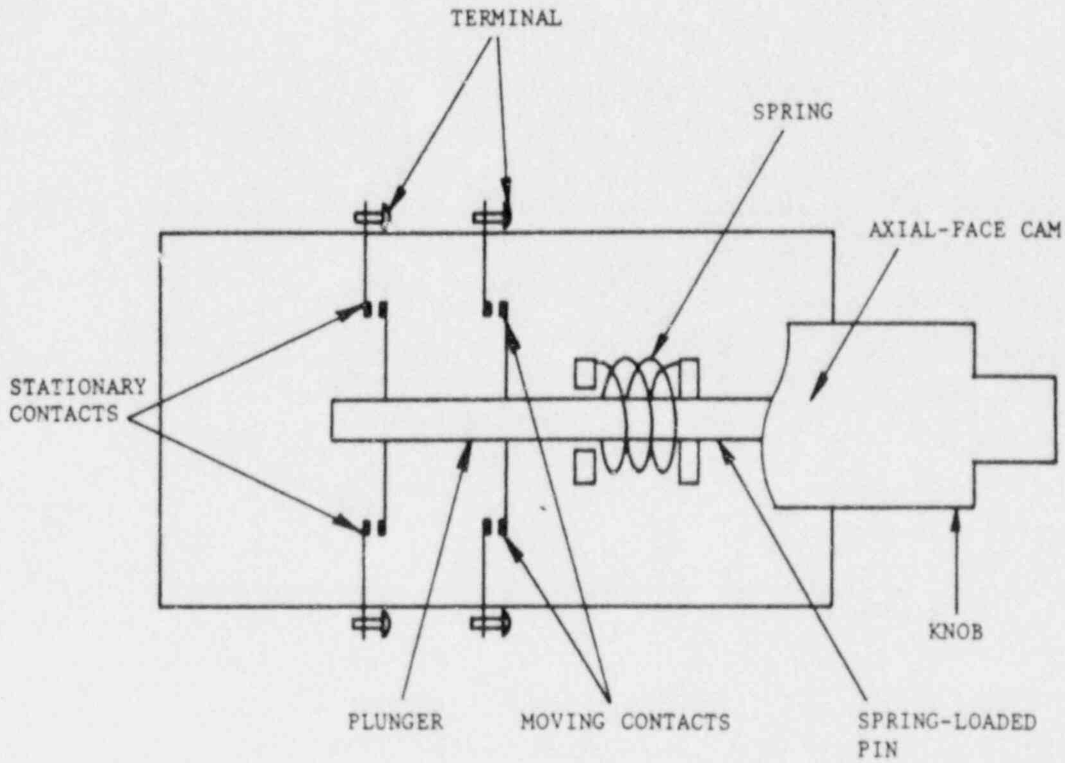

Fig. 16. Typical axial-face cam-operated rotary switch.

The Westinghouse OT2 rotary switch, which is found in some of the older operating nuclear power plants, is no longer offered by the manufacturer because it has been replaced by the PB series switch. However, under special agreement with at least one facility, the OT2 is still being made available as a replacement component. The OT2 rotary switch is very similar in design and operation to the PB series switches.

3.3 Electroswitch Corporation Multistage Rotary Switches

3.3.1 Electroswitch Series 24 switch

The Electroswitch Series 24 instrument and control switch is a heavy-duty rotary switch that is used in industrial and power industry applications.[6] It has a modular design in which one or more contact subassemblies are stacked together on a steel shaft to form a rigid, multistage rotary switch. The maintained position switch includes an additional detent positioning mechanism. Figure 17 is an assembly view showing the basic switch components. The mounting plate (1) is positioned on the shaft next to the detent subassembly (2), which contains a specially designed star-wheel and up to four spring-loaded ball bearings. One or more contact decks (3) are placed on the shaft behind the detent

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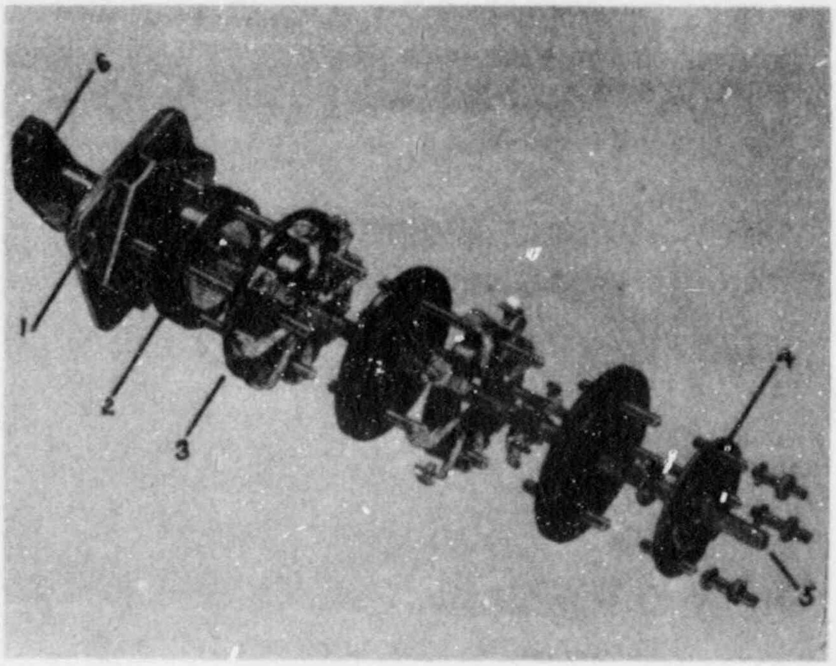

Fig. 17. Assembly view of Electroswitch Series 20 rotary control switch.

subassembly with a position-limiting stop plate assembly (4) positioned at the back end of the switch. The stop plate assembly basically consists of a steel stop arm that is placed on the shaft and a steel stop plate with eight holes of the same size arranged in a circle.

These assemblies are all tied together on the shaft (5) by four bolts that penetrate the switch assembly from the mounting plate to the position-limiting stop plate. A handle (6) completes the switch.

Positioning of the switch shaft is maintained by the star-wheel of the detent mechanism and the spring-loaded ball bearings. When the handle is moved from one position to an adjacent position, the springs holding the ball bearings against the detent wheel are compressed as the high points of the star wheel pass under the bearings. As the wheel is advanced further, the ball bearings force the wheel to the next low point, thus providing positive indexing.

Switching takes place in a contact deck assembly where double-sided, double-wiping, self-cleaning, knife-blade contacts carried on a rotating disk operate against both sides of fixed contacts in a wiping action. Each deck has eight stationary contacts that are arranged on a circle of equal intervals.

3.3.2 Electroswitch Series 20 switch

The Electroswitch Series 20 switch is a miniature rotary control switch that mounts on 3-in. centers.[7] A ten-stage switch assembly with handle has an envelope of ~1.90 × 1.90 × 6.99 in. The Series 20 switch, like the Series 24 switches, is used in industrial control and utility applications; however, the Series 20 switch is a more compact design.

The Series 20 switch (Fig. 18) is a modular design with switching decks (3), stacked with a detent mechanism (6), a mounting plate (12), and a handle (13). A steel shaft (10) couples the handle to the operating parts, and two steel securing rods (11) are used to bolt the whole mechanism together rigidly.

<u>The detent assembly</u> (Fig. 18). The detent assembly (6) consists of a spring-loaded detent block (7) with a roller coming into contact with a notched detent wheel (8). Through selection of a detent wheel, the handle can provide a standard 45° rotation between switch positions, as well as an optional 30, 60, or 90°. Stop arms (9) located under the mounting plate limit the angular rotation of the switch handle to the number and location desired by the application.

<u>The contact assembly</u>. The contact assembly (3) consists of a rigid thermosetting plastic housing, two sets of stationary contacts (5), and two spring-loaded movable contacts (1) held in cam-followers (2). Positioned on the shaft and held within the contacting chamber are the two independent cams (4), which are notched to provide the contact "close" angles desired by the specific switch application. The contacts are

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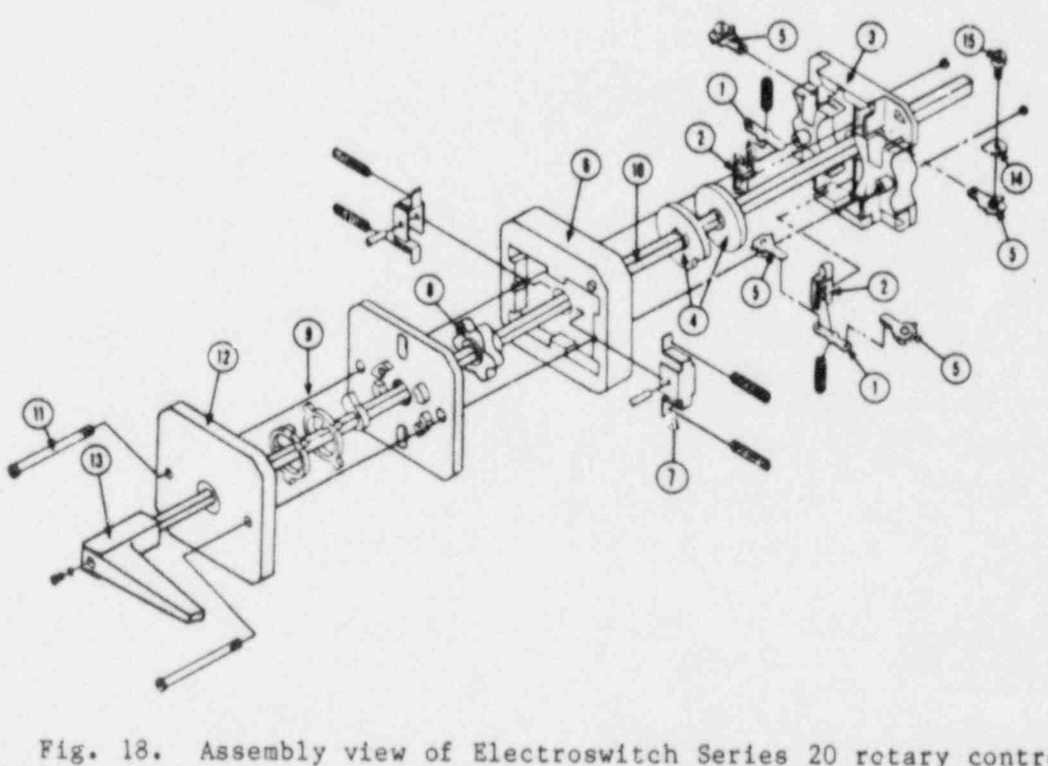

Fig. 18. Assembly view of Electroswitch Series 20 rotary control switch.

closed by spring action and mechanically opened by cam action to avoid sticking.

The nameplate. The standard nameplate is a two-piece assembly. One piece secures the switch to the panel using two mounting screws; the other piece, which also contains the engraving, snaps onto the first piece and hides the mounting screws. A mechanical target is also available in this style. A green target shows that the last activated position was TRIP, and a red target shows that the last activated position was CLOSE in circuit breaker control applications.

Handles. A choice of interchangeable handles is available for various instrument and control applications. Round knurled, oval, and pistol grip are three handle shapes in common usage. An oval removable handle design is also available.

Other available features. The Electroswitch Series 20 rotary switch is also available with a pull-to-lock mechanism. This feature enables an operator to turn the handle beyond the left (normally TRIP) position to the 90° left location, pull out the handle, and thereby lock the switch in this position.

The series 20 switch is also available with slip contacts that allow the switch handle to spring return to the normal vertical position without changing the contact arrangement from that of the last switch function. A spring-return mechanism is available in place of the standard detent mechanism for those applications that require a momentary contact in either the counterclockwise or clockwise position. Upon release of the handle, the switch spring-returns to the normal vertical position.

A gear-train option is also available to permit combination of two or more switches for operation by one handle where the number of contacts is greater than the capacity of one switch or where there is a panel depth restriction. A key-operator can also be provided.

Contact operation. The contact operation consists of shunting two isolated contacts to make a circuit (Fig. 3). Using this simple principle, two independent sets of contacts are placed in each deck (3) shown in Fig. 18. The moving portion of the contact (1) is spring-loaded to close the contact (Fig. 19). A notch on the cam (3) that is affixed to

ORNL-DWG 87-4491 ETD

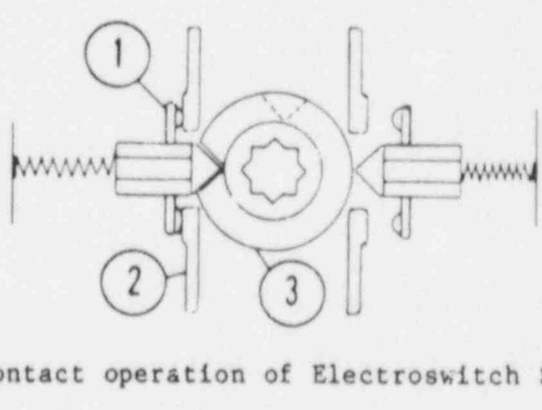

Fig. 19. Contact operation of Electroswitch Series 20 rotary control switch.

the operating shaft allows the moving contact (1) to spring close, thereby bridging the stationary contacts (2); this action is illustrated in Fig. 19.

The same operation occurs on the right-hand contact. This circuit is held open by the cam and will close when the notch on a second independent cam is rotated around and comes in contact with its cam follower (the second cam notch is illustrated by the dotted lines — this cam is underneath the first cam).

Contact ratings. The Series 20 instrument and control switch has been tested to many different circuit conditions. The interrupting ratings (Table 4) are based on 10,000 operations, using suddenly applied and removed rated voltage, with no extensive burning of contacts. Inductive ratings are based on tests using standard inductance L/R = 0.04 for dc and cos θ ≈ 0.4 for ac. The Interrupting Rating column headed "double contacts" means two contacts in series. Short-time and continuous ratings are based on temperature rise in contact members and supporting parts not exceeding 50°C above ambient.

Table 4. Circuit interrupting ratings of Electroswitch Series 20 instrument and control switch[7]

Contact circuit (V)	Interrupting rating (A)				Short-time rating[a]	Continuous rating (A)
	Resistive		Inductive			
	Single contact	Double contact	Single contact	Double contact		
125 dc	3		2.5	7	40	24
250 dc	1		0.5		40	24
600 ac	20				40	24

[a]Short-time current is for 1 min.

Circuit-breaker control switches must "make" the circuit, but independent means (such as breaker auxiliary contacts) "break" the circuit. In these and similar applications, a "make" rating is useful (because the switch interrupts on no-load). The Series 20 make rating is 120 A at 125 V dc.

Allowable variation from rated voltage. Series 20 instrument and control switches are not sensitive to normal variations in voltage. The interrupting capacity is important (Table 4). Variations of ±20% in rated voltage need not be considered as long as the interrupting current is not exceeded.

3.4 Microswitch Multistage Rotary Switches

3.4.1 Microswitch CMC series

The Microswitch CMC series switches are of three basic types: (1) pushbutton, (2) selector, and (3) selector/push-button combination. The three switch types have a lighted, square face plate and are of oil-tight construction for protection against oil, water, and coolant penetration behind the panel or device.

The selector switch type shown in Fig. 20 is of rotary design and is available with two- or three-position, maintained or spring-return operation and also with four-position maintained operation. The basic components of the selector switch are the operator, the contact blocks, legend plate, cover plate, and the cover plate inserts.

The operator section of the switch houses a turn cam that, when the knurled knob at the front of the switch is turned, operates spring-loaded plungers in the contact blocks. The plungers, which carry shorting bars, are so designed that the back ends of the plungers in one contact block engage the front ends of the plungers in the next contact block in tandem. Turning the operating knob causes the plungers to move along the axis of the switch and the shorting bars to make and break circuits as required by the contact sequence of the application.

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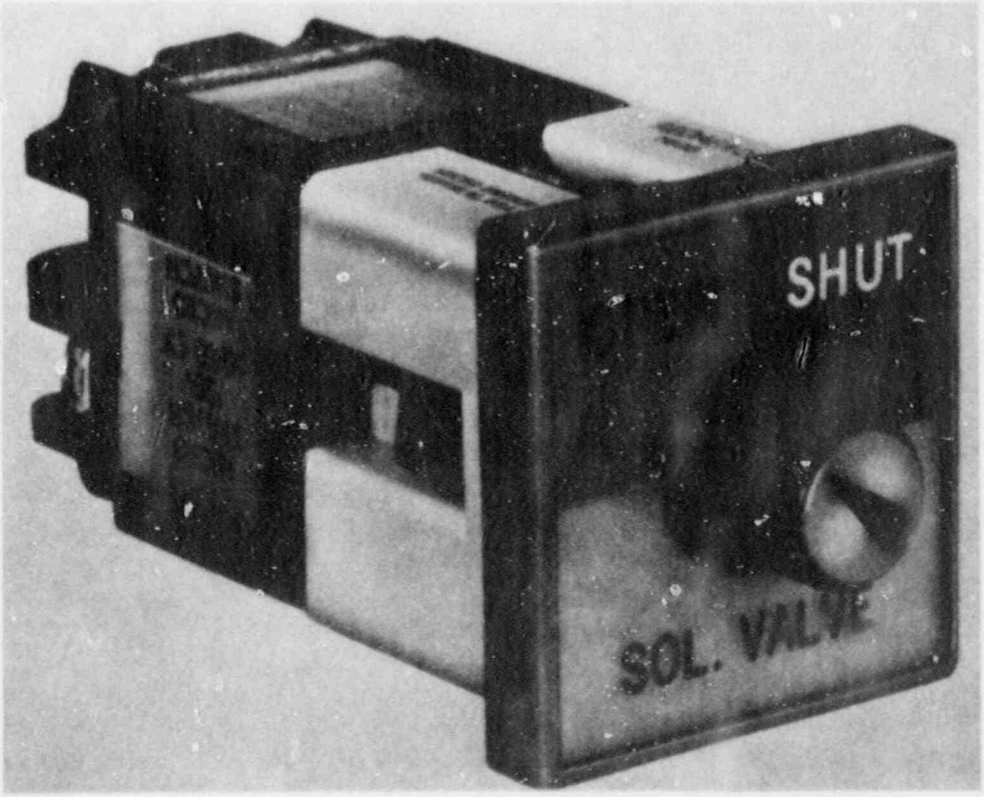

Fig. 20. Microswitch CMC Series selector switch.

Each contact block consists basically of four pairs of contacts and two plungers. Up to 4 contact blocks can be mounted in tandem to accommodate 16 heavy-duty circuits or 32 electronic-duty circuits. A four-plunger adapter block permits four separate sequences of contact action in the contact blocks.

The legend plate is inscribed with the notations pertinent to the switch application. For example, a selector switch used to operate a solenoid-operated valve may have the following notations:

- OPEN
- SHUT
- SOL VALVE

Beneath the cover plate, colored inserts are to be found. There may be from one to four of these inserts, each one a different color and placed in a separate section of the lighted display. Behind each color insert there is a lamp that is individually controllable. The colors of the inserts are keyed to the status of the device being controlled. For example, a green insert may be used to indicate an open solenoid-operated valve; a red insert denotes a shut valve.

The cover plate is basically a piece of transparent plastic framed by a hard plastic material. An important variant of the CMC selector switch is the 920/921 rotary cam-actuated unit (Fig. 21). In this version of the switch, the contacts within the contact blocks are operated by cams instead of by plungers. Up to 12 rotary positions of the selector knob are available with positive detent positioning. The switch can be configured to control up to 24 circuits and has optional turn and push-to-lock capability and make-before-break contacting.

3.4.2 Microswitch PT series

The Microswitch PT line of switches, like the CMC series, is available in push-button, selector, and selector/push-button designs with contact blocks designed specifically for logic level, low-energy electronic, high-ac in-rush, dc inductive, or NEMA size 4 contactor and motor starter applications (with motor ratings of 30 hp at 230 V ac and 60 hp at 460 V ac for ac magnetic starters and contactors in applications requiring repeated interruptions). The selector version of the switch shown in Fig. 22 is a rotary design with up to four contact blocks mounted in tandem for operation by the same operator, similar to the CMC rotary switch. This version is available with two- or three-position, maintained, or spring-return operation.

The operator and contact block, including the four-plunger adapter block, are similar in design and operation to the corresponding CMC selector switch parts.

The PT selector is also available as a cam-actuated unit similar to the CMC 920/921 unit.

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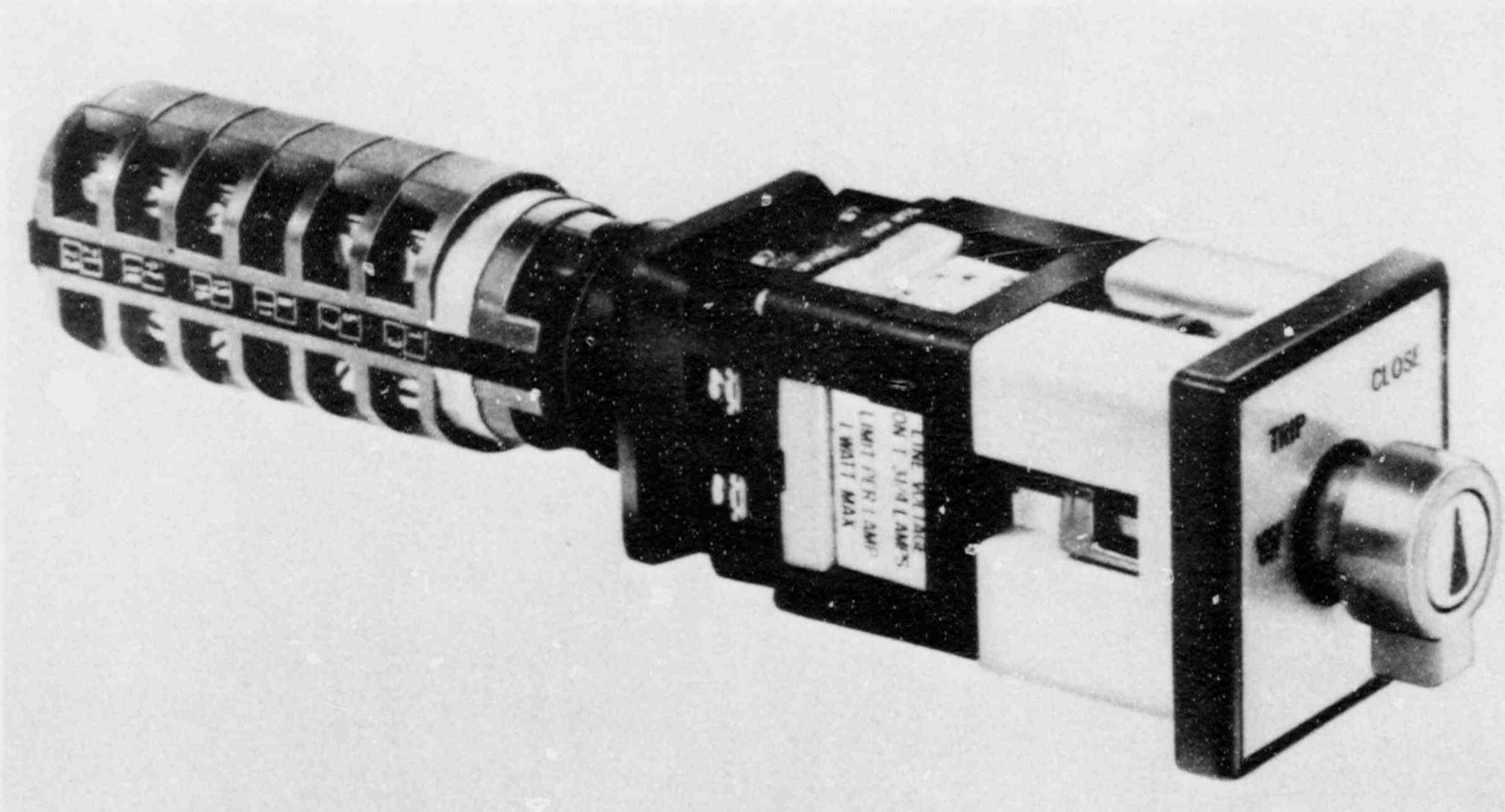

Fig, 21. Microswitch CMC 920/921 rotary cam-actuated switch.

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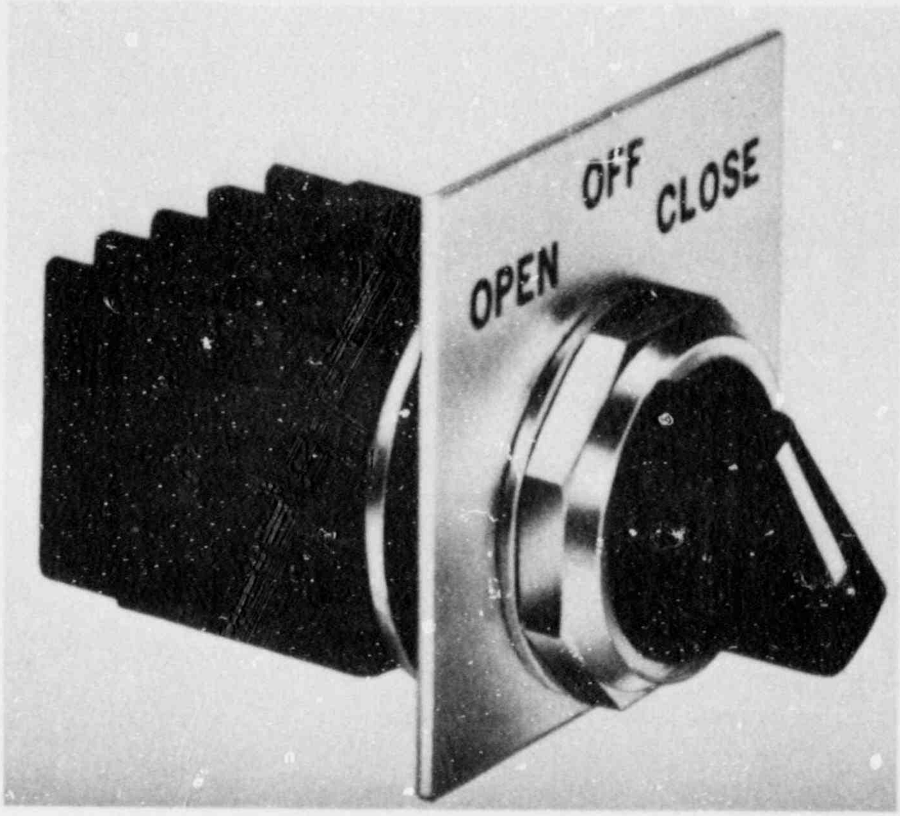

Fig. 22. Microswitch series PT selector switch.

3.5 Materials of Construction

The components of the multistage rotary selector switches used for safety and control applications in nuclear power plants are generally constructed of materials similar to the switches discussed previously. The fixed and moving contacts are usually of solid precious metal, such as silver, or precious metal alloy composition.[2] Plastic insulation material is used to support the fixed contacts and to provide insulation between multiple sets of contacts. Moving contacts are held against the fixed contacts by metallic springs which also return them to their original position. The switch handles are generally made of a plastic or phenolic insulating material. The cams that operate the moving contacts are normally plastic or phenolic mounted on a metallic shaft. The faceplate, screws, nuts, washers, and other hardware are typically of brass or plated steel. Identification of some of the materials used is given in Table 5.

Table 5. Materials of construction of typical multistage rotary switches[3]

Switch components	Material chemical (name)	General Electric		Westinghouse PB
		SBM	CR 2940	
Cams	Polyphenylene oxide (Noryl)		X	
	Acetal (Delrin)			
	Phenolic			X
Supports	Polyvinyl chloride (Vinylite)	X		
Contact block Barriers Covers	Phenolic		X	
Seals Spacers	Acryloritrile-Butadiene (Buna-N)		X	
Detent positioning wheel	Vulcanized fiber	X		
Contact block cam follower wafer	Polycarbonate (Lexan)	X		
Caps	Polyphenylene oxide (Noryl)		X	
	Acetal (Delrin)			X
	Phenolic			
Rings/ plates	Polyester			X
	Polyphenylene oxide (Noryl)		X	
	Phenolic			
Knobs Contact block Handles	Polycarbonate			X
Contacts	Silver or silver alloy	X	X	X
Spacers Shafts Locks Springs Screws/nuts Stops Knobs/dials	Steel/ or aluminium or brass	X	X	X

4. STRESSORS AND AGING MECHANISMS

4.1 Identification of Stressors and Aging Mechanisms

During its service life in a nuclear power plant, a rotary switch can experience degradation as a result of the action of several operating stressors that can be mechanical, chemical, electrical, or thermal or a combination of these types. These stressors, which are superimposed upon normal environmental stressors, are of importance in determining the useful life of the components of a switch. Evaluation of the effect of the stressors on the operational capabilities of a device may allow projection of useful life and, when combined with monitoring techniques, may allow detection of incipient failures. Polymeric materials, such as the material used in making cams for some rotary switches, are susceptible to chemical reactions, such as scission, which are accelerated at elevated temperatures and weaken the material over time. In the scission degradation process, molecular bonds are cut, thus dividing the chain into smaller, weaker segments and eventually resulting in catastrophic breakdown of the cam. Degradation over time that is attributable to operating and environmental factors is known as aging. Many of these stressors are common to all switches because of the similarities in materials, design, and operating conditions.

Some of the most significant aging mechanisms include

Expected stressors

1. resistive self-heating of contacts and contact supports,
2. mechanical stress between the contact surfaces on closing,
3. stress because of mechanical cycling,
4. stress because of electrical cycling,
5. convective and radiant heat transfer from other energized devices and from process lines,
6. corrosion of contacts and springs because of moisture and contaminants in the air,
7. mechanical stress in detent and contact assembly when changing positions, and
8. inductive switching transients and contact arcing in the absence of surge protection.

Abnormal stressors

1. chemical attack of polycarbonate switch materials by hydrocarbon cleaning solutions,
2. exposure to high levels of radiation, and
3. exposure to high moisture levels or dirty (dusty or chemical vapor) environments.

4.2 Expected Stressors

Stressors arising out of the heating effect of an electrical current contribute to the thermal aging of rotary switch materials. When current passes between the stationary and moving contacts, energy dissipated through the contact resistance, which is never zero, appears as heat generated in the immediate vicinity of the switch contacts.[3] The temperature rise is greatest in the area of actual physical contact and varies with the condition of the surfaces. Because of increased electrical resistance, corroded surfaces will produce a greater temperature rise than will clean contact surfaces. The heating can increase the rate of contact corrosion, thereby setting up a progressively worsening situation that eventually leads to burnout or welding of contacts if the current is high enough. However, such failures have been relatively rare in nuclear service. As indicated in Sect. 5, only 24 switch contact failures have been observed from licensee event report (LER) data for a 13-year period, and not all of the switch failures were from contact corrosion.

The heat generated by the electrical current also affects the nonmetallic parts of the switch on which the contacts are mounted. Conduction of heat from the contact surfaces to the supports contributes to the thermal degradation of the support materials. A test[3] conducted on the GE SBM switch has shown that at a maximum rated 20-A continuous load, the temperature of the cam follower rose to 49°C (120°F). The ambient test condition was 27°C (81°F), indicating a rise of 22°C (39°F). If organic materials with poor thermal qualities are used in the vicinity of contacts with high currents, significant thermal deterioration and shortening of switch life could be expected. However, switch materials are selected with thermal properties in mind. In the case of the tested switch, the properties observed at rated load were well within the temperature limitations for the material.

In addition to aging, electrical cycling of a rotary switch with relatively long off-and-on cycles produces mechanical stressing of the contact material because of thermal load cycling. The area of contact between the contact surfaces has an inherent resistance that results from the inability to achieve complete contact at every point. As a result, the current passing between the moving and stationary contacts generates heat, which flows out from the area of contact to the surrounding bulk material, producing a nonuniform temperature distribution. The bulk material's nonuniform expansion and contraction as a result of nonuniform temperature distribution promotes material deformation and the propagation of cracks. As noted above, such failures have not been significant sources of failure in nuclear applications.

Mechanical stresses in the rotary switch contacts contribute to wear of the contacts and, consequently, limit the useful life of the switch. Most switches are designed so that a wiping action occurs when a contact closes. This action removes corrosion products from the surfaces in contact. In addition, to maintain good electrical contact, the movable contact is held against the stationary contact by a spring force. These two mechanisms together produce normal and shear stresses on the surfaces of the contacts and can cause pitting, deformation, and wear when the switch is cycled.

Frequent cycling of a switch can lead to fatigue failure of mechanical components, such as detent, movable contact, and handle-return springs. The existence of stress levels above the high-cycle fatigue endurance limit (maximum stress level that will not produce failure regardless of the number of applied cycles), combined with any weakening of the spring structure (as is caused by corrosion, for example), makes these parts likely candidates for failure through cracks that might eventually lead to fracture.

Failure to operate or misoperation of a rotary switch can also result from the wear of moving components in contact with other switch parts. Cam wear produced by the rubbing of the contoured cam surface against the cam follower can eventually lead to an out-of-tolerance condition. Such a condition can cause a change in the contact arrangement originally specified for a given switch handle position.

The proximity of a rotary switch to other energized devices and to process lines can contribute to the thermal aging of the switch. Thermal energy transported by radiation and convection imposes a heat load that adds to the electrical self-heating of the switch in causing material degradation.

Corrosion of switch parts, especially contacts, and spring materials is a major cause of switch malfunction. The elevated temperatures in the region of surface contact enhance tarnishing and oxidation of the silver contacts. The tarnishing effectively increases the contact circuit resistance and the self-heating of the current. The result is that the potential drop across the switch contacts is increased and the supply voltage to the device being controlled is decreased, possibly to a level insufficient to enable proper functioning of the device. Self-wiping action is designed to reduce the effects of contact corrosion.

In the control circuits of highly inductive devices (such as coils), rotary switches are subjected to large transient currents that create additional thermal loads on the contacts. The higher temperature rise caused by the transients accelerates the tarnishing of the contacts and increases deformation as a result of nonuniform temperature distribution of the contact and contact support materials.

Switching inductive circuits has the potential for producing arcing between contacts, leading to burning and pitting of the surfaces. The high energy density of an arc vaporizes the contact surfaces, causing degradation. However, the effect of these stressors can be moderated by installing protective devices, such as arc suppression and voltage surge protection circuits.

4.3 Abnormal Stressors

Exposure to high levels of radiation, such as during an accident, might have damaging effects on the plastic materials of cams, cam followers, and insulating barriers. Such high radiation doses could cause swelling, warping, or cracking of the parts, resulting in switch malfunctions. For example, swelling of a cam and follower might cause a contact to close when, based on switch handle position, it should be open. Franklin Research Center (FRC) has observed such failures after exposure of switches to >20 Mrd of gamma radiation.

The incompatibility of cleaning solutions with the plastic materials of which some switch parts are made is a source of stress that adversely affects switch life. Hydrocarbon cleaning materials chemically react with polycarbonate switch materials, which can lead to environmental stress cracking or crazing.[8]

The relative effect of the various rotary switch aging mechanisms is dependent on the environment and the application of the switch. An elevated-temperature environment contributes to the thermal aging of susceptible switch parts. Use in high-voltage, high-current circuits imposes additional thermal stressors on contacts and contact support materials.

Wear of shaft-bearing surfaces and of the detent wheel and roller surfaces can produce enough looseness or slip between the shaft assembly and stationary components to cause the contact arrangement to be out of synchronization with the switch handle position.

An occasional cause of switch malfunction is loosening of the tie bolts used to assemble the contact segments in a multistage rotary switch. The result is that the segments move with respect to each other, producing a change in the internal tolerances and in the relative state of the contacts.

A degradation of lubricants used in the shaft bearings can cause seizing of the bearing. Environmental factors, such as high temperatures, can cause chemical changes in the lubricants, leading to a deterioration in their lubricating properties.

Foreign materials, such as dust and metal filings, for example, can cause a failure of the shaft bearings of a rotary switch by obstructing the rotation of the switch handle if the material becomes lodged in the bearings. Another factor contributing to the failure of multistage switches is the relatively loose internal tolerances inherent in a switch made up of many stages. In many switch designs, the difference in distance between contacts making an electrical circuit and remaining open is physically minute. Thus, because tolerances are, for most practical purposes, additive, the increase of the number of stages on one shaft will increase the rate of switch failure as a result of changes in the contact sequence specified for a given switch handle position.

5. EVALUATION OF MULTISTAGE ROTARY SWITCH FAILURE DATA

5.1 Source of Failure Data

The failure data used for this study were the Nuclear Regulatory Commission's LER System and the Institute of Nuclear Power Operations' (INPO's) Nuclear Plant Reliability Data System (NPRDS). The LER data were provided by ORNL's Nuclear Operations Analysis Center (NOAC). The NPRDS failure records were provided for this project by INPO through a cooperative agreement with the NRC Office of Nuclear Regulatory Research.

5.2 LER Failure Data

The LER failure data were obtained from the RECON (remote console) and Sequence Coding and Search System (SCSS) data bases and cover the period from January 1, 1974, through June 1, 1987. Entries in the LER data base are determined by the NRC reporting requirements provided in 10 CFR 50.72 and 10 CFR 50.73. The NRC reporting requirements address only events that have an effect on the safe operation of the plant and may not necessarily include all multistage rotary switch failures that have occurred in operating U.S. nuclear power plants. The reporting criteria are described in greater detail in Ref. 9.

The RECON and SCSS data base sorting was performed using the keywords "instrument" and "switch." The sorting criteria were developed using the expertise of the NOAC personnel responsible for operation of the SCSS data base. A total of 3353 records that matched the keywords were identified. The records were reviewed, and 109 of the 3353 records were identified as failures of multistage rotary switches. The balance of the records were associated with failures of other equipment, such as pressure switches, level switches, and torque switches.

Table 6 provides a breakdown of the LER failure records categorized by cause. Of the 109 LERs applicable to multistage rotary switches, the largest number of records (26) were associated with degradation of contact surfaces, including tarnishing, pitting, or surface contamination. A total of 16 failures were associated with worn or defective detent mechanisms. Several of the defective detent mechanism reports were identified as incorrect or intermittent contact closures on reactor mode switches.[1] An additional 16 failure records were caused by improper assembly during manufacture or by improper modifications made in the field. Nine failures were caused by cam fatigue; the cam failures were the result of exposure to hydrocarbon cleaning solutions that were incompatible with the cam material. The balance of the failure records identified were distributed among 7 different causes (Table 6), with [illegible] of the failure records stating that the cause was not known.

Analysis of the failure data indicates that the causes of failure directly linked to age-related degradation are the tarnishing, pitting, or wearing of contact surfaces and wear of the detent mechanism. A total of 42 age-related failures over a population of an estimated 1500 multistage rotary switches per plant over a 13-year period represents a number of events that should raise very little concern in the industry.

Table 6. Breakdown of failures of multistage rotary switches documented in LERs

Cause	Failure to operate as required	Failure to operate	Not stated
Seized shaft		3	
Radiation damage to cam	1	1	
Assembly/modification	14 (15%)	2	
Loose or broken jumper wire	2	2	
Tarnishing, pitting, wearing of the contacts or surface contamination	6	20 (24%)	
Loose/damaged operator	3	1	
Degradation of switch components caused by aging (type of aging undefined)		1	
Switch components not properly adjusted or aligned	2	4	
Faulty switch; transmitted noisy control signal	1		2
Cracked plastic cam caused by exposure to non-compatible chemical environment		5	4
Worn or defective detent mechanism	12 (15%)	4	
Unknown	4	11	7
Total	43	54	12

5.3 NPRDS Failure Data

The NPRDS data were obtained from the INPO failure data base, which is updated by operating power plants on a quarterly basis. The NPRDS data base was searched using the component engineering data Instrumentation Bistable/Switch (IBISSW) keywords, which provide the only sorting criteria where switches would be found. The database was searched for all reports through May 1987. A total of 1219 records matched the IBISSW sorting criteria. Of the 1219 records, only 14 applied to multistage rotary switches. The description of the cause of failure for each of the 14 records is provided in Table 7. The remaining 1205 records applied to various other types of switches, including pressure, level, flow, position, and torque switches.

As can be seen through review of Table 7, no trend or high incidence of failure is apparent, and the data provided do not lend themselves to analysis. The low incidence of failure, however, coincides with the analysis of the LER failure records.

Table 7. Summary of NPRDS failure records

Record No.	Failure cause description
13	Old switch was repaired by replacing contacts
20	Cause was wear and age of the switch
21	Cause was wear and age of the switch
239	Control switch did not make
313	Cog for the contact on the handswitch was broken because of normal age and wear
727	Logic test switch was defective and needed to be repaired
773	Control switch was oversensitive because of use and needed to be replaced
774	Probable cause of failure was dust inside the switch
826	Discussions with the supplier concluded that worn and/or dirty contacts were the cause
897	Troubleshooting found that the pressure pin for the HS internal spring leaf, which connects the movable contacts, had dropped through and was not applying enough pressure for proper contact
1039	End of life
1112	This switch has dirty contacts that cannot be cleaned adequately
1124	TSH-22137 was found to have a dirty test switch that resulted in intermittent electrical contact, thereby energizing the channel
1125	Dirty contacts on the test—operate switch apparently are not fully cleanable

6. FAILURE MODE AND CAUSE ANALYSIS

6.1 Information Sources

The analysis of failure modes and causes for multistage switches was conducted using information on failures in operation obtained from manufacturers and nuclear power plant maintenance personnel. In most instances (probably because of cost and ease of replacement), feedback to the manufacturer on switch problems was limited to incidences of manufacturing problems. To identify any potential manner in which a failure could occur, a thorough evaluation of each component and its function within the multistage rotary switch was then performed using detailed manufacturing or assembly drawings of each type of rotary switch. The failure modes and causes contained within the LER and NPRDS data were then compared with the results of the analysis to verify that actual operating experience was addressed. The limited number of failures reported in the LER and NPRDS data precludes complete validation of the failure mode and cause analysis; however, for those failures reported, all modes and causes are included in the analysis.

For the purposes of this study, the multistage rotary switch boundary was defined to include the switch handle, escutcheon plate, internal operating mechanisms, and terminations. Electrical leads connected to the switch were considered outside the device boundary.

6.2 Multistage Rotary Switch Failure Modes

From the information sources, it was determined that the failure modes for the multistage rotary switches could be grouped into two generic categories: (1) failure to operate and (2) failure to operate as required.

Failure to operate may be defined as follows: upon rotation of the switch handle from position 1 to position 2 (with positions 1 and 2 being any normal position for switch operation), contact opening or closure determined by the position of the switch handle does not occur. Failure to operate as required indicates that upon movement of the switch handle as described above, one or more of the contacts required to change from the open to closed state (or vice versa) do not do so. Failure to operate, therefore, is complete failure of the switching function to occur, and failure to operate as required involves completion of some required, but not all, switching functions upon change of handle position.

6.3 Rotary Switch Failure Analysis

Table 8 summarizes the postulated failure modes and related probable causes. Many of the failure modes were deemed improbable because of the construction of rotary switches (e.g., shearing of a 1/4-in. square steel shaft); however, all postulated failure modes were included for completeness. Although the table is not broken down into manufacturer or model-

Table 8. Failure modes of multistage rotary switches

Failure mode	Component	Failure cause	Failure mechanism	Effect on device
Failure to operate	Contact	Contamination of contact surface[a]	Corrosion or oxidation of contact surface, imbedding of foreign material	Contact will not close properly, high electrical resistance
		Broken or distorted moving contact[a]	Fatigue caused by cyclical stresses or thermal effects	Contact does not close
		Loose contact terminal screw or solder joint[a]	Vibration; frequent use	Short or open circuit
		Sticking moving contact[a]	Contaminants obstructing motion	Contacts will not change state
	Contact block	Loose contact bank[a]	Vibration or shock	Contacts do not mate properly
	Moving contact spring	Spring break[b]	Fatigue caused by cycling	No positive return of cam followers; contacts may open and close randomly
	Moving contact assembly	Gear break[b]	Fatigue caused by cycling	Contacts do not change state
	Moving contact pin	Pin break[a]	Thermal stresses, fatigue caused by cycling	Contacts will tend to remain closed during opening cam action
	Cams	Closing cam fracture[a]	Thermal/mechanical stresses; radiation damage	Contacts do not change state
		Opening cam fracture[a]	Thermal/mechanical stresses; radiation damage	Contacts do not change state
	Cam follower	Broken or warped follower[a]	Thermal/radiation stresses; shock vibration	Contacts do not change state
	Switch handle	Broken or loose set screws[a]	Vibration; shock	Switch will not change position
	Shaft	Broken camshaft[b]	Mechanical stress cracking	Switch will not change position
	Shaft bearings	Bearing freeze-up, wear[a]	Degradation, or loss, of lubricant	Switch will not change position
	Gear	Gear failure[b]	Fatigue caused by cycling stresses	Switch will not maintain position
Failure to operate as required	Camshaft	Bent or twisted shaft[b]	Excessive actuating torque	Contact alignment incorrect
	Contact	Pitted, worn, or welded contact[a]	Thermal stresses; inductive switching transients; arcing; friction	High contact resistance
	Detent mechanism	Worn detent mechanism[a]	Cycling stress	False indication of position change; contacts do not properly make up
		Loose detent roller pin[a]	Mechanical stresses, cycling stresses	False detent position caused by contact closing torque
	Detent stop arm	Bent stop arm[b]	Excessive actuating torque	Overtravel of cams at end stop
	Cam follower	Slipping of cam follower[a]	Worn cam follower	Incomplete contact closure
	Contact jumpers	Broken or loose jumper[a]	Corrosion; contaminants	Random open or short circuit

[a]Anticipated failure cause.

[b]Improbable in normal plant operation.

specific failure modes, the predominant component features of each switch style are included.

The most predominant failure (as evidenced by the LER data) of rotary switches is related to contact failure. The causes associated with the contact failure include contamination, pitting, oxidation, and wear. Each of these failure causes may, in turn, be related to aging phenomena. Pitting normally results from the electrical surges at the contact surface caused by arcing from breaking an electrical current. Oxidation, on the other hand, results from the silver contacts being continously exposed to the environment. Wear is normally associated with frequent cycling and the wiping action included in many contact designs. Contaminants may impede contact closure and in high dust environments may provide sufficient coating to increase contact resistance enough to provide an insulating barrier between the switch contacts, defeating the switch function.

The other predominant failure cause, observed from the failure data, is wear of the detent or other sliding surfaces so that improper switch operation occurs because of frequent operation of a rotary switch. The normal friction on the detent mechanism, cams, and other sliding surfaces slowly causes the materials to wear away so that over time, the critical dimensions of switch parts change. The detent mechanism may also wear in such a manner as to allow over- or under-travel of the switch mechanism, resulting in failure to operate as required.

7. TESTING AND MAINTENANCE REQUIREMENTS

The GE, Westinghouse, Electroswitch, and Microswitch manuals[2,4-7] were reviewed for periodic maintenance and surveillance instructions. None of the manufacturers provided any recommendations for periodic maintenance and surveillance. The multistage switches are considered to be useful for the life of the nuclear power plant with refurbishment or maintenance on a corrective basis only.[3]

A review of the standard technical specifications[10-13] did not reveal any specific surveillance requirements related directly to multistage switches. The switches are operated on a periodic basis because the multistage switches are integral parts of the control systems for instrumentation, pumps, valves, and other equipment that is subjected to channel and operability checks. As a result, the switches are checked during periodic operation of associated system components. The operation normally consists of transfer of the multistage rotary switch from one position to the next to verify the operability of the device (e.g., valve or motor). The operability of the device under test is verified through changes in status lights or by other means of validation. Improper operation of the system components during these periodic checks would result in isolation of the defective component and corrective action to restore system operability. Failure or improper operation of multistage switches would be identified during the determination of the cause of failure.

8. AGING AND SERVICE WEAR MONITORING AND ASSESSMENT

A search for methods to assess the condition of switch components and to possibly predict age-related failures has identified several potential techniques. These methods are based on experience with failure analyses of rotary switches, review of manufacturers' technical bulletins, and material obtained during this study.

8.1 Monitoring of Deterioration and Detection of Failures

Monitoring techniques for switch deterioration and failure do not appear to be in use. As described in Sect. 7, switches are operated periodically during system tests. The periodic operation of the rotary switches to meet technical specification requirements would allow discovery of rotary switches that had failed.

To determine potential means for monitoring deterioration of switches, the predominant failure modes discussed in Sect. 6 were reviewed, and methods for identification of the failure causes were examined. Table 9 provides the results of this analysis.

Table 10 lists a number of parameters that might be of value in evaluating trends in degradation and incipient failure detection of multistage rotary switches. Some of these are currently in use; others have been identified as a result of this study. Measurements of component dimensions, torque, and contact resistance are of interest in assessment of age-related degradation. Many of the techniques described may be more useful in evaluating actual failures so that corrective action can be taken on like switches. Repeated disassembly is recognized as costly and damaging to the switches. Some of these potential monitoring techniques are impractical for use during normal power plant operation.

Deformation of such critical parts as shafts, cams, cam followers, and contacts will be detectable by measurement of component dimensions. For example, warping of a cam caused by curing after assembly or thermal and irradiation aging or damage is a potential cause of switch failure because of changes in critical dimensions. A verification of switch dimensions will indicate any change in the contour of the critical cam surface where it acts upon the cam follower.

Measurement of the torque required to move the switch handle from one position to another can provide information about the condition of such switch components as shaft, detent or positioning mechanism, cam follower, handle, cams, and gears. Wear of a detent wheel, for example, may show up as a reduction of the maximum torque level in such a measurement. Deformation of the stops in the extreme positions of the switch may be identifiable from a measurement of the changes in angle at the extreme positions of the switch.

Based on operating experience, contact failure has been determined to be a major cause of failure of multistage rotary switches. Failure cause evaluations have shown that several factors may affect the quality

Table 9. Method for identifying failure causes of rotary switches

Failure mode	Component	Failure cause	Method for identification
Failure to operate	Switch handle	Broken or loose set screw	Visual inspection; operational check
	Shaft	Broken camshaft	Visual inspection
	Shaft bearing	Bearing freeze-up, wear	Operational check; visual inspection
	Gear	Gear failure	Visual inspection
	Contact block	Loose contact bank	Visual inspection; hold-down screw tightness check
	Camshaft	Bent or twisted shaft	Visual inspection
	Contacts	Pitted, worn, or welded contact	Visual inspection; contact resistance measurement
	Detent mechanism	Worn detent mechanism Loose detent roller pin	Torque measurement; operational check; cycling torque measurement; visual inspection
	Detent stop arm	Bent stop arm	Visual inspection
	Cam follower	Slipping of cam followers	Operational check
	Contact jumpers	Broken or loose jumper	Contact resistance measurement; visual inspection
Failure to operate as required	Contacts	Contamination of contact surface	Visual inspection; contact resistance measurement
		Broken or distorted moving contact	Visual inspection; contact resistance measurement
		Loose contact terminal screw or solder joint	Visual inspection; contact resistance measurement
		Sticking moving contact	Visual inspection
	Moving contact spring	Spring break	Visual inspection; operational check
	Moving contact assembly	Gear break	Visual inspection
	Moving contact pin	Pin break	Visual inspection; operational check
	Cams	Closing cam failure	Visual inspection; continuity check
		Opening cam failure	Visual inspection; continuity check
	Cam follower	Broken or warped follower	Visual inspection; continuity check; contact resistance measurement

Table 10. Measureable parameters for evaluation of degradation of rotary switches

Failure mode	Component	Failure cause	Measureable parameter
Failure to operate	Contacts	Contamination of contact surface	
		Broken or distorted moving contact	Contact resistance
		Loose contact terminal screw or solder joint	Contact resistance
		Sticking moving contact	Contact resistance
	Contact block	Loose contact bank	Appearance; contact resistance; torque
	Moving contact spring	Spring break	Appearance; dimensions; force
	Moving contact assembly	Gear break	Appearance
	Moving contact pin	Pin break	Appearance
	Cams	Closing cam failure	Appearance; wear patterns
		Opening cam failure	Appearance; wear patterns
	Cam follower	Broken or warped follower resistance, continuity	Appearance; dimensions, contact
	Switch handle	Broken or loose set screw	Appearance
	Shaft	Broken camshaft	Appearance
	Shaft bearing	Bearing freeze-up, wear	Appearance
	Gear	Gear failure	Appearance
Failure to operate as required	Camshaft	Bent or twisted shaft	Appearance; dimensions
	Contacts	Pitted, worn, or welded contact	Contact resistance; appearance
	Detent mechanism	Worn detent mechanism	Torque; appearance
		Loose detent roller pin	Torque; appearance
	Detent stop arm	Bent stop arm	Appearance; dimensions
	Cam follower	Slipping of cam follower	Dimensions; wear pattern
	Contact jumpers	Broken or loose jumper	Continuity; contact resistance

of the electrical contact of closed switch contacts. Contact deformation, wear, corrosion, erosion, and pitting caused by arcing are prominent factors. Measurement of contact resistance of a switch that is periodically removed from service can be valuable in degradation tracking of the switch contacts.

Although qualitative rather than measurable parameters, appearance and feel are of major importance in monitoring component degradation caused by aging and normal service wear. Visual inspection can identify problems, such as corrosion of contacts, deformation, fractures, and contamination, that eventually may lead to switch failure. Operators often are able to detect when components in a switch are loosening or binding. Reporting of such observances may allow repair before total failure.

A summary of switch part failure assessments discussed in this report is given in Table 11. This table lists relationships between materials, stressors, failure causes, and measurable parameters.

8.2 Potential Monitoring Techniques

A computerized data search was conducted to identify publications pertinent to this program. The National Technical Information Center (NTIC) engineering data base, as well as the Dialog Information Services, Inc., data bases, was searched. Of the articles and publications reviewed from these data bases, no practical information relating to condition monitoring methods or techniques for multistage rotary switches were identified.

Methods that may be considered for potential condition monitoring programs have been identified by FRC and are discussed briefly below. Some techniques could be used on a sampling basis but would not be recommended for use on a plantwide basis.

1. Measurement of selector torque:

   Measurement of the torque required to move the rotary switch handle out of one selected position to another position can provid information about the condition of internal switch components. Binding and wear of mating surfaces are examples of internal conditions that would more than likely affect the effort needed to turn the switch handle. Measurement of selector torque would require development of an instrument for measurement of torque for many different types of rotary switches. Acceptance criteria would need to be developed for each type of switch, depending upon the type of detent mechanism and the number of contacts provided on each switch. Plant personnel performing the testing would be required to receive training on conducting the testing, and procedures would need to be developed to satisfy plant technical specifications so that testing could be performed. A large cost burden would appear to be associated with implementation of this technique.

Table 11. Summary of failure assessment of multistage rotary switch parts

Part	Generic materials	Significant stressors and failure causes		Measureable parameters
Camshaft	Stainless steel, steel, aluminum, and brass	Mechanical:	Torsion, bending	Dimensions, appearance, and shaft torque
		Chemical:	Corrosion	
Bearings	Steel and bronze	Mechanical:	Wear, seizure	Feel and appearance
		Chemical:	Corrosion	
Contacts	Silver and silver alloy	Mechanical:	Wear, distortion, welding, fracture, loosening	Contact resistance and appearance
		Chemical:	Erosion, corrosion	
Contact pin	Steel, aluminum, and brass	Mechanical:	Fatigue	Appearance and feel
		Chemical:	Corrosion	
Contact block	Phenolic and polycarbonate	Mechanical	Loosening	Appearance and feel
		Thermal:	Corrosion	
Cams	Phenolic, polyphenylene oxide, and Acetal	Mechanical:	Loosening, wear, fatigue	Shaft torque, appearance, and dimensions
		Thermal:	Hardening, embrittlement	Appearance
		Radiation:	Embrittlement	Appearance
Cam follower	Plastic and Lexan	Mechanical:	Wear, fatigue	
		Thermal:	Hardening,	Shaft torque and dimensions
			embrittlement	Appearance
		Radiation:	Embrittlement	Appearance
Detent wheel	Rubber and plastic Vulcanized fiber	Mechanical:	Wear	Shaft torque and dimensions
		Thermal:	Hardening, embrittlement	Appearance
Detent roller	Rubber and plastic Vulcanized fiber	Mechanical:	Wear	Shaft torque and dimensions
		Thermal:	Hardening, embrittlement	Appearance
Contact spring	Steel, aluminum, and brass	Mechanical:	Fatigue	Appedrance
		Chemical:	Corrosion	
Detent stop arm	Steel	Mechanical:	Bending	Total angle of rotation, dimensions, and appearance
		Chemical:	Corrosion	
Contact jumpers	Copper with plastic or rubber insulation	Mechanical:	Vibration	Appearance
		Thermal:	Hardening, embrittlement (of insulation)	
Switch handle	Plastic	Mechanical:	Vibration Excessive torque	Shaft torque, appearance, and play
Gear	Steel	Mechanical:	Fatigue	Shaft torque, appearance, and play
		Chemical:	Corrosion	

2. Visual inspection of switch components:

Visual inspection is particularly useful in assessing the condition of switch contacts. Conditions such as burning or pitting of contact surfaces, broken shunts on moving contacts, and insufficient contact wipe should be readily observable. Visual inspection of rotary switches would require disassembly in many instances. To allow disassembly, lead wires connected to the switch would have to be disconnected. This would require procedures for lifting and tagging of leads, as well as for postmaintenance operability checks on the connected equipment.

3. Measurement of contact resistance:

The resistance associated with the interface between stationary and moving contacts that can give some indication of the state of the contacts. The buildup of a film of oxidation products on the surfaces will cause a measurable increase in the contact resistance and may also reveal itself through the erratic nature of the reading obtained. Measurement of contact resistance, as mentioned for visual inspection, would require disconnection and reconnection of leads and postmaintenance operability checks on the connected equipment.

4. Operator feedback:

The feel of a switch to an operator or to a test technician is frequently useful in providing qualitative data about the condition of a switch. Any discernible change in the effort required to move the handle from one position to another would suggest that a closer examination of the switch is advisable.

5. Evaluation of failed switches:

Close examination of a failed switch to determine the root cause of failure is very important. Such information can indicate whether the failure is from a random flaw or a generic problem, in which case the replacement of the remainder of the population of the specific switch design may be required.

6. Periodic disassembly of a switch:

The disassembly of a switch that has been randomly selected can provide indication of the degree of degradation of the switch components in this and other switches subjected to the same service conditions. This approach, however, requires a very knowledgeable evaluator and may be of limited usefulness because the analysis will be mainly qualitative and the environments and service factors of switches may not be sufficiently similar.

7. Surveillance testing of system

System surveillance tests required by technical specifications generally provide information on the operability of the total system. However, failure of the system to operate as required results in an investigation to identify the defective component. Failure of the system's control switches would be identifiable. This method of condition monitoring has the advantage of not requiring any interruption of the circuit function beyond what would be required by the surveillance testing and does not demand any additional disassembly or modification of the switch console. The major disadvantage is that it would not detect incipient failure of the switch.

Although identified as a possible technique for condition monitoring, megger (insulation resistance) testing is not recommended for use in a control panel. The performance of a megger test will require interruption of switch operation and disconnection of leads, all of which increases the probability of system malfunction caused by improper reconnection.

9. CONCLUSIONS

Evaluation of aging mechanisms, failure records, and potential monitoring techniques for multistage rotary switches results in the following conclusions:

1. The incidence of failure for rotary switches in safety and control applications as reported in the LERs has been low (109 failures over 13 years).
2. The greatest number of failures, as identified in the LER data base, was associated with degradation of contacts.
3. With the exception of operator feedback and root-cause failure determination, the existing monitoring methods for determination of switch degradation appear to be intrusive in nature and would be burdensome on plant operations.
4. Root-cause evaluation of multistage switch failures should be performed to identify steps necessary to preclude additional failures.
5. Because the failure rate of multistage rotary switches in nuclear power plants has been low, the cost of the implementation of any plantwide or industrywide monitoring programs will outweigh the potential benefits. Therefore, development of monitoring techniques is not recommended.

10. RECOMMENDATIONS

It is recommended that plant operators be instructed to provide feedback on any perceived problems with operation of multistage rotary switches and that all in-service failures be thoroughly analyzed to determine whether they are random or are the consequence of generic problems with the particular switch model.

It is further recommended that multistage rotary switches be deleted from further consideration in the NPAR Program because

1. review of the LER and NPRDS failure data indicates that the incidence of multistage rotary switch failures is low, and
2. the cost of development and implementation of surveillance and monitoring techniques would outweigh the potential benefits.

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13. ABSTRACT (200 words or less)

An assessment of the types and uses of multistage switches in nuclear power plant safety-related service is provided. Through a description of the operation of each type of switch, combined with knowledge of nuclear power plant applications and operational occurrences, the significant stressors responsible for multistage switch deterioration are identified. A review of operating experience (failure data) leads to identification of potential monitoring techniques for early detection of incipient failures. Although the operating experience does not justify extensive deterioration monitoring of multistage switches, nondestructive testing methods that could be used to evaluate the condition of switches are identified.

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