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Development of Sealed Contact Pushbutton Switch

By Ryohei Kinoshita, Yoshiaki Oohashi, Masami Ishizawa, Masatoshi Kubo, Hajime Sasaki

(Manuscript received August 13, 1969)

Along with a rapid and remarkable progress of the data processing techniques, the relevant applied equipment and units are used in a wider range of applications including for general purposes, not limited only to the special fields. This tendency is now growing, and where a man exists, there will be always a terminal equipment and there may be a strong demand in the future for highly reliable communication and exchange of data between the man and machine.

From the viewpoint of reliability, a consideration has been formerly paid to using of a reed switch for the contact of a pushbutton switch, and some of those already exist in the field. A pushbutton switch for the general purpose has been developed with a sealed contact and those families are made to be easily applicable to various uses. The basic type is the pushbutton switch of a momentary type; by adding or changing some of the parts, the type available will be alternate type, lamp indication type and their combination for a single switch unit. Further, a number of the switch units may be assembled into a frame and a few parts may be added to provide a selective pushbutton switch and ten-key type unit.

This switch has been already assembled into some equipment and its compactness and high reliability are highly evaluated and is therefore assured to have larger use in wider applications in the future.

1. Introduction

There have been considered many methods and means for actuating a machine to operate by giving it an order. For the means to economically convey the order to the machine, not affected very much by the number of types of the orders, a pushbutton switch has long been used. The pushbutton switch of the simplest function is based on a mechanism in which the pushbutton has been depressed it connects or disconnects the circuit, and when the pushbutton is released the circuit is disconnected or connected. Many other mechanisms have been also employed for the pushbutton switch, in which the first depressing of the button permits the operation, and the operation is continued even if the button has been released, and will stop as the second depressing is made, or in which only one of the set switches is permitted to operate. There is also a type of switch added with a simple display unit, so that the data is transferred to a man from the machine through the on/off control of the built-in lamps.

These types of the pushbutton switches have been used in general applications and more will be utilized along with the progress of the data processing techniques. Accordingly, there have arised various demands to meet the growing range of applications of the switch.

It may be easily expected that use of a reed switch of high reliability will considerably improve the reliability of the pushbutton switch: if a general concept for smaller size, economization and adaptability of the switch is realized and reflected into the reliability improvement, the range of the applications will further be widened. With this borne in mind, the authors have developed the pushbutton switch which may be assembled into family construction.

2. The design concept

The pushbutton switch is defined to be an equipment which, when depressed by a finger of a man, will produce an output operation called switching of an electric circuit.

With respect to the input, the pushbutton switch may be divided into the following types.

(1) One in which the depressing force is transfered into the displacement through a spring or the like and this displacement used for an input signal.

(2) One in which the depressing force itself is used as an input signal.

(3) One in which a mere touch of a finger is utilized for an input signal instead of a depressing force.

The popularity of these types of switches is in the above order. For the finger feeling upon touching the button, a type of switch which causes a certain reasonable reaction and follow-up displacement is better than that which stops abruptly. In this regard, the conversion method of type (1) above mentioned is superior to all others. However, regarding the switch which is not so much frequently used (such as a lift or an elevator pushbutton), it may be better to use the one which will easily turn on by finger touch only. The authors aimed primarily at making one which is suitable for various control desks at which some special personnel or if not a limited number of operators will control the pushbuttons, and have employed the method (1) above. This is naturally associated with selection of the output element.

The output element may be used for the following subjects.

(1) Mechanical contact point (often non-sealed type) to be directly on/off controlled by the mechanical force.

(2) Reed switch with the on/off control performed by magnetic force.

(3) A semiconductor switch in which the impedance is varied by means of the mechanical pressure.

(4) A semiconductor element which causes an impedance change due to change in outside magnetic field.

The type (1) above is losing its popularity because of the lowering reliability as the operation circumstance is becoming worse along with expansion of the application range, and a reed switch which is not affected by the ambient atmospheric condition are to be used. The mechanical contact as the types (1) and (2) shows a merit of large on/off impedance ratio which is more than 10^{11}, and this fact is considered to be one of outstanding features for improvement of the S/N ratio of the signal. In addition, the cost per switch is comparatively low. With these points taken into consideration, the determination has been made to use the sealed contact (so-called reed switch).

The greater the number of the contact points are, the more desirable is the pushbutton switch, because of popularity and versatility. However, it causes an increase of space for installation and may prevent realization of smaller sized equipment. Therefore, from the view point of minimum space restriction (mainly the mounting pitch at the intallation surface), the pushbutton switch is sized to an extent where only two contact points can be included. Those contact points are constructed enabling the 2-make or 2-break or 1-transfer arrangement selection for requirements. In order to facilitate the contact point arrangement and to make the pushbutton switches smaller in size, the FDR-7 reed switch is used.

A family system is constructed in which the basic parts are compatible as much as possible, so that various types of the pushbutton switches may be realized by partly changing the parts and/or adding them. This may be effective to lowering the cost of the completed switch unit and shortening of the delivery period. The switch construction available may be classified into the following.

(1) A pushbutton switch without lamp indication

(a) A type to be installed from the front side of the panel (FES-1)

Momentary type and alternate type (various contact arrangement is possible).

(b) A type which is installed from the rear side of the panel (FES-3)

Momentary type, alternate type and mutually interlock type.

(2) Pushbutton switch with lamp indication (FES-2)

Momentary type and alternate type

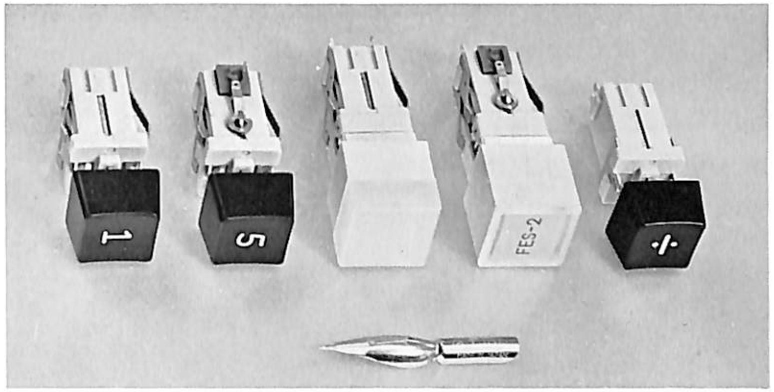
These types may be further classified by the type of the display unit, types of lamps and its color and number, and presence of display spliting.

(3) Lamp display only (FES-2)

This type is obtained by eliminating the switching mechanism from the above types.

(4) Interlock type pushbutton switch

A number of switches (a) or (b) are installed to a separately-designed frame, thus providing the interlocking function.



Type FES-1 switch Type FES-2 switch Type FES-3 switch

Fig. 1—Outer view of FES type switches.

3. Basic design

The requirements for the reed switch have been set up based on the idea mentioned in the preceding paragraph, and a magnet suitable for the said reed switch has been designed.

3.1 Reed switch

Reed switches consist of two flat reeds of nickel iron alloy, hermetically sealed into a glass envelope so that they overlap to give a suitable contact area. The contact surfaces are plated with noble metal to reduce the contact resistance and the glass envelope is filled with an inert gas. The cotacts are separated and one or both of the reeds is flexible.

When the switch is placed in a magnetic field the contacts are magnetized in opposite polarities and attractive force is produced between them. When this force is sufficient to overcome the restoring forces of the reeds they are attracted together and since the attraction force increases inversely for the separation distance the switch closes rapidly. The converse occurs as the field is weakened and the contacts open. Since a reed switch has small and simple construction, a high speed switching of less than 1 msec is possible; further, since it is perfectly sealed, it will not be affected by the ambient atmosphere and therefore the contact shows high reliability and long life.

Therefore, it is most suitable for the switching element of the keyboard of the desk-top calculator and terminal equipment.

The characteristics of the reed switch may vary depending upon the shape of the reed contact material, sealed gas, etc.

The FDR-7 switch is suitable for the switching element of an electronic equipment from the following features.

(1) Very small size of glass tube, 2.56 mm in diameter and 14 mm in length.

(2) Because of off-set type, a break contact is easily obtained only by arranging the make switch in reverse.

(3) Since the contact surfaces are plated with gold, the contact resistance is very stable and the switch is suitable for the transmission of the input signal to the transistor circuit.

(4) Since the chattering time is very short, high speed switching of 1 ms order is possible.

(5) In accordance with the low operate ampere turn, there is a little difference between the positions "ON" and "OFF", so that the pushbutton stroke may be minimized.

Table 1 Major features of FDR-7 type reed switch

Operate NI	25~50 AT
Release NI	13~30 AT
Overall length	40 mm
Glass tube length	15 mm max.
Glass tube diameter	2.7 mm max.
Contact	Diffused gold
Operate time (including bouncing time)	0.8 ms max.
Release time	0.05 ms max.
Contact rating	4 VA
Contact resistance (initial)	200 mΩ max.
Breakdown voltage	DC 400 V
Insulating resistance	10^9 Ω min.

From these features, the FDR-7 has been selected for the switching element.

3.2 Magnet

The change of the magnetic field necessary to open or close the switch is obtained by relative movement between switch and magnet or by movement of a shunt or other magnet to control the operating field.

The typical example of the change is shown in Fig. 2.

A type having a movable magnet is suitable for the pushbutton switch because of stable operations and its simple construction.

The annular magnet, since its internal magnetic field is uniform, will not affect the operate and release position of the switch even when the installation position of the reed switch has changed to some extent, thus permitting non-adjusting assembling. However, when the number

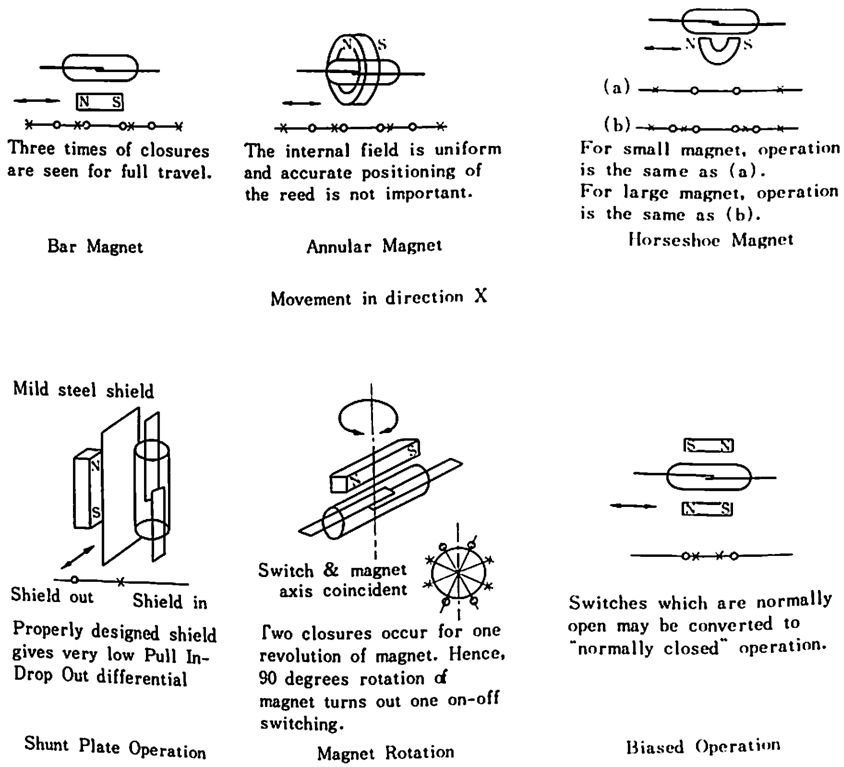


Fig. 2—Several forms of magnetic actuation.

of the switches increases, the pushbutton switch construction is bound to become larger and complex. Therefore, the authors have adopted the bar magnet.

When the bar magnet has been moved in the X direction (in parallel with the reed switch axis) and Y direction (perpendicular to the reed switch axis), the magnetic potential difference (ϕ) at the gap of the reeds is divided into two regions, as shown in Fig. 3, one where the change rate is small and another the change rate is great. The change rate at the latter is in inversely proportional to the 3.7th power of the magnet displacement in the X direction and to the 2nd power

in the Y direction. In order to minimize the variation of the position of magnet where the reed switch opens or closes even though characteristics of the reed switch varies, it is necessary or desirable that the change rate ($\Delta\phi/\Delta X$) of the magnetic potential difference near the operate position be large, namely the magnetic potential difference at which the reed switch operates be less than 0.7 times of the maximum potential difference.

The relation of effective magnetic flux (ϕ_e) which passes through the reeds versus the clearance between the magnet and reed switch is given as in Fig. 4. If this clearance is set at 0.5 mm, the value ϕ_e/ϕ_M will be approximately 0.12 and the magnetic flux quantity (ϕ_M) of the magnet will be

$$\phi_M \geqq \phi_{OP}/0.7 \times 0.12 \qquad \text{..............(1)}$$

Since the operate flux (ϕ_{OP}) of the FDR-7 switch is 25 Maxwell as shown in Fig. 5, the magnet is needed to generate a magnetic flux of more than 300 Maxwells.

The open/close position of the switch varies depending upon the direction of the magnet motion, magnet shape and magnet material as well as the relative position.

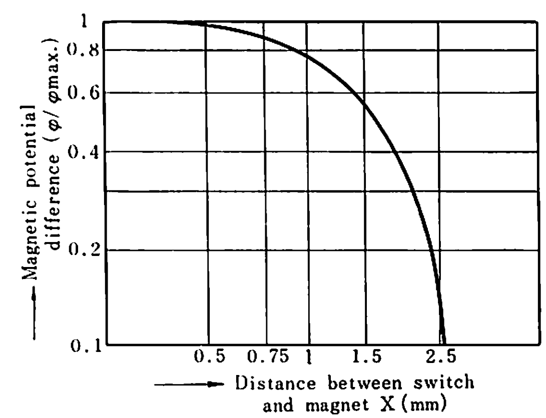


Fig. 3—Characteristics of X vs. φ/φ_{max}.

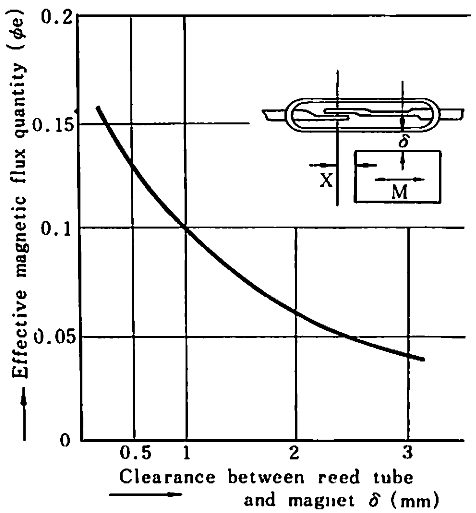


Fig. 4—δ vs. ϕ_e characteristics.

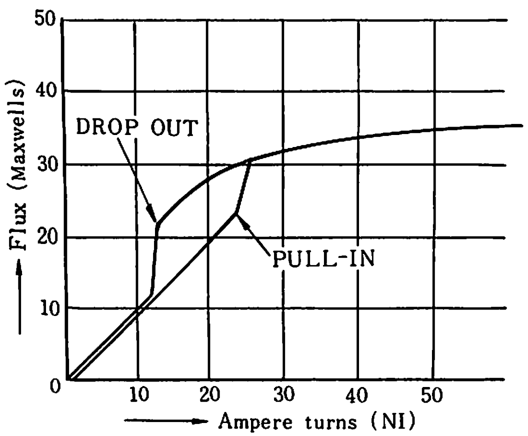


Fig. 5—Magnetization curve of FDR-7 type reed switch.

Table 2 Factor and level

Factor	Notation	Level	
		1	2
Width of magnet	W	4	6
Length of magnet	L	4.5	6
Height of magnet	H	5	10
Arrangement	P	P_1	P_2
Material	M	M_1	M_2

cf) P_1; P_2; } See Fig. 6
M_1; Isotropic barium ferrite
M_2; Anisotropic barium ferrite

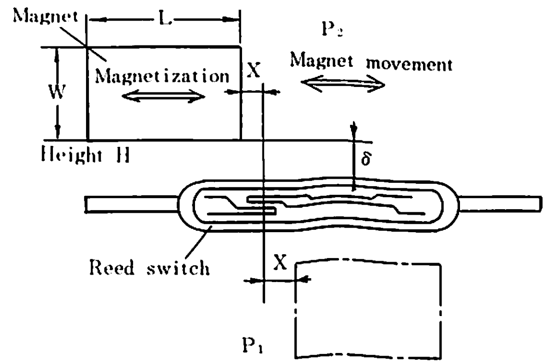


Fig. 6—Location of magnet against reed switch.

Here, an experimental study has been performed on the effect of the factors dimensions of magnet in three perpendicular direction, magnet material and relative arrangement in L_{16} orthogonal array. In this experiment, the FDR-7 type switch was combined with magnet as shown in Fig. 6, which produce a magnetic flux of more than 300 Maxwells, and the operation position of the reed switch has been measured in relation with the magnet motion parallel to X axis.

An analysis of variance was made on the results of this measurement. The ratio of variance of the significant factor against the total variance was found as shown in Table 3. The variance caused from

Table 3 Variance for factors of L_{16} (in %)

No.	Factor	$\overleftarrow{ON}$			$\overleftarrow{OFF}$			$\overrightarrow{ON}$			$\overrightarrow{OFF}$		
		0.25	0.5	1.0	0.25	0.5	1.0	0.25	0.5	1.0	0.25	0.5	1.0
1	W								10	14			
2	L				10	9	9	16	14	13			
4	H									15			
7	M×P	8	9	10								7	7
8	M												
16	P	74	69	54	71	71	69	53	53	40	74	76	71

the relative position between the switch and magnet occupies as much as 70% of the total variance. This is due to the shape of the reed switch, and by pressing-forming the reed terminal, the relative position is automatically fixed upon switch installation, this variance is neglected.

While on the other hand, the open/close positions was found as shown in Fig. 7 combining with various magnets. Hence, choosing (P_1) as its relative position and ($\overleftarrow{ON}$), ($\overleftarrow{OFF}$) as its open/close position, the distance between the open/close position and reed tube center becomes small, so that in getting a break switch with the reversely arranged reed switch the shorter length of the magnet is accompanied.

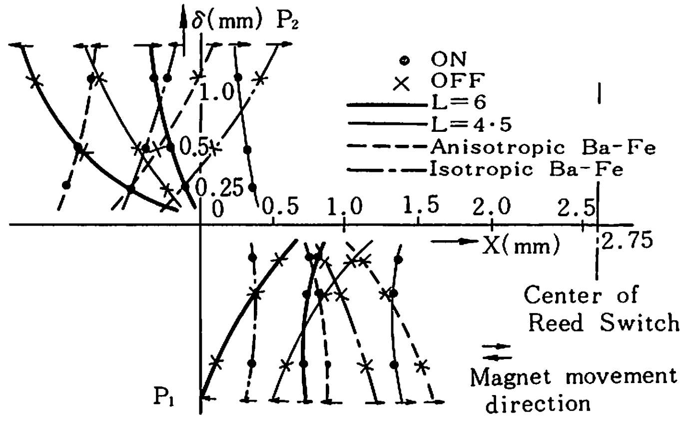


Fig. 7—"On" and "Off" position (mm).

Table 4 Variance for factors of L_8 (in %)

No.	Factor	$\overleftarrow{ON}$			$\overleftarrow{OFF}$			$\overrightarrow{ON}$			$\overrightarrow{OFF}$		
		0.25	0.5	1.0	0.25	0.5	1.0	0.25	0.5	1.0	0.25	0.5	0.1
1	W				26			30	33	37			
2	L				26				16				
3	M×H	35	33	28	27						49	47	47
4	H								22	28			
5	W×H								17				
6	M×W	15	15	16							16	17	18
7	M	49	50	48							29	31	34

When the data is arranged and summarized by the L_8 orthogonal array with the relative position fixed at (P_1), each variance ratio for the factors against the total variance is found as shown in Table 4. Looking at this analysis, the open/close position ($\overleftarrow{ON}$) and ($\overrightarrow{OFF}$) is determined only by the magnet material without being affected by the magnet shape, so that it may be said that the best arrangement between the reed switch and magnet is obtained in accordance with Fig. 8.

The open/close position of the switch is as shown in Table 5 and the distance between them is found as shown in Fig. 10. In order to

Table 5 "On" and "Off" positions (mm)

Gap (δ)			0.25		0.5		1.0	
Material			M_1	M_2	M_1	M_2	M_1	M_2
$\overleftarrow{ON}$	M×W	W_1	0.41	0.75	0.42	0.80	0.39	0.88
		W_2	0.75	0.41	0.80	0.42	0.88	0.37
	M×H	H_1	0.32	0.85	0.33	0.89	0.31	0.96
		H_2	0.85	0.32	0.89	0.33	0.96	0.31
$\overrightarrow{OFF}$	M×W	W_1	0.89	1.13	0.99	1.26	1.20	1.50
		W_2	1.13	0.89	1.26	0.99	1.50	1.20
	M×H	H_1	0.79	1.23	0.90	1.35	1.11	1.59
		H_2	1.23	0.79	1.35	0.90	1.59	1.11

control the switch at a small stroke, short open/close distance and an anisotropic magnet are magnetically desirable. However, the latter has some disadvantages such as an irreversible change at low temperatures, and shape restriction in forming and expensiveness. The authors have decided to use an isotropic barium ferrite magnet of a shape as shown in Fig. 9 located at one side of a shorter reed as shown in Fig. 8, thus controlling the switching on/off operation.

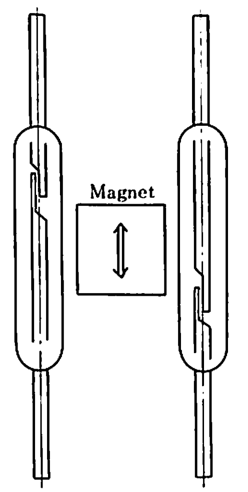


Fig. 8—Arrangement of magnet and switches.

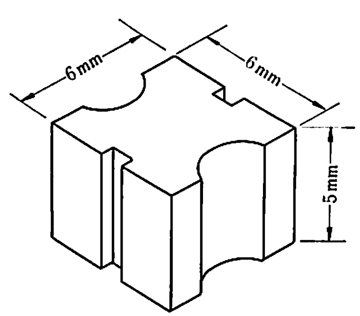


Fig. 9—Shape and dimension of magnet.

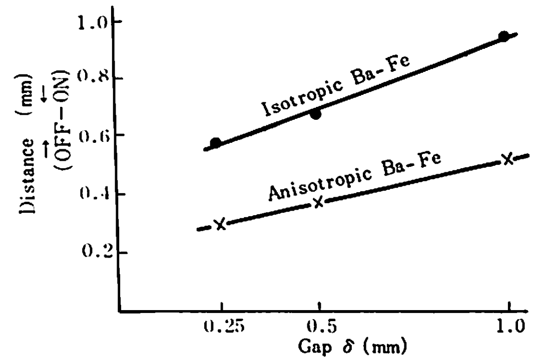


Fig. 10—Distance between "On" and "Off" positions.

3.3 Operating characteristics

The operating characteristics are important for determination of the pressing feeling, and are considered to include the following factors.

(1) Pressing force
(2) Button stroke
(3) Inclination of pressing force vs. displacement characteristic curve
(4) A small variation of pressing force (due to a small roughness of the parts surface)
(5) Difference between operate and release characteristics
(6) Rigidity of stopper upon completion of motion

This pushbutton switch operates simply by vertically moving the magnet, so that the values given under (1) through (3) may be freely selected as desired.

In accordance with the results of studies made on design of the pushbutton dial mechanism, it is understood that a desirable operation characteristics is composed of minimum pressing force, stroke of approximately 3 mm and pressing force-displacement characteristics of plus inclination. Therefore, with shock and vibration proof characteristics

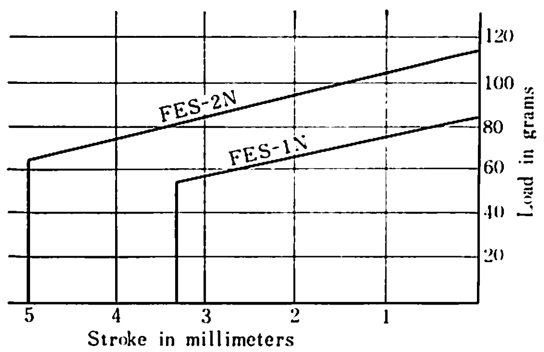


Fig. 11—Typical load characteristics of FES type pushbutton switch.

taken into consideration, the pressing force-displacement characteristics have been set up as shown in Fig. 11.

The looseness and irregular catch which occur upon sliding motion may irritate the operator and also cause unaccuracy of the contact operation, so that an ample care should be directed to material selection of the sliding parts and accuracy of dimensions.

4. Construction

An electronic equipment has its tendency to be smaller in size and complex in functions along with the employment of IC and an increase of processing data; therefore more pushbutton switches are concentrated in the front panel. Consequently, the pushbutton switch to meet such demands should be one with an illumination arrangement and color identification for decrease of mis-operation and for efficiency improvement.

This pushbutton switch is arranged to permit free selection of the following function by combination of various parts, so that it may be used in the optimum form to meet the requirement.

(1) Various contact arrangement from 1 make to 1 transfer.

(2) Momentary or alternating operations.
(3) Lamp indication up to 2 divisions.
(4) Mutually interlock switch or interlock switch.
(5) Installation freedom having a pitch of more than 16 mm.

4.1 Basic construction

Fig. 12 shows the construction of FES-1N type switch which is the basic momentary type for the FES type pushbutton switch, while Fig. 13 shows the outer view of the component.

When the button is pressed, the magnet is driven through the drive rod and the reed switch in the housing is closed. In release, the magnet moves upward by the spring force and the switch is then opened. Given are the explanations of the construction that this pushbutton switch features.

(1) Drive rod

The drive rod holds the magnet securely between its legs and the assistance of restoring spring force from downward eliminates the need

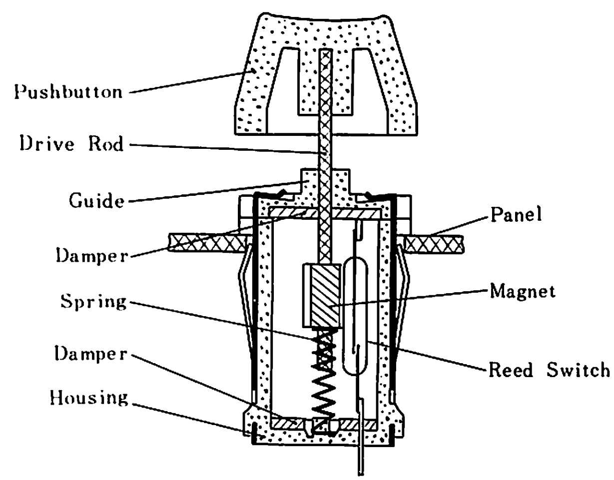


Fig. 12—Construction of FES-1 type pushbutton switch.

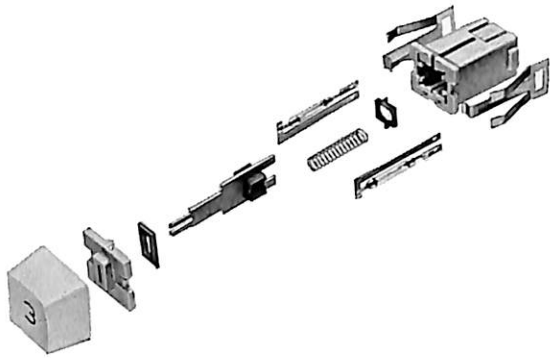


Fig. 13—Element parts composing FES-1N type pushbutton switch.

of a rivet or adhesives or the like, and thus the drive rod and magnet makes a vertical motion together.

Drive rod is made of brass plate, and provides an arm at the center portion as shown in Fig. 14, which is useful to get easily such as a mutual interlocking function.

(2) Housing and guide

The housing is provided with a guide groove for drive rod, further provided with a slit on both walls of it that accommodates up to two reed switches, an opening on one wall through which the drive rod arm protrude for use with the alternating operation, and a groove on the other wall into which a lamp terminal is inserted. It is also provided with catches on its outerside to retain the holder.

The housing and guide are required to permit smooth sliding operation of the drive rod in it. The operation and performance are directly affected by the friction coefficient, wear resistance, dimension change due to temperature and humidity and fitness upon initial manufacture. Hence, a preferable material is one with high antiwear characteristic at a low coefficient of friction and with a good dimension stability. Further, since the housing is required to provide a high mechanical strength and heat insulation against the terminal soldering heat, a glass fiber reinforced polyacetal resin is used.

(3) Holder

In order for the drive rod to operate smoothly in good fit, the relative location between the housing and guide should always be secure. Therefore, the center arm of the holder is inserted into the notched portion of the flanges of the housing and guide, thus determining their locations, and these are tightened by the bottom square hole and the top bend of the center arm.

The switch is installed to the panel by the spring force of the both side holder arms; this requires the switch to be only pressed into the 14 mm square hole.

4.2 Lock mechanism

In order to get the locking of the alternate type pushbutton switch, the following mechanisms exist.

(1) The cam groove is traced by either the pin or ball.

(2) Ratchet gear.

(3) Electromagnet

The electromagnet requires an external power source and the ratchet system is disadvantageous in points of life and complexity of construction. Therefore, the cam groove system has been employed. There are the following shapes available for the cam.

(1) Heart type

(2) Saw type, etc.

The following methods are available for working them.

(1) Power press work

(2) Diecasting

(3) Resin moulding

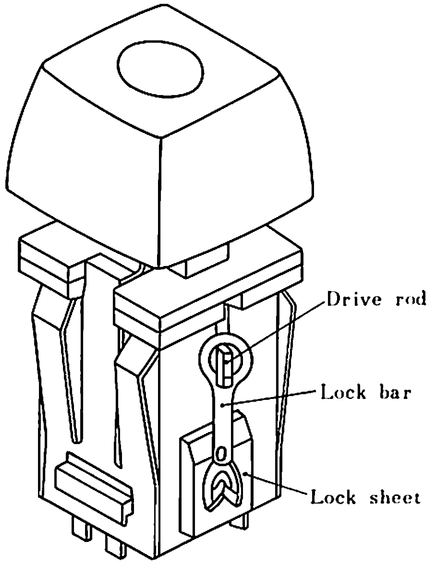


Fig. 14—Alternate switch (FES-1L).

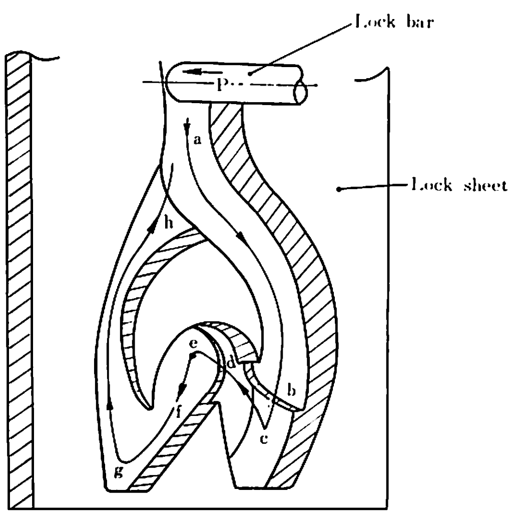


Fig. 15—Lock sheet.

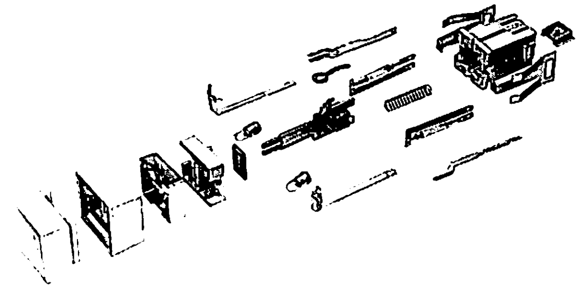


Fig. 16—Element parts composing FES-2L type switch.

Employed has been the lock mechanism in which a sheet spring, whose top end is shaped like a pin, traces under a certain constant pressure on the 3-dimensionally shaped heart type groove, since the space and stroke may be minimized and a stable operating characteristics are proved as shown in Fig. 18. The lock sheet having a heart-shaped groove may cause change because of wear and water absorption during operation, possibly resulting in difficulties in locking or in restoring. Therefore, considering those features of wear, water absorption, friction coefficient and aging change, a glass fiber filled polyamid resin or tefron fiber filled polyacetal resin is selected and tested under the continuous operation and high temperature/humidity. This prooved that the latter material has been found to be the optimum one at present. A million time operation has been performed and guarantee is obtained.

4.3 Construction of display unit

For the display method of the illuminated pushbutton switch, the followings are available.

(1) Transmitted color system

(2) Projected system

The method (1) is provided with a pigment screen and is based on a method in which the lamp illumination is observed by the light intensity of the pigment screen. This method is disadvantageous in difficulty of recognition between on and off as the lamp intensity is lowered or when the room is brighter. The method (2) is provided with a white translucent screen, with a colored filter installed between it and the lamp, so that when the lamp is not lit, the screen is white translucent and when the lamp is lit the filter color is seen. For the filter, generally a silicon rubber, colored transparent cap is used because of heat insulation. However, because of large light absorption and the lowering of the illuminating, both the color base as a pigment screen or color filter, and non-colored transparent or white translucent name plate are used and either one may be utilized as necessary depending upon the purpose. Namely, when a noncolored transparent name plate is used, a transmitted color system is obtained, and when a white translucent name plate is used, a projected system is realized.

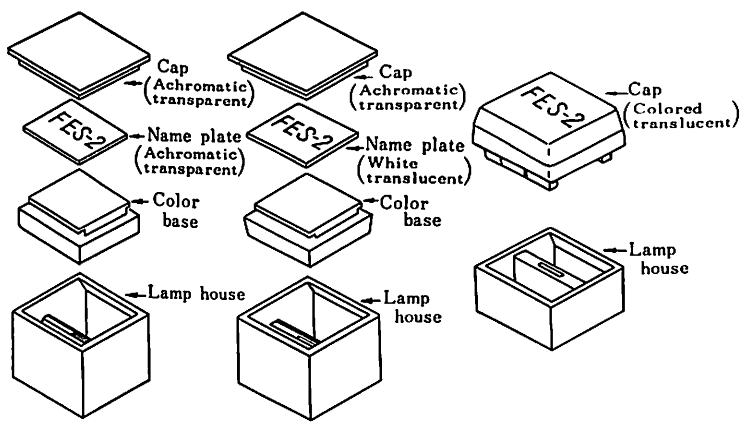


Fig. 17—Lighted display methods.

In addition, the third type is available. In this type, the illumination condition of the lamp may be fully observed from the side and the switch is incorporated with the elegancy in design, permitting various display in one family system.

5. Characteristics

5.1 Operating characteristics

The operating characteristics are important in determining the pressing feeling as previously mentioned. Fig. 18 shows typical force-displacement characteristics for this switch. Since the momentary switch has less friction and further it is provided with rubber dampers at both ends of stroke, rigidity and noise of the stoppers upon completion of the stroke are eliminated; a comfortable feather-like touch is expected when pressing the pushbutton.

The alternate switch causes variation of the friction force due to groove height difference as the pin traces the heart-shaped groove, thus showing a wavy load curve. The knee points of a through h corres-

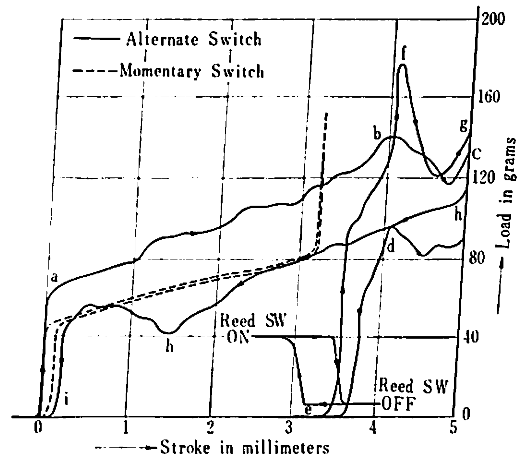


Fig. 18—Load characteristics.

pond to those of a through h given in the lock sheet groove of Fig. 15. When the pushbutton is pressed, a lock bar shifts from point a to point b and will drop in one level at point b: when pressing force is released, the lock bar jumps over point d and is locked at point e. When the pushbutton is pressed again, the lock bar slides the diagonal surface and arrives at g; when the pressing force is released again, the lock bar may drop in one level at point h, returning to its original point a and being ready for the subsequent operation.

5.2 Electrical characteristics

The electrical characteristics dominate the switching characteristics and are determined mostly by those characteristics of the FDR-7 type switch as shown in Table 1. In order to guarantee the sequential operation between two switches, it is very important to minimize the position change of each switch and open/close position distance. Therefore, the contact arrangement requiring sequential operation is realized by choosing reed switches which have a low operate ampere turn of 25 to 35 AT, so that the switch operation has been able to be guaranteed at a stroke of 3.3 mm, the same as other contact arrangement.

5.3 Display characteristics

5.3.1 Identification of display

It will be difficult to identify the lamp display when light intensity is lowered due to deterioration of the lamp or voltage drop of the power source, or when the button is put under the bright sunlight.

Fig. 19 shows the result of studies of the display identification for each cap.

The colors of white, red and yellow have showen good results but the green one is hardly recognizable at the roombrightness of more than 2,000 lux and should therefore not be used under bright sunlight as nearby the window.

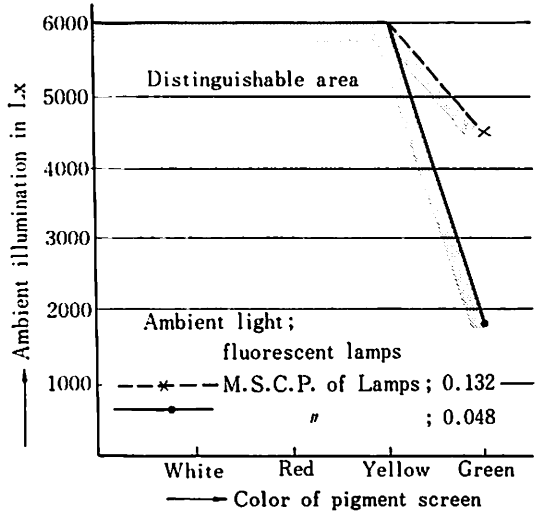


Fig. 19—Illumination characteristics.

5.3.2 Thermal resistivity of cap

Because the major component parts are made from injection moulding, deformation or deterioration of the resin due to the radiant heat produced upon continuous lighting of the lamp were studied and the results are that there is no abnormality caused at the ambient temperatures of up to 55°C even in the state of locking.

5.4 Durability

The durability has become an important characteristic along with an increase in operation frequency of the switch and spreading of the operation circumstances.

5.4.1 Thermal test

In this switch, the permanent magnet is used to drive the contact, and the flux quantity of the magnet changes along with the ambient temperature, thus causing some changes in the operation position of the switch.

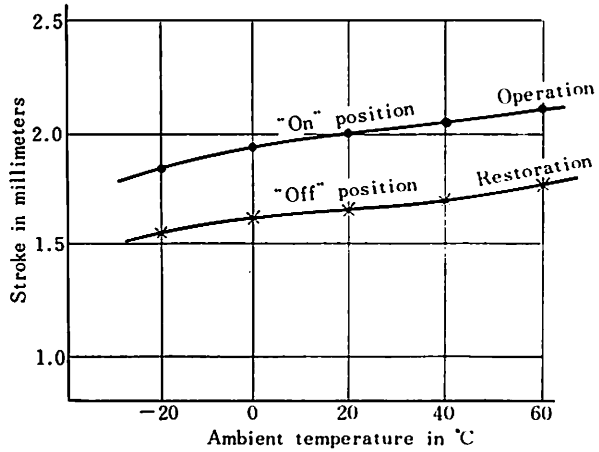


Fig. 20—Change of "On" and "Off" corresponding to ambient temperature.

Since the permanent magnet of this pushbutton switch shows the negative temperature coefficient and the total magnet flux is lowered in accordance with the ambient temperature rise. Fig. 20 shows the result of measurement on the relationship between the ambient temperature and on/off position. From this result, it is understood that the relationship between the ambient temperature and on/off position of the switch is nearly linear between the temperature range from −20°C to +60°C, and the following are obtained.

(1) The rate of the "on" position change is approx. 3.5×10^{-3} mm/°C
(2) The rate of the "off" position change is approx. 3.0×10^{-3} mm/°C

5.4.2 Damp-heat cycle test

The damp-heat cycle test was conducted in conformity with the JIS-C-5024 test method for accelerated evaluation of deterioration of the switch placed under the tropical condition of high temperature and humidity, in which the change in the characteristics was studied measuring them before and after the test.

The force-displacement characteristics and the switch on/off position of the switch have shown almost no change; the minimum value

of the insulation resistance was 500 MΩ at 500 V, so that the deterioration extent is negligible in actual application.

5.4.3 Vibration test

A vibration test was conducted based on test method 201 A of the MIL-STD 202 C in order to determine the resistivity against vibration. The switch under test was vibrated at an amplitude of 0.03 inch (max. 0.06 inch) and at a reciprocal cycle rate of 10 Hz to 55 Hz in 1 minute, in the three directions perpendicular to each other for duration of two hours each. There has been noted no change in the force-displacement characteristics before and after the test. No other abnormality has been seen in other portions.

5.4.4 Shock test

When a considerable shock is applied to the switch, the drive rod is considered to move against the restoring force of the spring, thus permitting the contact to move or the lock to release. Therefore, a

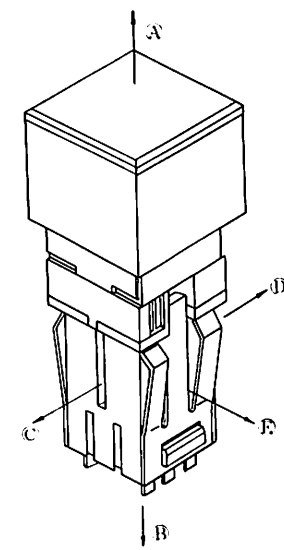


Fig. 21—Direction of shock test.

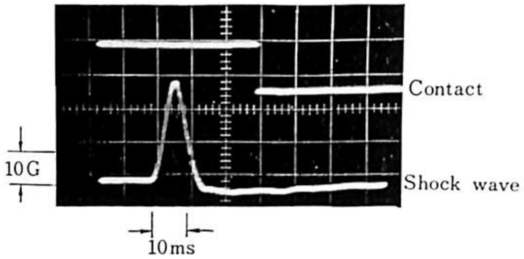


Fig. 22—Shock wave (alternate switch is unlocked by the shocks of the 30-gravity unit (G), 11-millisecond duration, and contact is opened).

five-direction shock is applied to the switch under two conditions, one restored and another locked, as shown in Fig. 21, and the contact open/close condition was studied and observed by a synchroscope as shown in Fig. 22.

As a result, it is understood that no change has been occurred in all of these five directions against the shock up to 20 G. For the shock of 30 G, a change has been noted only in the longitudinal direction of the switch, some resulting in switch operation of the released switch and other resulting in release of the locked switch. After test, no abnormality has been noted in the operation characteristics and the constant resistance.

As easily seen from the above-mentioned results, the test condition A (15 G/11 msec) of the MIL-STD 202 C are fully met.

5.4.5 Running test

Even when the momentary type switches were driven by the plunger magnet for 10 million operations and the contacts were loaded with a 12 V, 5 mA resistive load, the change in the force-displacement characteristics and the contact resistance has been small as shown in Figs. 23 and 24; wear at all parts has been very small. The 10 million operations may be guaranteed.

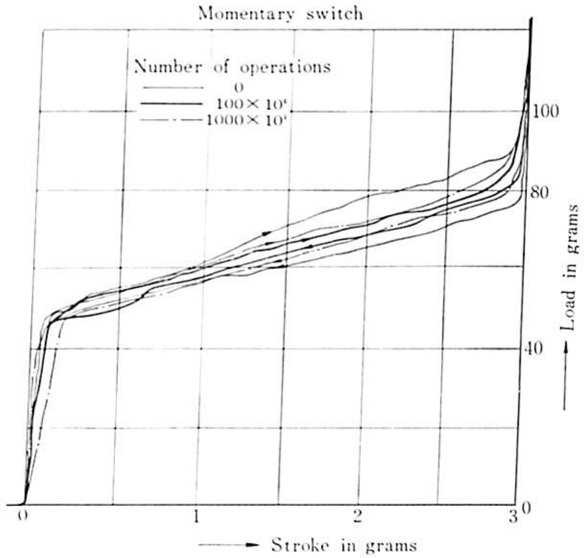


Fig. 23—Change of load curve produced by running test.

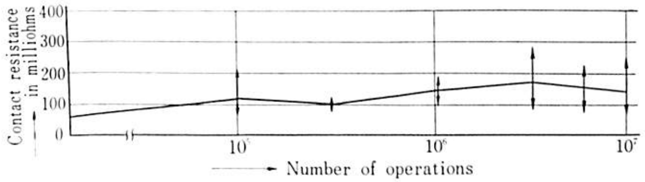


Fig. 24—Change of contact resistance.

A running test of a million operations was conducted by the plunger magnet on the alternate type switch. As shown in Fig. 25, as the number of operations increases, the hysteresis of the load goes beneath in the force-displacement characteristics. This is caused mainly from the decrease of the lock bar pressure due to wear of the lock bar and

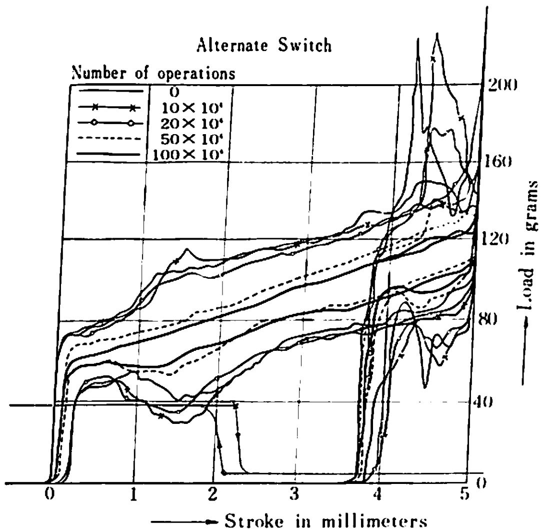


Fig. 25—Change of load curve by running test.

lock sheet. However, the locking performance has been confirmed in each operation during a million operations. There has been no trouble after the completion of the test.

6. Specifications

Table 6 shows the specifications and features of general purpose type pushbutton switch.

7. Conclusion

A general purpose pushbutton switch which fits to the use of signal input device for various types of electronic equipment has been studied and satisfactory results were obtained. This pushbutton switch is developed with careful considerations reflected upon the visual sense and touch feeling, and shows a superior features on so-called hard aspect such as high reliability, small size, long life and availability in many variations. The switch is expected to find out a wider applications field because of its superior features and characteristics not only in individual form but also in combined one.

Table 6

Item \ Type of switch	FES-1N	FES-1L	FES-2N	FES-2L	FES-3N	FES-3L
Lighted display	None		Can be divided to accommodate 1 thru 2 barrier segments		None	
Action	momentary	alternate	momentary	alternate	momentary	alternate
Mounting	Front panel mounting				Rear panel mounting	
Size (mm)	15.6×15.6 ×44.2	15.6×17.1 ×44.2	18.6×18.6×53.8		15.6×15.6 ×44.2	15.6×17.1 ×44.2
Weight (g)	9.5	10	15.5	16	9	9.5
Initial load (g)	55	65	65	65	55	65
Stroke (mm)	3.3	5	5	5	3.3	5
Contact arrangement	2 reed switches available (in forms M or B and combination)					
Contact rating	4 VA					
Contact resistance (initial)	200 mΩ max.					
Insulating resistance	10^9 Ω min.					
Breakdown voltage	DC 400 V					
Contact chatter	600 μ sec max.					
Ambient temperature	−20°C~55°C					
Vibration	Withstand MIL-STD 202 C test method 201 A					
Shock	Withstand 15 G (11 ms) (MIL-STD 202 C test cond A)					
Life	10^7 Operation	10^6	10^7	10^6	10^7	10^6

8. Acknowledgement

The authors wish to express their deep appreciation to Dr. S. Kojima, Director of FUJITSU LABORATORIES LTD. for his kind guidance and also to the staff members of the Industrial Design Section of the FUJITSU LABORATORIES LTD. for their earnest cooperation in the key top design of the switch.

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Phase Forming Process in Tantalum Films through Sputtering

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(Manuscript received September 25, 1969)

The tantalum film is used in various phases for the application to each element in the hybrid integrated circuit. There are α and β phase in pure tantalum films used in the capacitor and Ta_2N and TaN in tantalum nitride used as the resistor. The capacitor through anodization of β-Ta is less ionic and superior in stability to that of α-Ta. However, the origin of phase transition was not clarified yet. On the reactive sputtering of tantalum in the mixture of argon and nitrogen "plateau region" appears, which is promising to obtain good reproducibility during manufacture, and to keep good stability of the film resistor. But still they have a little information about the generation of the plateau region. Here they tried to explain such phenomena through the experiments by plasma sputtering.

As a result, it was found that α-Ta was deposited in a contaminative atmosphere under presence of partial pressure of impurity gas of approximately 1×10^{-5} Torr, while β-Ta was deposited in a clean atmosphere under presence of partial pressure of impurity gas less than 1×10^{-6} Torr. The phenomena may be best understood if considered on the basis of quenching by their studies. It was also noted that the phase transition could be caused where the discharge gas pressure was high. Such phenomena may be presumable that the impurity gas or the quenching of the sputtered particles is attributable.

In the case of the tantalum nitride, the plateau is caused when $P_{N2}/P_{Ar}=0.06$ to 0.10 (where P_{N2} or P_{Ar} is each partial pressure of nitrogen or argon) at the partial pressure of nitrogen is 1.5 to 8×10^{-4} Torr. The