Reliability and Applications of Magnet Driven Reed Switch*

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Reed switches are used in many of the keyboards presently on the market. However, their contact reliability can be a problem especially when they are used in "on-line" systems. Though there are many papers discussing the reed switch reliability under coil driving, data on the reliability of magnet driven reed switches can scarcely be found.

Following differences exist in magnet driving method compared to coil driving.

(1) The magnetic field is non-uniform.

(2) The velocity of magnetic field change is small, and moreover, it has a wide variance.

(3) A large mechanical shock follows immediately after contact closure, when used in push-button switches.

Influences of these three factors on the contact reliability has been studied.

As the result, the best driving condition of reed switch restricting in the push-button use has been found. The application of this result has led to the development of a new highly reliable push-button switch. This push-button switch, composed of an annular magnet, a keeper plate and three coil springs, provides snap action. This snap action mechanism contributed largely to the improvement of contact reliability and also gives a sensory feedback to the operator.

Spring design through computer simulation of magnetic motion is also presented in this paper.

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1. Introduction

Reed switches are now in use in many of the keyboards on the market. However, their contact reliability is a problem especially when they are used in computer peripheral equipment.

In these cases, reed switches are actuated by a permanent magnet. This differs from coil driven switches as follows.

(1) The magnetic field is non-uniform.
(2) The rate of magnetic field change is low. Moreover it has a wide variance.
(3) Large mechanical shock follows contact closure.

Influence of these three factors on contact reliability has been studied from the point of view of operational characteristics and economy.

As a result satisfactory operating methods have been developed. This led to the development of a new snap action push-button switch. In it the magnet moves at a certain speed, independent of the key-top speed. This contributed considerably to the improvement of contact reliability and also enabled sensory feedback to the operator.

Numerical analysis of magnet motion has been made from the point of view of mechanical characteristics of push-button switch and operator's finger. It agreed fairly well with experimental results. Sufficient effective data has now been compiled.

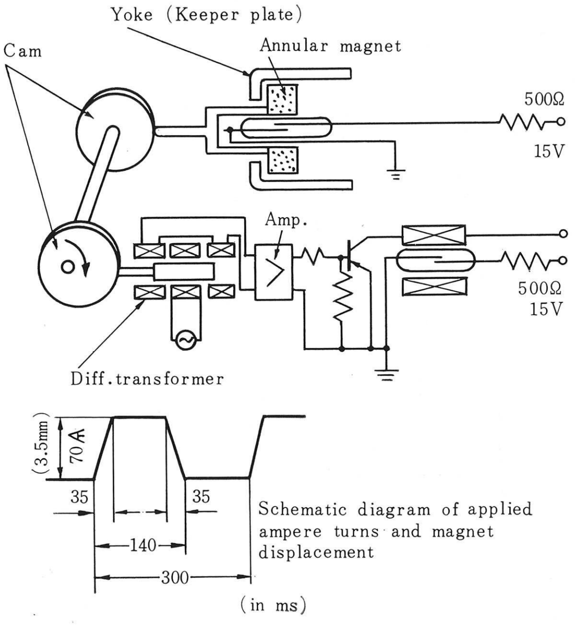
2. Contact reliability

Though many papers have been published on reliability of coil-driven reed switches, few can be found on magnet driven switches. Since the magnetic field in magnet driven switch is non-uniform and changes slowly as compared to the one in coil driven switches, the operating conditions of reed switches are different and hence the contact reliability also differs. In order to clarify these differences, the following experiments were conducted.

2.1 Difference due to magnetic field distribution

Normally, coils generate a relatively uniform magnetic field but the field from the magnet is not uniform. Effects of non-uniform magnetic field on the contact reliability was examined using the test apparatus shown in Fig. 1. In this apparatus, an annular magnet moves at a given uniform speed along axis of reed switch. The core of differential transformer was attached to the apparatus and was made to move at the same speed. Voltage change from the differential transformer was amplified and applied to the driving coil.

Analogy will be obtained through such test method between magnet and coil drive with respect to the rate of field change. Reed switches having rhodium contacts were tested. The contacts were loaded with a 15 V, 30 mA resistive load and were checked at each operation for resistance and open failure. Contact resistance greater than 2 ohms



Schematic diagram of applied ampere turns and magnet displacement

Fig. 1—Test apparatus (1).

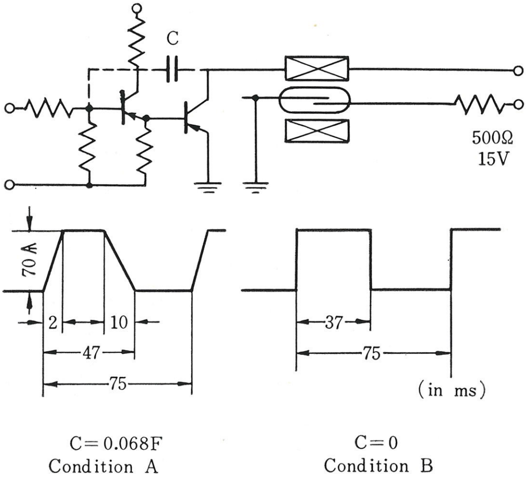


Fig. 2—Test apparatus (2).

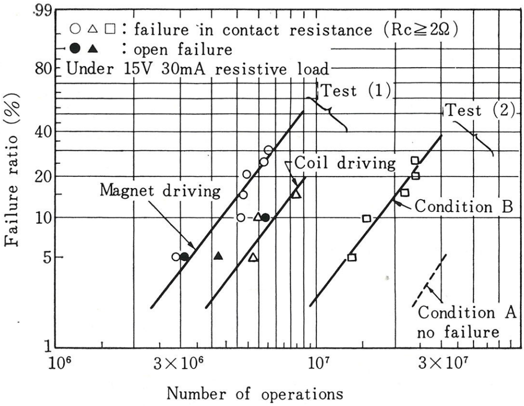


Fig. 3—Contact failure behaviour.

was considered to be a contact miss, and ten misses in the same reed switch were considered to be contact failure. The result of the test is shown in Fig. 3. Coil driving was found to be better than the magnet driving from the point of view of contact reliability. (See Fig. 3)

Magnetic particles produced through wear and tear of the contact portion accumulate at the contact gap as magnetic flux concentrates in that region. This is likely to give rise to problems with the contact. Non-uniform magnetic field and magnet motion along reed axis is considered the primary cause of this phenomenon.

2.2 Difference due to magnetic field changing rate

In order to study the difference due to magnetic field changing rate, coil driving experiment was performed as shown in Fig. 2. Results are shown in Fig. 3. The reed switch actuated in condition A was more reliable than that in condition B. The rise time in condition A was 2 ms, and the fall time, 10 ms. This will give rise to different motion in accordance with the difference of the magnetic changing rate on the operating and release time. The higher the changing rate in operation, the longer the contact bounce will continue because of higher collision speed. This will reduce the life span of the contact. Similarly the lower changing rate in release, the slower will be the decrease in the contact force. Therefore the partial heating of the contact will result in greater contact abrasion.

From the above mentioned experimental result, it is desirable that the magnet speed should be a suitable, independent of key depressing speed in order to get the high contact reliability. Based on these considerations a push-button switch having new functions has been developed.

3. Push-button switch design

3.1 Operational characteristics

In order to assure high system reliability in addition to improving the reliability of configurating parts, the reliability of their connections must also be taken into consideration. As the key board switches are operated manually, sufficient man-machine communication is a must, so that the operator can make sure that the switch has operated properly. In order to satisfy these requirements a new snap action switch has been developed. Its basic construction, external view of components and key touch characteristics are shown in Figs. 4, 5 and 6. It consists of a key top, annular magnet, iron keeper plate to which the magnet is attracted in release position, upper, middle and lower springs, reed switch and phenolic resin molded housing. When the key is depressed, coil spring (U) having light initial force and low stiffness is compressed first. Thus light and soft key touch is assured.

When the key is pressed further additional force of the spring (M) is felt. Therefore the operator should exert additional force as required.

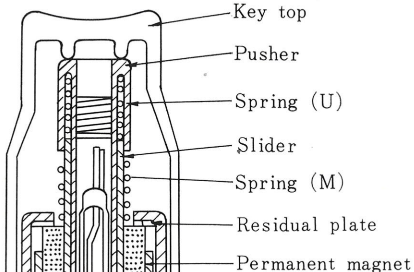


Fig. 4—Construction of the new push-button switch.

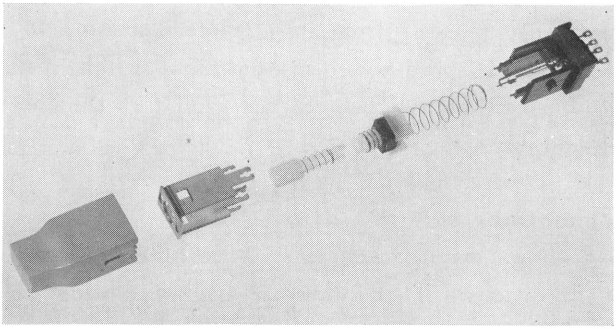


Fig. 5—Exploded view of the new push-button switch.

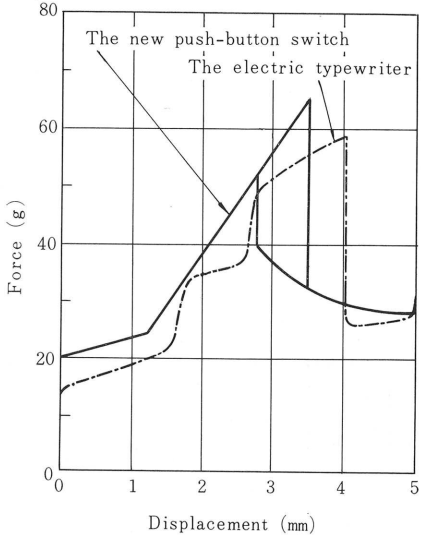


Fig. 6—Touch characteristics.

When the depressing force overcomes the sum of attractive forces of the magnet-to-keeper plate and upward force of the coil spring (L), the magnet is suddenly released from its attracted position to the bottom and moves at a high speed to close the reed switch instantaneously. Operator can feel that the switch has closed as the key pressure is reduced considerably.

3.2 Magnet motion

Figure 7 shows magnetic characteristics of reed switches and pull-in, drop-out positions. The following magnet motion characteristics are required to ensure high contact reliability.

(1) The magnet must move with optimum speed at pull-in and drop-out positions regardless of depressing speed.

(2) The magnet must be stable within 3～5 mm range in order to keep the reed switch magnetically saturated while the key is being depressed. Further, bouncing of magnet must not cause contact chattering and change of dynamic contact resistance. Here motions of the key and the magnet including the operators finger are considered to form a system. It is shown in Fig. 8.

A differential equation was set up and analyzed with a computer. Key and magnet motions are roughly divided into three stages and differential equations are given by

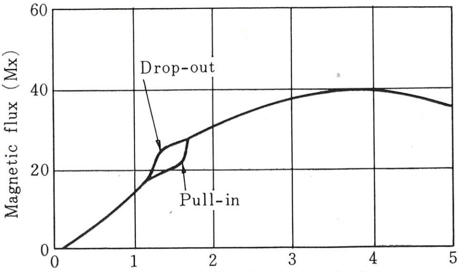


Fig. 7—Magnetic characteristics and pull-in, drop-out positions.

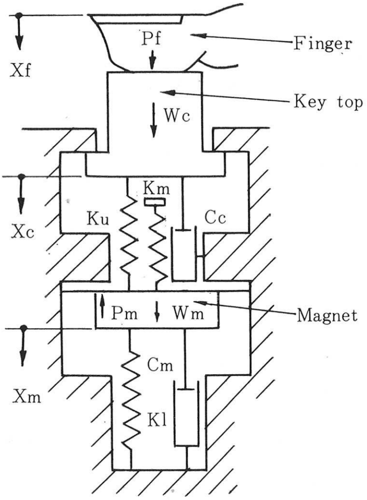


Fig. 8—Dynamic model for magnet motion.

(1) After the key starts to move until the magnet starts to move:

$$M_c\frac{d^2X_c}{dt^2}+C_c\frac{dX_c}{dt}+(K_u+K_m)X_c=P_f(X_c,\ t)+(W_c-P_{oc})$$

(2) After the magnet starts to move until it collides with a stopper:

$$M_c\frac{d^2X_c}{dt^2}+C_c\frac{dX_c}{dt}+(K_u+K_m)(X_c-X_m)=P_f(X_c,\ t)+(W_c-P_{oc})$$

$$M_m\frac{d^2X_m}{dt^2}+C_m\frac{dX_m}{dt}+(K_u+K_m+K_l)X_m-(K_u+K_m)X_c$$

$$=-P_m(X_m)+(W_m-P_{om})$$

(3) After the magnet rebounds:

$$M_m\frac{d^2X_m}{dt^2}+C_m\frac{dX_m}{dt}+(K_u+K_m+K_l)X_m=-P_m(X_m)+(W_m-P_{om})$$

$$+(K_u+K_m)\,X_{co}$$

where

M_c: mass of key top

M_m: mass of magnet

W_c : key top load
W_m : magnet load
X_f : displacement of finger
X_c : displacement of key top
X_{co} : key top stroke
X_m : displacement of magnet
P_{oc} : initial external force for key top
P_{om} : initial external force for magnet
K_u : stiffness of spring (U)
K_m : stiffness of spring (M)
K_l : stiffness of spring (L)

$P_f\,(X_c,\,t)$ is the depressing force of operators finger.

The experimental data shown in Fig. 9 was used. Depressing force was measured with a pressure sensitive semi-conductor and the displacement with an optical displacement follower. $P_m\,(X_m)$ is the at-

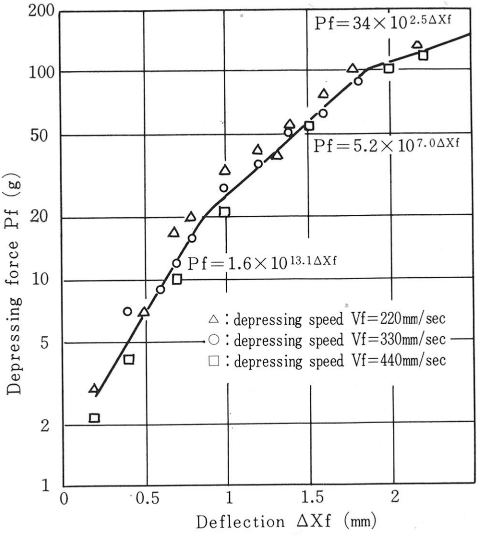


Fig. 9—Dynamic characteristic of a human finger.

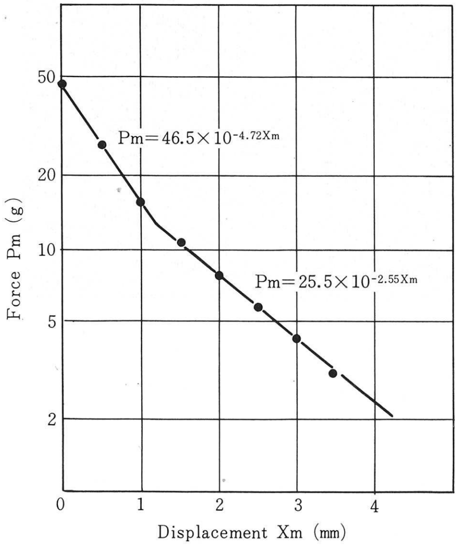


Fig. 10—Attractive force of magnet.

tractive force between the magnet and the keeper plate. The static characteristics shown in Fig. 10 were used.

Fundamental experiment in which the magnet was fixed to the keeper plate and motions of the key and the finger was performed in order to determine the coefficient of frictions (C_c). It was found to be $C_c = 1.3$. Simulation was continued till the calculated value agreed with the experimental value.

The coefficient of repulsion $e = 0.4$ and the coefficient of friction $C_m = 0.6$ were obtained in the same way as C_c. Runge-Kutta-Gill Method was adopted for numerical calculations and the time interval was set at 10^{-4} seconds.

Figures 11 and 12 show experimental and theoretical results respectively. They correspond fairly well. Therefore it is evident that this model is a good representation of the dynamics of the system,

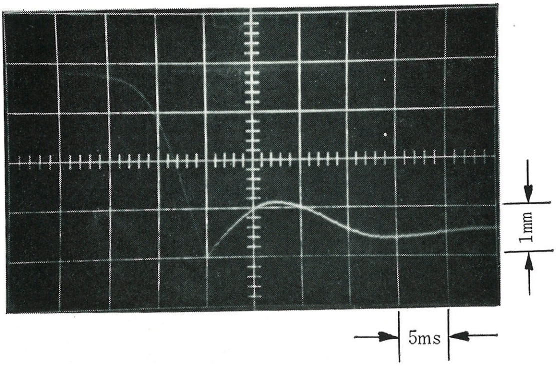


Fig. 11—Magnet rebound.

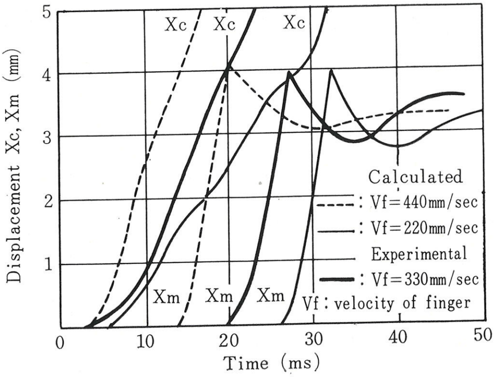


Fig. 12—Motions of key (X_c) and magnet (X_m).

and that the magnet actuates the reed switch at a speed of about 800 mm/sec regardless of the depressing speed.

When the location of the magnet is changed from 3 mm to 5 mm, theoretically the magnet rebounds as shown in Fig. 13. In this simulation, in order to keep the reed switch magnetically satulated while the magnet is bouncing, optimum location for the magnet stopper was found to be 4 mm.

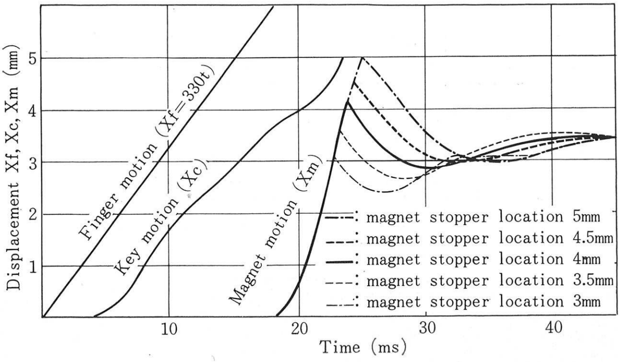


Fig. 13—Theoretical rebound of magnet.

3.3 Reed switch holding

Method for holding the reed switch was decided upon after taking the followings into consideration.

(1) The holding clamp must not strain the switch capsule.

(2) Characteristics of reed switches must remain unchanged throughout the operation.

(3) The construction must suitable for mass production.

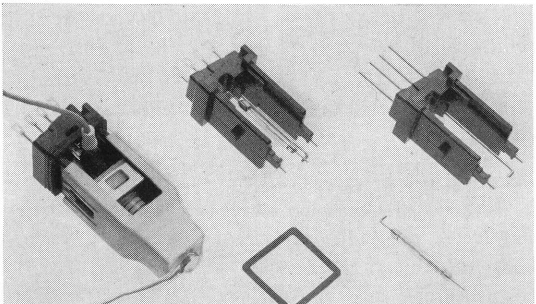
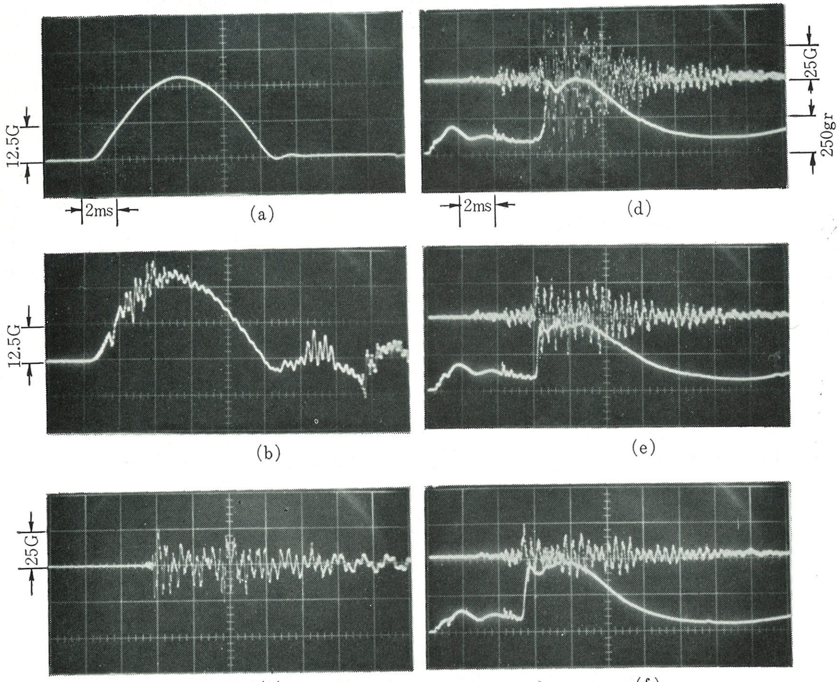


Fig. 14—Reed switch holding method.

Here, a new construction was developed as shown in Fig. 14. Reed switches were welded by an automatic welder on terminals of insert-molded phenolic resin housing which can be molded continuously. After the welding, a check was made to make sure that they were not under strain and their characteristics remained unchanged. Moreover, the shock waves were observed which glass tubes of reed switches received when an operator struck strongly push-button switches assembled a few



(a) (d) (b) (e) (c) (f)

(a) MIL specified shock wave.
(b) Shock wave which glass tube of reed switch received.
(c) Shock wave in perpendicular to reed axis.
Thickness of damper. $t=1.6$ mm
(d) Striking force and shock wave along reed switch axis. $t=0$
(e) Striking force and shock wave along reed switch axis. $t=0.8$ mm
(f) Striking force and shock wave along reed switch axis. $t=1.6$ mm

Fig. 15—Striking force and shock wave.

sort of dampers. The results of the test are shown in Figs. 15 (c), (d), (e) and (f).

On the other hand, the shock wave for reed switches is limited to below 30 G, 11 ms (sine wave) in MIL specifications. When the MIL specified shock wave (a) in Fig. 15 was applied to the push-button without a damper, the glass tube of the reed switch received the shock wave (b). The wave (b) was superimposed on the high frequency wave inherent to the holder on the wave (a) and its peak value did not change appreciably.

Neoprene damper thickness of 1.6 mm was found to be ideal to limit its value to under 25 G both vertically and horizontally. This also contributed to improving the touch characteristics.

Moreover we examined the changes in pull-in and drop-out positions in case the key was subjected to a heavy blow by a spring balances. The result of the test is shown in Fig. 16. The positions remained unchanged even if the key was subjected to the force approx. 5 times of that observed when it was pressed by finger (40～500 grams observed in Fig. 15).

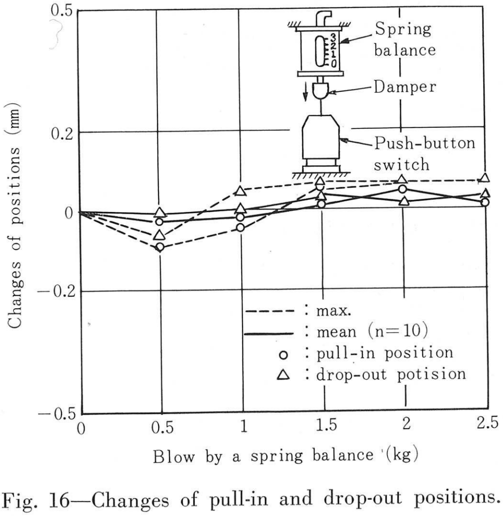


Fig. 16—Changes of pull-in and drop-out positions.

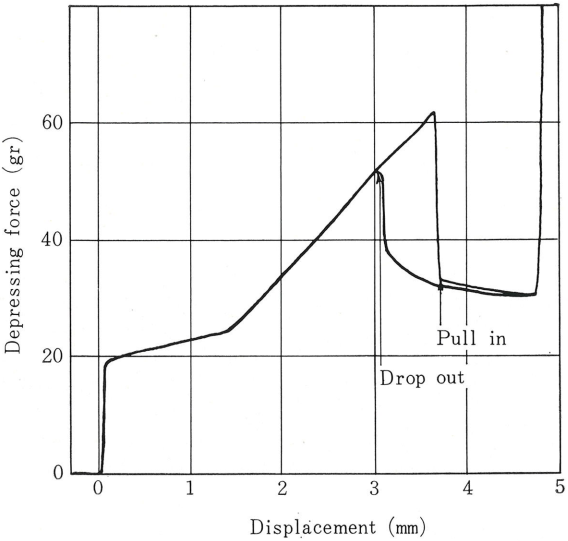


Fig. 17—Static touch characteristic and pull-in, drop-out positions.

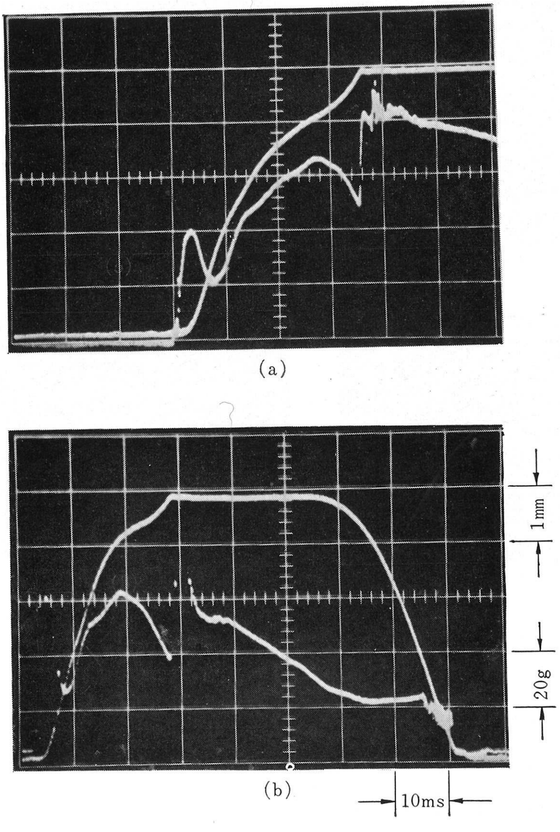
4. Characteristics

4.1 Static touch characteristic

A typical static touch characteristic is shown in Fig. 17. It shows the hysteresis peculiar to a snap switch, and the reed switch is pulled in at the snap action point and dropped out at the reset point. The sliding friction between molded parts is very low.

4.2 Dynamic touch characteristic

Figure 18 shows a typical dynamic touch characteristic in the most common operation (key striking). At the beginning of depressing, the finger was compressed and the depressing force suddenly increased to 40 grams. When the cap started to move, the force decreased. The depressing force gradually increased when the middle spring superimposed, but it suddenly decreased when the magnet started to move. Thus the operator can confirm the switch operation.



(a)

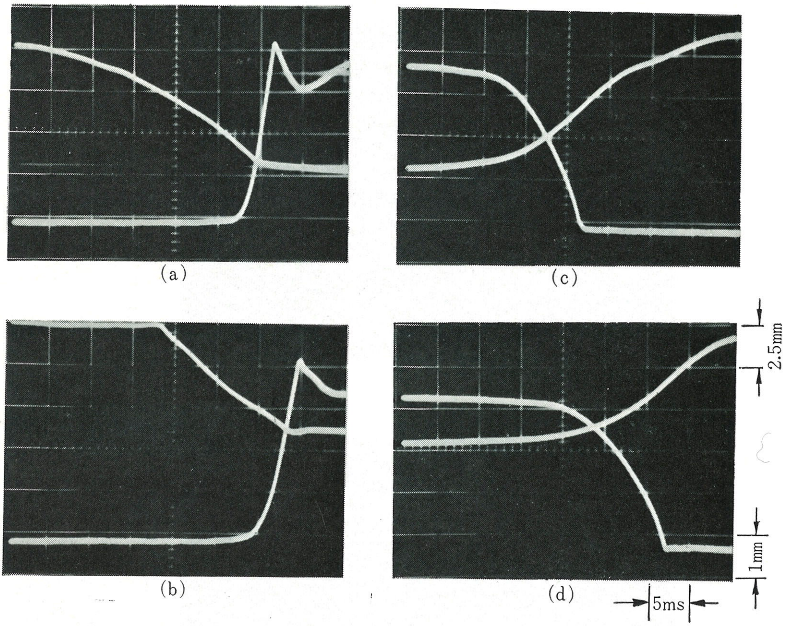
(b)

Upper: motion of the key top
Lower: depressing force measured at the key top
Fig. 18—Dynamic touch characteristic.

4.3 Magnet motion

Motions of the finger and the magnet are shown in Fig. 19. The magnet actuates the switch at an almost constant speed independent of depressing speed.

Magnet speed at reed switch pull-in position ;	850 mm/sec
Magnet speed at reed switch drop-out position ;	400 mm/sec



Upper curve: motion of magnet
Lower curve: motion of finger
Fig. 19—Motions of fingers and magnets

These values are close to

Speed during operation; 1,750 mm/sec
Speed when released; 350 mm/sec

which were obtained by converting rise and fall time, that showed good results in Fig. 2.

4.4 Shock test

Contact resistance and other characteristics of the reed switch did not change even if the operator struck the key hard. And the test method 201 A in MIL STANDARD 202 D was satisfied.

4.5 Running test

Effect of mechanical life on key touch characteristics and contact life in reliability were investigated by means of life tests.

Figure 20 shows the change of touch characteristic. Figure 21 shows changes of key stroke, snap and reset positions, Fig. 22 shows changes of depressing forces and return forces.

Figure 23 shows the change of the contact resistance. No abnormalities were found in the tests carried out 5 million operations.

Figure 24 shows the result of the contact reliability test. The characteristic life was approximately an intermediate value between the characteristic life in case of being driven slowly by magnet and that in case of coil driving (See Fig. 3), which is considered to show that the contact reliability has been increased by means of introducing the snap mechanism.

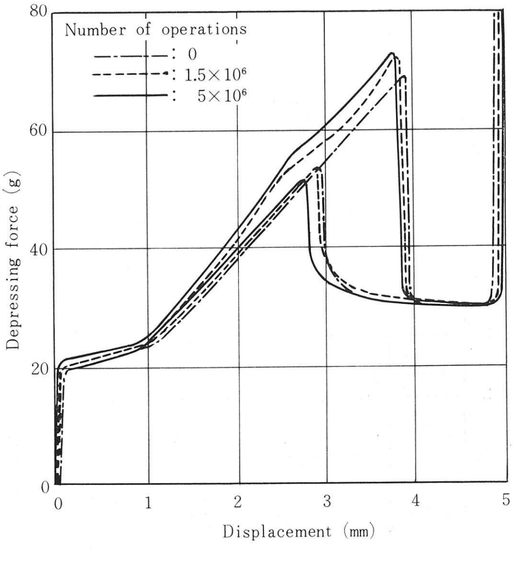


Fig. 20—Change of touch characteristic resulting from running test.

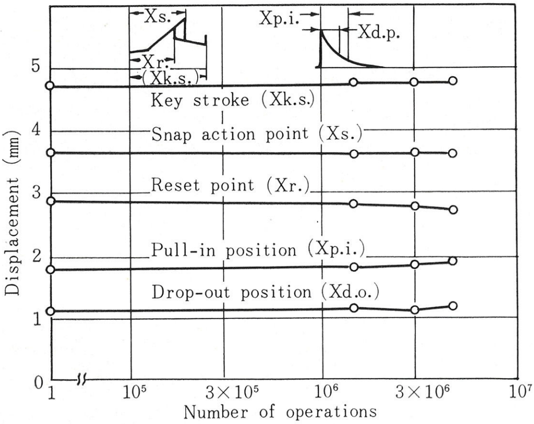


Fig. 21—Change of key stroke, snap and reset points, pull-in and drop-out positions.

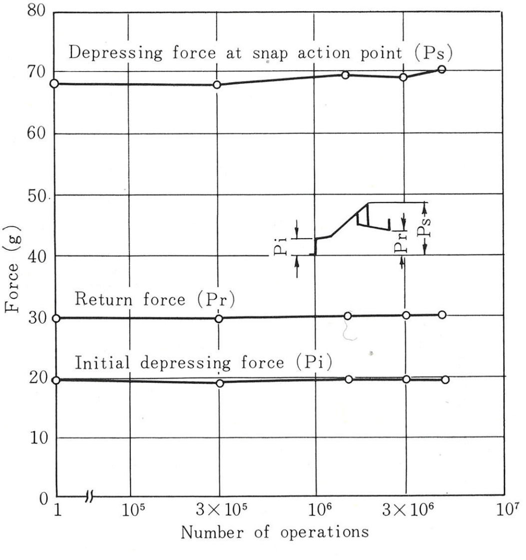


Fig. 22—Changes of depressing forces and return force.

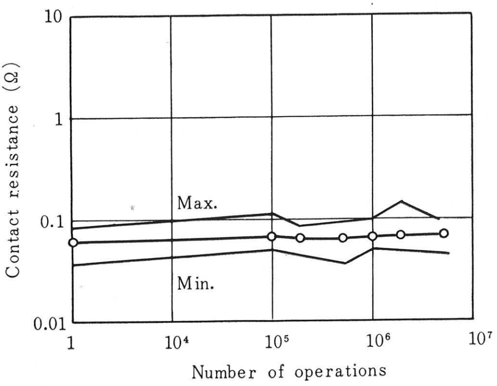


Fig. 23—Changes of contact resistance.

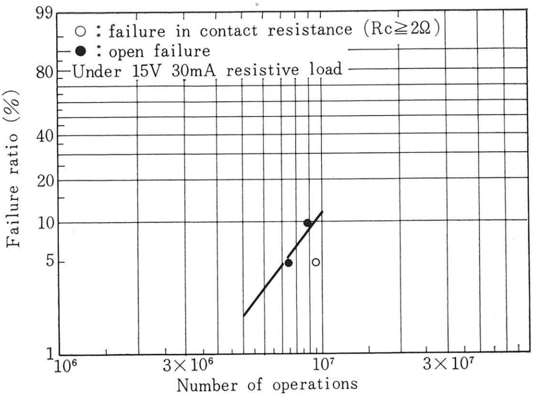


Fig. 24—Contact failure mode resulting from running test.

5. Conclusion

The result of the studies can be summarized as follows;

(1) In order to comprehend the difference of contact reliability between magnet driven reed switch and coil driven reed switch, we studied differences of contact reliability due to magnetic field distributions and its changing rate. From the result of the experiment, it was

concluded that the magnet moving speed should be a suitable value independent of key depressing speed in order to get high contact reliability.

(2) A push-button switch having snap action mechanism has been developed with these consideration. This action makes the magnet to move in a certain speed, independent of the key speed, and contributed largely to the improvement of contact reliability and also gives a sensory feedback to the operator.

(3) Numerical analysis of magnet motion has been carried out taking into consideration the mechanical characteristics of push-button switch and human finger. It resulted in good agreement with experiments and effective data has been obtained.

(4) Based on observation of striking forces and shock waves which the glass-tube of reed switch receive when the operator strikes hard on the key top, reed switch holding method which is also easy for mass production has been obtained.

6. Acknowledgement

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