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SWITCH ENGINEERING HANDBOOK

John R. Mason

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CONTENTS

CHAPTER 11

CONDUCTIVE RUBBER SWITCHES*

Although first introduced in the mid-1970s, conductive rubber switches are only now reaching their full potential as a reliable, low-cost, sealed switch technology. Conductive rubber switches are so called because the switch element is silicone rubber filled with conductive particles, usually carbon. Occasionally, silver or gold particles are used when minimal contact resistance is demanded by electrical requirements. A conductive rubber element is molded into a single sheet of silicone rubber, one conductive element for each switch position. The single rubber sheet holds the conductive elements in place beneath integrally molded bell-shaped domes (Fig. 11.1). The bell shapes impart the particular tactile feel required by the user. The sheet is placed over a printed wiring board which carries the necessary switch circuitry, backlighting means (if required), and connection device. The sheet also acts as a shield to prevent contaminants and spilled liquids from reaching the switch contacts and printed wiring board (Fig. 11.2).

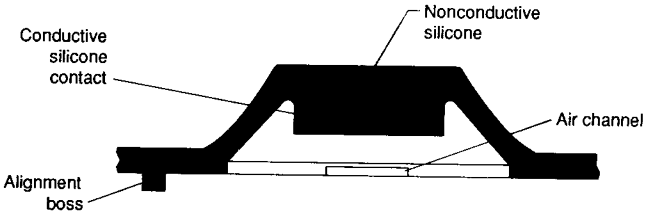

FIGURE 11.1 The conductive contacts are molded into the base rubber. (*Courtesy of Shin-Etsu Polymer America, Inc., Union City, Calif.*)

How Conductive Rubber Switches Are Constructed

Conductive rubber switches are mechanical-type switches made of a single molded piece of silicone rubber with conductive contacts (often called "pucks"

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*Numbers in parentheses indicate items in the References at the end of this chapter.

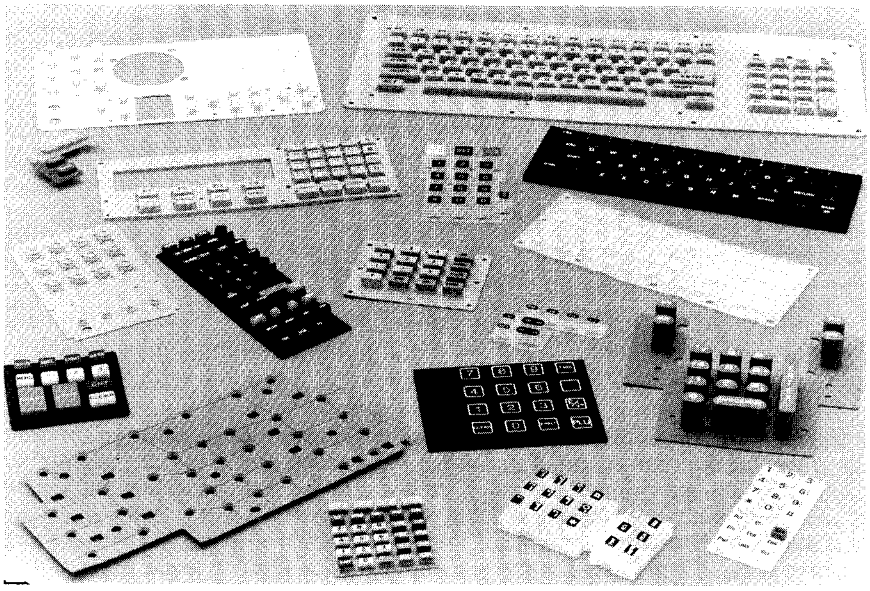

FIGURE 11.2 The one-piece molded rubber sheet provides sealing for the switch contacts. (*Courtesy of General Silicones Co., Arcadia, Calif.*)

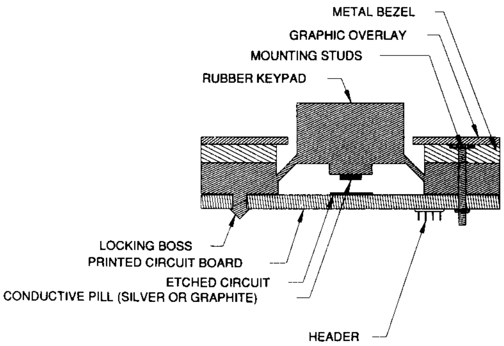

FIGURE 11.3 One method of securing the molded switch matrix to the PCB. (*Courtesy of Memtron Technologies, Inc., Frankenmuth, Mich.*)

for their resemblance to hockey pucks) integrally molded into the thin rubber keypad. This sheet, or switch matrix, is assembled between integral or separate keytops and a printed wiring board (Fig. 11.3). Each conductive rubber contact is directly over an etched interdigitated contact on the printed wiring board (Fig. 11.4). When pressed into contact with the printed wiring board etched contacts, the conductive rubber contact bridges the gap between the etched circuit and completes the switch contact.

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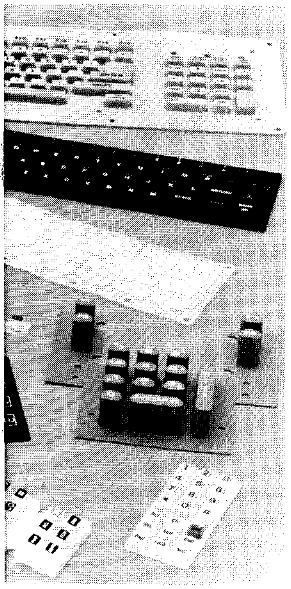

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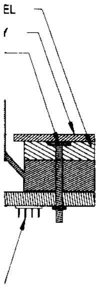

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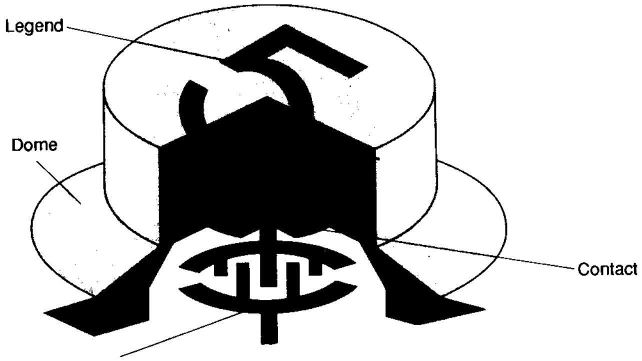

FIGURE 11.4 The conductive rubber contact is located directly above the interdigitated contact on the PCB. (*Courtesy of Shin-Etsu Polymer America Inc., Union City, Calif.*)

DESIGN CONSIDERATIONS

The following design considerations are meant only to educate the potential conductive rubber switch user in the wide variety of design options available in producing a completed switch and are not an encouragement to design and specify a switch in a figurative vacuum. The reason for this cautionary note is the relatively easy access to a large number of switch manufacturers producing high-quality custom conductive rubber switches. These switch manufacturers have broad experience in producing the exact switch required to meet customer specifications. It would be unwise, as well as uneconomical, for the user-engineer to attempt to design and specify a conductive rubber switch without consultation with these manufacturers. Indeed, most of them have direct relationships with molding facilities in the Far East (Taiwan, in particular) where, except for a few exceptions, almost all conductive rubber molding is done. Much of the labor involved in producing conductive rubber switches is tedious hand labor, hence the nearly universal use of more cost-effective sources such as can be found in the Far East. With this continuous molding experience has come insight into the "black magic" of silicone processing, leading in turn to a thorough understanding of complex combinations of silicone materials, legend printing and overcoating, rubber durometer, tactile force and stroke designs, PCB materials and circuit plating, color matching, and conductive material selection. This vast experience is a resource the user-engineer should take advantage of as early in the design stage as possible in order to yield the most cost-effective conductive rubber switch feasible within the constraints of the state-of-the-art. The penalty for waiting too long to bring in expert consultation from these switch manufacturers could be anything from a complete redesign of a system front panel to the expensive retooling of injection molded components designed to interface with the conductive rubber switch. The user-engineer should also note the lead times involved in producing these molded switches. The wise engineer will keep in mind that the manufacturer must have time to review the engineer's specification, fabricate the mold for the silicone processing, develop artwork for the legend printing (if required), and mold first articles for the engineer's approval.

With this in mind, we can now proceed to a discussion about conductive rubber design considerations, highlighting those details necessary for the user-engineer to consider as he or she develops a specification which is relevant, useful, and attentive to cost constraints.

Design Details of the Conductive Rubber Contact

The heart of the conductive rubber switch is the conductive rubber contact itself. The contact is silicone rubber material filled with a conductive material to allow the contact to carry an electrical current. The vast majority of conductive rubber switches produced utilize molded silicone rubber filled with carbon particles to impart conductivity to the silicone rubber base material. This combination of silicone and carbon provides a conductive contact with a contact resistance of approximately 200 Ω. The carbon contact is very reliable and is available in a variety of sizes. Carbon contacts can be supplied as small as 0.080 in (2,0 mm) diameter and are usually available up to a maximum of 0.315 in (8,0 mm) diameter. (1) Conductive contacts are produced from a higher durometer material than the basic keypad and are matte-finished to promote a cleansing action of the PCB contact pad. The conductive contact should never be larger than the contact pad on the PCB, but it can be smaller without causing operational problems. (2)

One drawback to the carbon contacts is that they are usually available in circular shapes only, although oval contacts can be supplied at slightly higher prices. This is a minor inconvenience, however, since the cylindrical carbon contact will suffice for the vast majority of applications.

The second most common type of contact for rubber keypads is screened, or printed, contacts. In this technique, contact material consisting of conductive particles suspended in a silk-screenable liquid is applied to the bottom of each key position normally devoted to the conductive rubber contact. After application, the screened conductive material is cured. Screened contacts are available in all shapes and sizes (limited only by the screening or printing mechanism's ability to access the bottom of each key) and allow design flexibility and cost effectiveness because of the way the contact is applied to the rubber keypad. Unfortunately, this versatility is offset by the eternal engineering "trade-off," in this case, the disadvantage that screened contacts exhibit considerably shorter life when compared with carbon-filled conductive rubber contacts. Screened contacts also demonstrate significantly higher contact resistance. It is not uncommon for screened contacts to have contact resistance in excess of 1000 Ω, so careful attention must be given to the keypad's electrical and life requirements when the contact type is chosen. (1)

In instances where lower contact resistance is required, however, precious metal particles can be incorporated into the silicone rubber, providing contact resistances of approximately 5 Ω (gold) and 25 Ω (silver), but at a substantial increase in cost. For applications requiring high current, such as POWER ON switches, several conductive rubber switch manufacturers mold a metal wafer inside the rubber dome in place of the standard conductive rubber contact, again at an increase in cost. (3) The metal contact is molded to the base rubber during the manufacturing process and once attached is almost impossible to remove. Depending on the metal selected and the type of plating used, if any, contact resistance is typically less than 25 Ω. Metal contacts are not frequently used in rubber keypads because of the higher costs and longer lead times associated with the process, but they should be considered for special applications. (1)

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TABLE 11.1 Specifications for Conductive and Insulating Silicone Rubber

Conductive rubber (carbon-filled):	
Specific gravity	1.05–1.10
Hardness, H°	50–65
Tensile strength, kg/cm^2	50–65
Elongation, %	150–300
Compression set, %	15–30
Volume resistivity, Ω-cm	2.5–4
Insulating rubber:	
Specific gravity	1.07–1.38
Hardness, H°	30–80
Tensile strength, kg/cm^2	50–80
Elongation, %	150–800
Compression set, %	13–21
Volume resistivity, Ω-cm	3×10^{14}–4×10^{15}

Source: Shin-Etsu Polymer America, Inc., Union City, Calif.

Table 11.1 shows physical properties for both the conductive silicone rubber and the insulating, or sheet, silicone rubber.

Design Details of the Molded Rubber Sheet

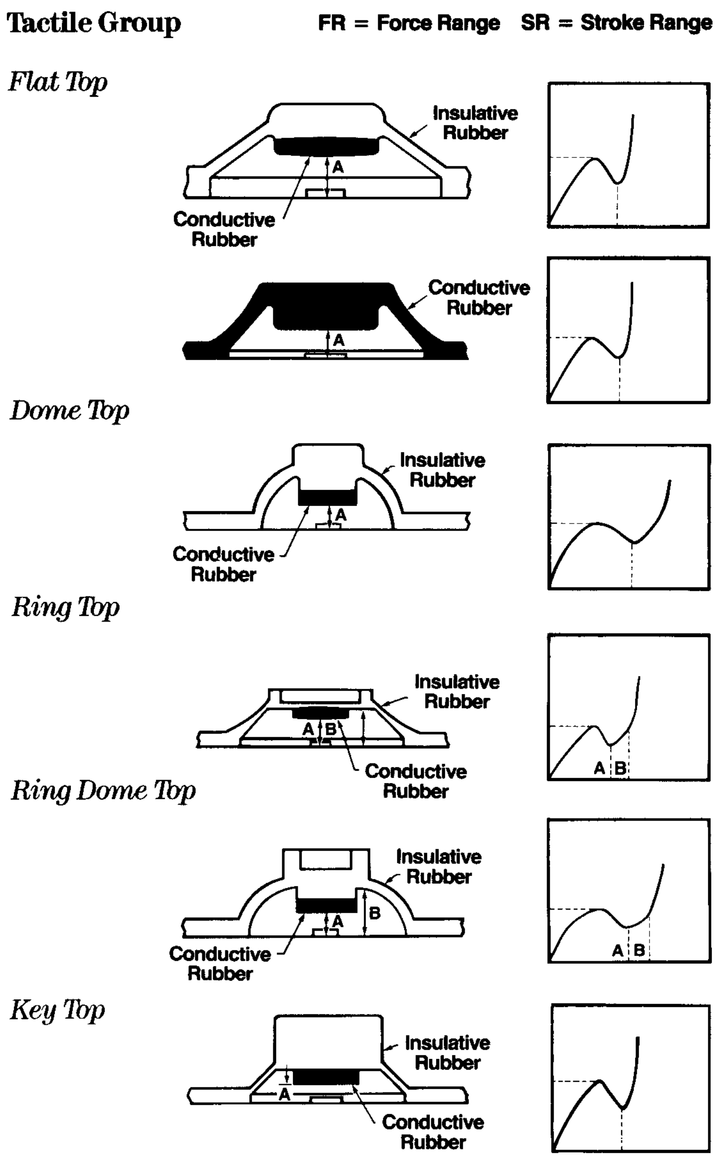
The sheet rubber that incorporates the bell-shaped tactile domes and the conductive elements is usually compression-molded as a single piece of silicone. The design of bell-shaped domes determines tactile feel and key travel. Figure 11.5*a* and *b* illustrates a few of the basic dome shapes which, when properly designed, can provide a nearly infinite variety of force and stroke combinations. The result is significant control over the finished keypad or keyboard's tactile feel, a very important *subjective* requirement in a switch.

Silicone rubber has extreme resistance to high-voltage ionization, remains flexible at −22°F (−30°C), and retains its shape and operating characteristics to 356°F (180°C). (4)

One of the most important considerations when designing and specifying molded silicone switches is the tolerances of the molded rubber sheet, in particular as it relates to potential mechanical interfaces on the control panel to which the switch ultimately mounts. Table 11.2 illustrates these standard dimensional tolerances.

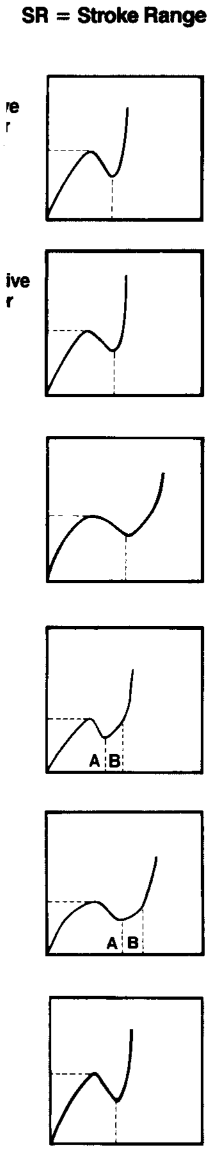
Silicone Rubber. Silicone rubbers are complex polymeric structures which effectively combine the most desirable properties of both organic and inorganic polymers and are unique within the large family of elastomeric materials owing to properties intrinsic in their chemical composition. The silicone rubber used in conductive rubber switches is an industrial-grade material available from a number of raw material manufacturers, such as Shin-Etsu Polymer, General Electric, and Dow Chemical.

Silicone rubber is available in many different formulations, and the product should dictate the material chosen in any given situation. Silicone rubbers are



(a)

FIGURE 11.5 Basic dome shapes and their associated force-deflection curves. (*Courtesy of Shin-Etsu Polymer America, Inc., Union City, Calif.*)



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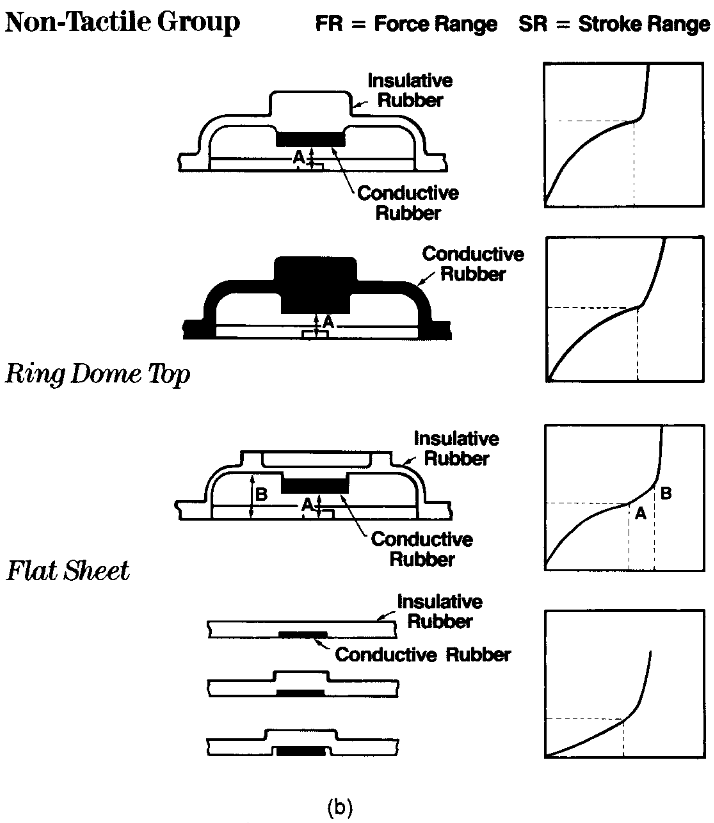

FIGURE 11.5 (*Continued*)

TABLE 11.2 Standardized Tolerances for Molded Silicone Switches

Inches	Millimeters
<0.250 ± 0.006	<6.36 ± 0.15
0.251–0.394 ± 0.008	6.37–10.02 ± 0.20
0.395–0.630 ± 0.008	10.03–16.00 ± 0.20
0.631–0.984 ± 0.010	16.01–25.00 ± 0.25
0.985–1.570 ± 0.014	25.01–39.89 ± 0.35
1.571–2.480 ± 0.016	39.90–63.00 ± 0.40
2.481–3.937 ± 0.020	63.01–99.99 ± 0.50
3.938–6.290 ± 0.028	100.00–159.77 ± 0.71
>6.290 ± 0.5%	>159.77 ± 0.5%

Source: Conductive Rubber Technology, Inc., Bothell, Wash.

classified in *standard, medium,* and *high-performance* grades. Most conductive rubber keypads are made with *standard-performance* material and, depending on various factors, have mechanical life expectancies, when molded, of 500,000 to 1,000,000 actuations. It should also be noted that most keypads are made with silicone rubber material that has a UL flammability rating of 94HB.

Table 11.3 depicts technical information on typical silicone rubber formulations. Particular attention should be directed to the *Appearance* entries in the table as it is very difficult for a conductive rubber keypad manufacturer to color match silicone rubber when dark gray or black base material is selected for a keypad because of its specific physical or flammability rating. Silicone rubber formulations that begin as translucent material or grayish-white material are normally used in most color matching applications because colored pigmentation can be added with relative ease. A unique design feature which adds versatility to the conductive rubber keypad is the capability to mix two different durometers of silicone rubber in the same keytop. Referred to as a *dual durometer* key in its final molded form, the example shown in Fig. 11.6 has the top portion of the key molded of 80 durometer rubber and the bottom portion, including the all-important membrane web, molded of 50 durometer rubber. The heat and pressure of the molding process inseparably joins the two durometers and, once molded, will not peel apart or separate. The advantages of this molding technique are twofold: first, the membrane web is molded from the softer, more flexible (and therefore longer life) durometer material, and second, the top portion of the key, in the harder durometer, retains the feel of a plastic key (which is generally more acceptable to keypad operators). Additionally, the harder durometer enhances the survivability of the key under harsh conditions of use. If the entire key was molded from the 80 durometer material, the tactile feel would be stiffer and mechanical life would decrease significantly. If the entire key was molded from the 50 durometer material, the softer feel of the key might be unsatisfactory to the keypad user and the key more susceptible to abuse. The combination of the two separate durometers produces a keypad which retains the best characteristics of both. The major design consideration here is that dual durometer keypads generally must be at least 0.236 in (6,0 mm) high to allow for the two-shot molding of the harder durometer keytop which is then molded to the base material of the keypad. If the specifying engineer is considering a dual durometer keypad, consult with the switch manufacturer to determine the best durometer characteristics for the keypad under design. Obtain samples from the manufacturer of the durometer pairs that most closely meet your requirements and collect comments from, ideally, the operator population or, if this is not feasible, other engineers or designers familiar with the operation of the final system. The determination of the durometer pairing is subjective, and no amount of calculation or analysis can replace the opinion of the ultimate user.

It should be noted that high-performance materials are more expensive than standard-performance materials and materials with flammability ratings of 94V-0 (or higher) are more expensive than those with ratings of 94HB. The following section discusses the flammability test procedures used to classify a material in either the 94V-0 (or higher) or 94HB category so the user can determine if the use of the more expensive material is necessary.[1]

Flammability Ratings. Flammability ratings for silicone rubber materials are derived in the same manner as similar ratings for plastic materials. They are in-

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[1] Since procedures can change from time to time, the user should obtain the latest test procedures directly from the agency responsible for approval of the equipment under design.

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TABLE 11.3 Silicone Rubber Formulations

Material	931	941	951	953	961	971	981	3801	5140	5150	5160	9511	9611
Typical properties before cure:													
Appearance	Trans.	Trans.	Trans.	Trans.	Grayish-white	Grayish-white	Grayish-white	Black	Trans.	Trans.	Trans.	Trans.	Trans.
Specific gravity, 25°C	1.10	1.12	1.15	1.15	1.22	1.30	1.42	1.20	1.09	1.11	1.12	1.14	1.14
Plasticity, Williams	130–210	200–260	230–290	230–330	270–340	330–400	420–500	600	160	170	175	200	205
After cure:													
Linear shrinkage, %	4.3	4.0	3.8	3.9	3.4	3.0	2.8	3.3	3.9	3.7	3.9	3.5	3.4
Hardness, JIS	30	40	50	50	60	70	80	73	40	50	60	50	59
Tensile strength, kg/cm^2	55	75	90	70	73	68	85	55	81	83	83	72	67
Elongation, %	530	450	340	400	280	200	130	180	550	480	410	290	290
Tear strength, kg/cm	8	11	14	18	15	15	10	10	14	19	15	8	10
Compression set, %	4.3	4.0	3.8	3.0	3.4	3.0	2.8	3.0	7.0	6.0	6.0	4.0	4.0
Flammability rating	94HB	94HB	94HB	94HB	94HB	94HB	94HB	94V-0	94HB	94HB	94HB	94HB	94HB
Fatigue test, cycle × 10,000	10	20–30	30–40	30–40	30–40	15–25	10–20	N/A	600–1000	400–800	200–400	200–300	150–200

Source: Glolite Sales, Ltd., Pauls Valley, Okla.

tended to serve as a *preliminary indication* of probable flammability in a particular application.

Flammability ratings are derived by using standard-size specimens and are intended to be used solely to measure and describe flammability properties of various materials in very closely controlled laboratory conditions. Actual response to flame and heat depends upon the size and form of the product and the end use of the product using the material. Other important characteristics identified by flammability testing include ease of ignition, burn rate, flame spread, intensity of burning, and products of combustion.

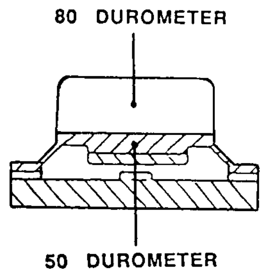

FIGURE 11.6 A dual durometer key. (*Courtesy of Glolite Sales, Ltd., Pauls Valley, Okla.*)

The final acceptance of the material itself is dependent upon its use in complete equipment which meets all applicable standards relating to the equipment.

The following describes the horizontal burning test for classifying material 94HB:

> Materials shall be classified 94HB on the basis of test results obtained on small bar specimens when tested in very rigidly controlled laboratory conditions.
>
> A material classified as *94HB* shall meet the following conditions:
>
> **A.** Not have a burning rate exceeding 1.5 in (38,1 mm) per minute over a 3.0 in (76,2 mm) span for specimens having a thickness of 0.120–0.500 in (3,05-12,7 mm) or
>
> **B.** Not have a burning rate exceeding 3.0 in (76,2 mm) per minute over a 3.0 in span for specimens having a thickness less than 0.120 in (3,05 mm) or
>
> **C.** Cease to burn before the 4.0 in (102 mm) reference mark.

Additionally, the vertical burning test for classifying materials 94V-0/V-1 is as follows:

> A material classified as *94V-0* shall meet the following conditions:
>
> **A.** Not have any specimens that burn with flaming combustion for more than 10 seconds after either application of the test flame.
>
> **B.** Not have a total flaming combustion time exceeding 50 seconds for the 10 flame applications for each set of five specimens.
>
> **C.** Not have any specimens that burn with flaming or glowing combustion up to the holding clamp in the test fixture.
>
> **D.** Not have any specimens that drip flaming particles that ignite the dry absorbent surgical cotton located 12 inches (305 mm) below the test specimen.
>
> **E.** Not have any specimens with glowing combustion that persists for more than 30 seconds after the second removal of the test flame.
>
> A material classified as *94V-1* shall meet the following conditions:
>
> **A.** Not have any specimens that burn with flaming combustion for more than 30 seconds after either application of the test flame.
>
> **B.** Not have a total flaming combustion time exceeding 250 seconds for the 10 flame applications for each set of five specimens.
>
> **C.** Not have any specimens that burn with flaming or glowing combustion up to the holding clamp of the test fixture.

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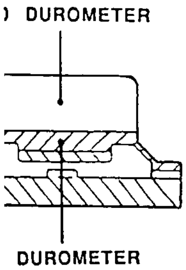

A dual durometer key. (*Cour-*
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D. Not have any specimens that drip flaming particles that ignite the dry absorbent surgical cotton located 12 in (305 mm) below the test specimen.

E. Not have any specimens with glowing combustion that persists for more than 60 seconds after the second removal of the test flame. (1)

Table 11.4 depicts silicone rubber compounds developed specifically to meet 94V-0 of Flame Test UL 94. Material KE-5606U has excellent resistance to oil and tracking, has excellent compression set, and is widely used for electrical devices requiring exacting electrical properties, thermal resistance, and self-extinguishing properties. Material KE-5612GU has excellent resistance to heat, tracking, and arc, and good electrical insulation characteristics. (1)

Characteristics of Silicone Rubber

HEAT RESISTANCE: Compared with organic rubbers, most silicone rubbers have incomparably high resistance to heat. Silicone rubbers can be used for very long lengths of time at 302°F (150°C) with almost no change in material properties and, depending on the compound, can withstand more than 10,000 h of continuous service at 392°F (200°C) (Fig. 11.7). If necessary, silicone rubbers can operate in temperatures as high as 662°F (350°C) for short periods of time. Because of these characteristics, silicone rubbers are widely used in applications requiring high heat resistance.

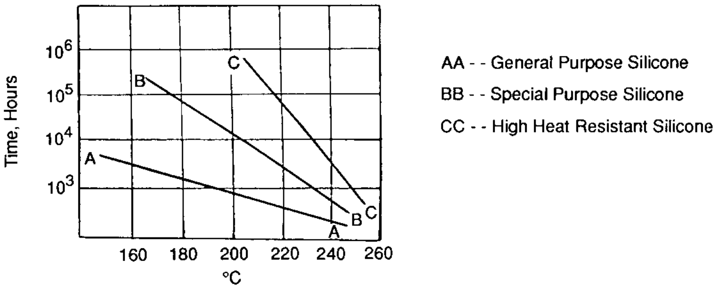
When silicone rubber is heat aged in open air, the hardness of the material increases and elongation decreases. Conversely, the hardness of silicone rubbers tends to decrease when heated under a hermetically sealed condition and the heat-resistance serviceable life may sometimes be shorter if heated in open air. This phenomenon is caused by the breakage of the polysiloxane chains of the polymer. Several different grades of silicone rubbers are available which exhibit improved heat resistance under hermetically sealed conditions by combining special additives with a proper postcure agent. Special formulations and the selection of a proper curing agent operate to prevent softening of the silicone due to the breakage of siloxane chains.

CHEMICAL, OIL, AND SOLVENT RESISTANCE: At temperatures below 212°F (100°C), the oil resistance of silicone rubber is somewhat inferior to that of nitrile and

TABLE 11.4 Properties of Two Specific Silicone Rubber Materials

Material	KE-5606U	KE-5612GU
Appearance	Gray	Grayish-black
Specific gravity, 25°C	1.46	1.49
Plasticity, Williams	270–330	247
Hardness, JIS	53	59
Tensile strength, kg/cm^2	65	69
Elongation, %	300	340
Tear strength, kg/cm	17	15
Compression set	20	19
Volume resistivity, Ω-cm	1.3×10^{15}	2×10^{15}
Dielectric strength, kV/mm	27	29
Dielectric constant, 50 Hz	3.6	3.3
Dissipation factor, 50 Hz	53	51
Rebound resilience, %	55	51

Source: Glolite Sales, Ltd., Pauls Valley, Okla.



*Life in hours is defined by the time taken for decrease of the ultimate elongation to one -half of the initial value.

FIGURE 11.7 Serviceable life of silicone rubbers. (*Courtesy of Glolite Sales, Ltd., Pauls Valley, Okla.*)

TABLE 11.5 Oil Resistance of Silicone Rubber

Oil type	Temperature	No. of hours	Changes in properties: Hardness, points	Tensile strength, %	Elongation, %	Volume, %
ASTM 1	150/302	168	−10	−10	−10	−10
ASTM 3	150/302	168	−25	−20	−20	+40
GM hydramatic fluid	94/201	70	−35	−40	−5	+35
Ford brake fluid	150/302	72	−20	−60	−40	+15
Diesel fuel	50/122	168	−30	—	—	+105
Gasoline	23/73	168	−20	—	—	+165
Sydrol 500A fluid	70/158	168	−5	−10	+5	+10
Motor oil (SAE 30)	175/347	168	−8	−70	−65	−8

Source: Glolite Sales, Ltd., Pauls Valley, Okla.

chloroprene rubbers (Table 11.5), but at temperatures above 212°F (100°C), the oil resistance of silicone rubber is superior to all types of organic rubber. In addition to being resistant to oil, silicone rubbers are chemical and solvent resistant as well (Table 11.6). Polar organic compounds such as aniline, alcohol, and dilute alkaline and acid solutions only slightly affect the properties of silicone rubber, as can be evidenced by its volume swell of only 10 to 15 percent. On the other hand, silicone rubber swells when contacted with nonpolar solvents such as benzene, toluenes, and gasoline (Table 11.7), but the original properties are quickly restored when the solvents are removed.

Silicone rubber should not be used in the presence of highly concentrated acids and alkaline solutions because they permanently damage it. Other solvents affect the properties of silicone rubber in different ways, so it is important that silicone rubber be tested thoroughly before being used in areas where solvents are deployed.

Tactile Feel. Tactile feel is a term commonly used with rubber keypads to describe the way a key feels to the operator when it is actuated. While this defini-

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TABLE 11.6 Chem

Chemical compou
Conc. nitric acid
7% nitric acid
Conc. sulfuric acid
10% sulfuric acid
Acetic acid
5% acetic acid
Conc. hydrochloric
10% hydrochloric a
20% sodium hydrox
2% sodium hydroxi
Conc. ammonia wat
10% ammonia wate
Water
Boiling water (70 h)
Water at 70°C
3% hydrogen peroxi

Source: Glolite Sa
Test condition: Aft

TABLE 11.7 Volur

Liquid
Gasoline
ASTM 1 oil
ASTM 3 oil
Diesel oil
Olive oil
Lard
Formalin
Ethyl alcohol
Ethylene glycol
Diethyl ether
Methyl ethyl ketone
Trichloroethylene
Carbon tetrachlorid
Benzene
Aniline
Phenol
Cyclohexanol
Distilled water
Sea water

Source: Glolite Sa

ral Purpose Silicone
ial Purpose Silicone
Heat Resistant Silicone

tesy of Glolite Sales,

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nsile ength, %	Elonga-tion, %	Volume, %
-10	-10	-10
-20	-20	+40
-40	-5	+35
-60	-40	+15
—	—	+105
—	—	+165
-10	+5	+10
-70	-65	-8

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TABLE 11.6 Chemical Resistance of Silicone Rubber

	Changes in properties, %				
Chemical compound	Hardness	Weight	Volume	Tensile strength	Ultimate elongation
Conc. nitric acid	−30	+10	+10	−80	+30
7% nitric acid	−2	1	1	−50	−30
Conc. sulfuric acid		Decomposed		Decomposed	Decomposed
10% sulfuric acid	−2	1	1	0	0
Acetic acid	+4	+3	+4	−20	+10
5% acetic acid	+8	+2	+2	−20	+10
Conc. hydrochloric acid	−6	+3	+4	−40	−20
10% hydrochloric acid	−4	+2	+2	−50	−50
20% sodium hydroxide	−2	−2	−1	−10	0
2% sodium hydroxide	−4	<1	<1	0	0
Conc. ammonia water	−4	+2	+1	−30	+10
10% ammonia water	−6	+2	+2	−20	0
Water	<1	<1	<1	0	0
Boiling water (70 h)	+2	<1	<1	−10	−10
Water at 70°C	<1	+1	<1	−10	+10
3% hydrogen peroxide	<1	<1	<1	0	+20

Source: Glolite Sales, Ltd., Pauls Valley, Okla.
Test condition: After dipping for 168 h at 25°C.

TABLE 11.7 Volume Swell after 168-h Dipping, 122°F (50°C)

	Nitrile rubber					
Liquid	28%	33%	38%	Natural rubber	Butyl rubber	Silicone rubber
Gasoline	15	10	6	250	240	260
ASTM 1 oil	−1	−1.5	−2	60	20	4
ASTM 3 oil	10	3	0.5	200	120	40
Diesel oil	20	12	5	250	250	150
Olive oil	−2	−2	−2	100	10	4
Lard	0.5	1	1.5	110	10	4
Formalin	10	10	10	6	0.5	1
Ethyl alcohol	20	20	18	3	2	15
Ethylene glycol	0.5	0.5	0.5	0.5	−0.2	1
Diethyl ether	50	30	20	170	90	270
Methyl ethyl ketone	250	250	250	85	15	150
Trichloroethylene	290	230	230	420	300	300
Carbon tetrachloride	110	75	65	420	275	300
Benzene	250	200	160	350	150	240
Aniline	360	380	420	15	10	7
Phenol	450	470	510	35	3	10
Cyclohexanol	50	40	25	55	7	25
Distilled water	10	11	12	10	5	2
Sea water	2	3	3	2	0.5	0.5

Source: Glolite Sales, Ltd., Pauls Valley, Okla.

tion for tactile feel is commonly used, it is misleading in that tactile feel is the result of a precise relationship between actuation force, contact force, return force, and stroke and travel. Keypads that demonstrate what is described by operators as "good" tactile feel do so because close attention has been given to the interaction of these four components.

In order for a switch or keypad to display good tactile feel it must have a snap ratio of at least 40 percent. The snap ratio of any keypad can be determined by utilizing the formula

$$\frac{F_1 - F_2}{F_1}$$

where F_1 = actuation force
F_2 = contact force

In order to have distinct tactile feeling (strong tactile feel) the snap ratio of the keypad should be 50 percent or higher. Table 11.8 illustrates the relationship of actuation force to subjective feel, snap ratio, and life. The higher the snap ratio the stronger the tactile feel. Conversely, if a keypad does not require distinct tactile feel the snap ratio should be less than 40 percent. The snap ratio range available for rubber keypads is 25 to 80 percent. Figure 11.8 compares force-deflection curves for "weak" and "strong" tactile feel. Figure 11.9 depicts a force-deflection curve that is typical for a rubber switch that has *overstroke,* such as is found in computer terminal keyboards and keypads. Rubber keypads that produce overstroke are always fitted with some type of plastic caps or covers for rigidity, as the molded rubber switch is hollow rather than solid in order to get the light tactile feel necessary for fast data entry type applications.

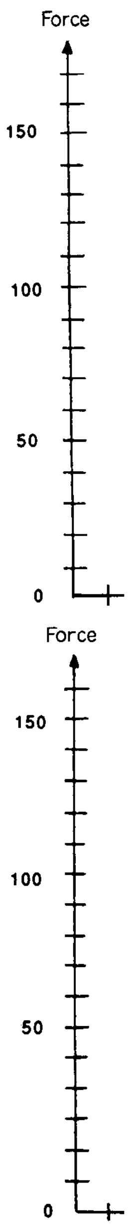
TABLE 11.8 Relationship of Actuation Force to Feel, Snap Ratio, and Life

Typical actuation force parameters*			
Actuation force, g	**Tactile feel**	**Snap ratio, %**	**Typical life, actuations**
40–60	Excellent	50	1,000,000
75–100	Excellent	50	1,000,000
100–150	Excellent	50	1,000,000
150–200	Good	40	500,000
200–300	Fair	25	300,000
Standardized actuation force tolerances†			
50 g ± 15 g			
75 g ± 20 g			
100 g ± 25 g			
125 g ± 30 g			
150 g ± 35 g			
175 g ± 40 g			
200 g ± 50 g			
250 g ± 50 g			

Tactile feel is influenced by actuation force, stroke, and size of keytop. The data are based on similar size keytops with stroke of 1.0 mm.

**Source:* Glolite Sales, Ltd., Pauls Valley, Okla.

†*Source:* Conductive Rubber Technology, Inc., Bothell, Wash.



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	1,000,000
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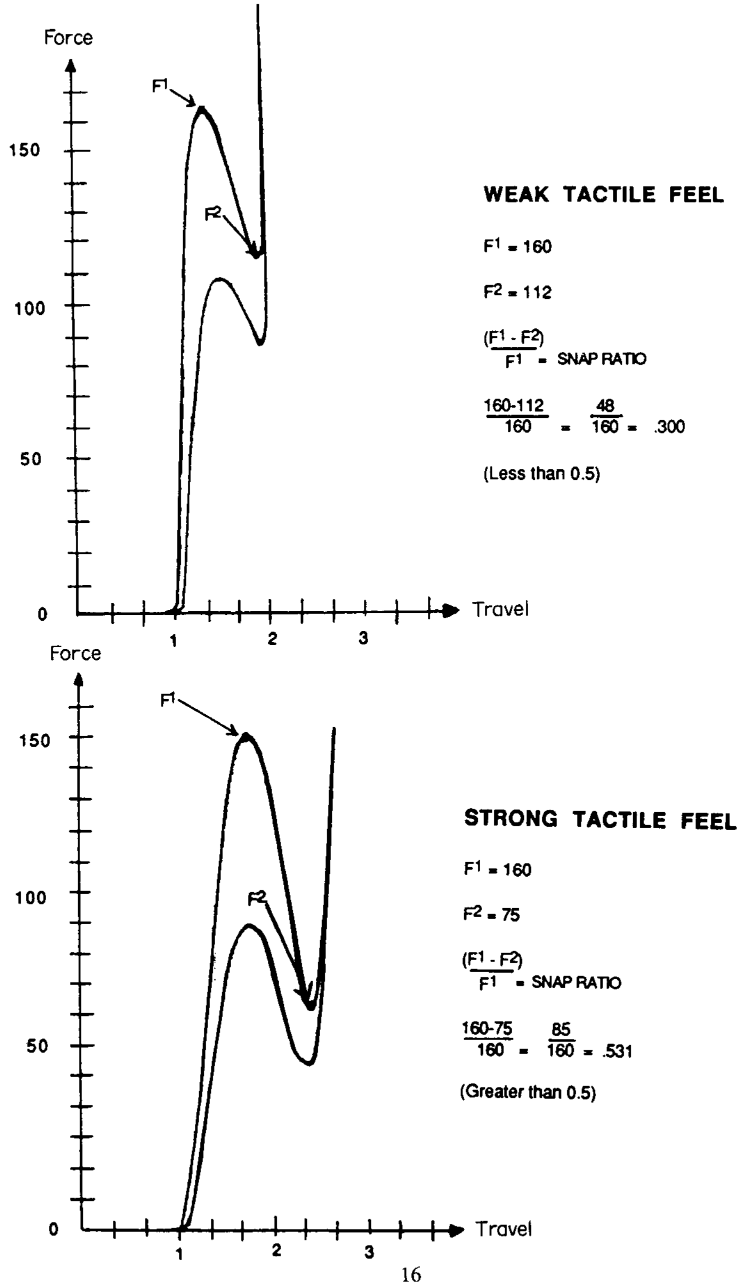

FIGURE 11.8 Comparison of force-deflection curves for "weak" and "strong" tactile feel. (*Courtesy of Glolite Sales, Ltd., Pauls Valley, Okla.*)

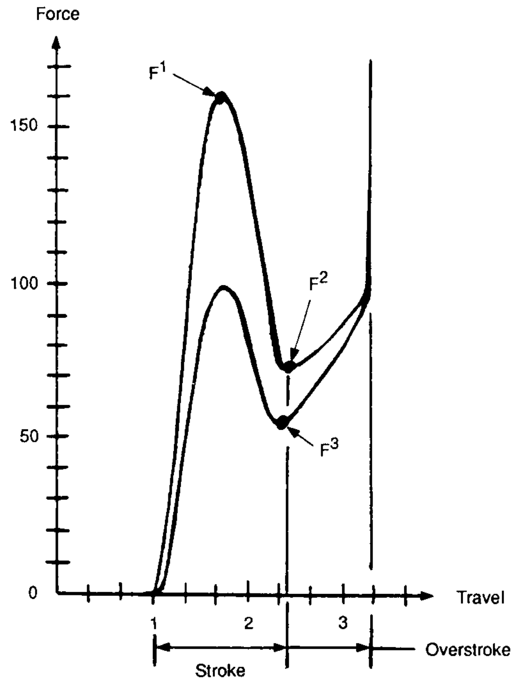

FIGURE 11.9 Typical force-deflection curve for a rubber switch with overstroke. (*Courtesy of Glolite Sales, Ltd., Pauls Valley, Okla.*)

It should be noted here that the snap ratio of a keypad also affects the *life* of the keypad. Keypads with high snap ratios exhibit shorter life than keypads with low snap ratios. Regardless, all keypads (high snap ratios as well as low snap ratios) should be able to realize a life of 250,000 to 500,000 actuations. It is not unusual for indirect contact switches (i.e., rubber keypads fitted with plastic keycaps) with very light actuation and return forces to yield life measurements in excess of 5,000,000 actuations.

It is difficult to recommend specific guidelines for creating the best tactile feel, but if actuation force and stroke are quantified it is possible to precisely design the key's membrane web in order to give the keypad a good tactile feel. It is imperative that the user understand that the design of the membrane web *must* be left to the switch manufacturer. The manufacturer must be allowed to shape the web as needed in order to achieve a certain stroke, actuation force, and life expectancy. High snap ratios create excellent tactile feel, but great care must be exercised to make certain the keypad also has a proper return force so that sticking keys are not encountered. Leave tactile feel to the switch manufacturer, but establish very strict parameters in the switch specification as to what type of tactile feel is desired. As demonstrated in Chap. 1, the best method for specifying tactile feel is the force-deflection (stroke) curve. Since tactile feel is a very subjective parameter, one method of finalizing a satisfactory force-deflection curve is to obtain samples of previously molded keypads from selected manufacturers, decide which sample "feels" the best for the application, and have the manufac-

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turer measure the actuation force and stroke. Develop the force-deflection curve from these measurements and incorporate it into the switch specification. If the engineer wishes to make the tactile feel decision his or herself, it is recommended that a number of people (especially from the customer's operator population, if possible) actuate the samples and come to some sort of consensus about the right tactile feel. This can become a very frustrating exercise for the engineer when the tactile feel of several *different* force-deflection combinations are selected as the "best" and no particular combination stands out. People have their own ideas of what tactile feel works best for the individual, and if the engineer is unfortunate to be confronted with a number of strong but divergent opinions, the art of compromise should be practiced.

A general guideline that can be followed for establishment of an acceptable tactile feel is that large keys require higher actuation forces than small keys. This same rule also applies to key height. Tall keys require higher actuation force than short keys. A general rule for actuation force is that keys with heights of 0.394 to 0.590 in (10 to 15 mm) should have minimum actuation forces of 2.8 to 3.5 oz (80 to 100 g), while keys with heights of 0.590 to 0.985 in (15 to 25 mm) should have minimum actuation forces of 5.3 to 6.2 oz (150 to 175 g).

If the desired stroke and actuation force for a keypad are *not* known or fully defined, it is *imperative* that the following design rule be followed:

Always tool the keypad with relatively low actuation force and long stroke. Why? Because mold tooling can be easily modified to *increase* actuation force and *reduce* stroke (removing metal from the mold), but it is more difficult (and therefore more expensive in money and schedule) to modify tooling to *reduce* actuation force and *increase* stroke (adding metal to the mold).

It should also be noted that large and small keys with *identical actuation forces* will feel very different when they are actuated by the human finger. This difference of feeling is caused by the overall size of the switch and the fact that the force being applied is being dispersed or concentrated over a comparatively smaller or larger surface area. When keypads incorporate different-sized keys it is wise to use more than one actuation force in the keypad so that the tactile feel will remain fairly constant for all keys.

Determining Maximum Keystroke. Stroke and tactile feel in rubber switches are dependent upon the shape, thickness, and density (durometer) of the material used in the membrane web area of the keypad. Stroke typically ranges from 0.010 in (0,25 mm) to 0.200 in (5,0 mm) in rubber keypads and can be precisely controlled with proper design and accurate tooling.

Stroke, or travel, is depicted in Fig. 11.10 as the distance indicated by *d,* and is the distance between the PCB and the closest surface of the conductive pill on the individual switch.

The maximum stroke of any key and switch is *equal to or less than* the combined thickness of the base material and the height of the membrane area of the switch. When this dimension is determined it is important that the thickness of the conductive pill be subtracted from the total to accurately calculate the key's stroke. The normal thickness of a conductive pill is 0.015 in (0,4 mm) to 0.020 in (0,5 mm).

In order to increase the stroke and travel of any key, the base thickness must be increased or the membrane web area must be made steeper than originally designed.

Sticking Keys. One problem associated with poor design practices relating to conductive rubber is sticking keys. It is important to note that rubber keypads should always have a *minimum* return force of 1 oz (30 g) to prevent sticking keys

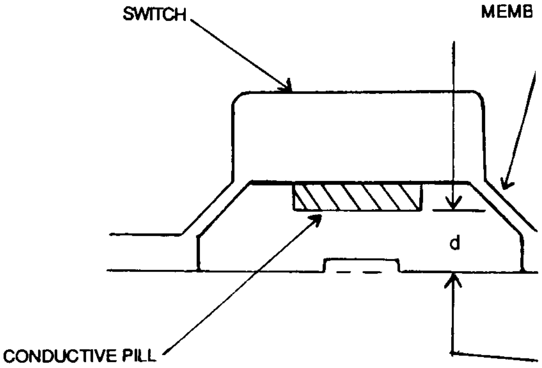

FIGURE 11.10 Stroke is defined by distance *d*. (*Courtesy of Glolite Sales, Ltd., Pauls Valley, Okla.*)

and other related problems, and the following considerations should be part of a designer's checklist to minimize the occurrence of sticking keys:

1. Obstruction of switch membrane web: If the rubber keypad is covered with a faceplate (bezel), it is imperative that close attention be paid to the design of this faceplate. The faceplate (bezel) should incorporate a 45° chamfer at least 0.040 in (1,0 mm) high on the bottom side around each key to prevent interference with the operation of the membrane web of the switch. This feature is typically required when the bezel will fit very close to the membrane web of the switch and the clearance between the two is very small.

2. Key opening clearance: In addition to being careful not to obstruct the operation of the key's membrane web, it is important that enough clearance is designed into the faceplate's key opening. A general rule of thumb for this clearance dimension is that the opening be 0.012 in (0,3 mm) (minimum) larger than the key itself on all sides of the key.

3. Switch return force: Another common cause for sticking keys is that the key's return force is not high enough to overcome the friction created by the bezel. A key's return force is typically 25 to 30 percent of its actuation force. It is suggested that keys with printed legends (direct contact switches, i.e., the human finger operates the key directly) should never have an actuation force of less than 2.8 oz (80 g) or a return force of less than 1 oz (30 g). Close attention should also be paid to the relationship between a key's actuation force and desired travel when tactile feel is being finalized. Always consult with the potential switch manufacturer's engineering department for assistance in this somewhat complex, but quantifiable, area.

4. Flash in the key opening: Make certain that all key openings are free of flash. To guarantee that all flash has been removed it is recommended that the key openings be cleaned with emery paper.

5. Absence of air channels or obstruction of air channels: In order for keys to be able to return to their normal rest position, it is critical that air channels be incorporated into the keypad design. Keys may be vented to the outside of the keypad or, if the keypad needs to be waterproof, vented to each other. Air channels are typically at least 0.008 in (2,0 mm) wide and 0.012 in (3,0 mm) deep.

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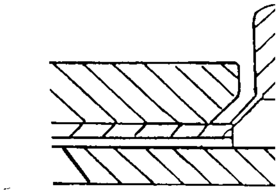

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Make certain that this important feature is *not* overlooked when the keypad design is finalized.

6. Make certain that the edge radius of the rubber key is *always less* than the radius of the key opening in the faceplate (bezel). Overlooking this detail can cause keys to hang up on the bezel even if all other design guidelines have been followed closely.

7. Incorrect switch and key height: In order to make certain that a key's stroke does not create sticking problems with the bezel, very close attention must be given to the key's height. The key's height *must be equal* to the combined thickness of the bezel and the base (apron) of the keypad *plus* the stroke of the individual key. When this value is calculated, a minimum clearance dimension of 0.020 in (0,5 mm) *must be added* to the figure to guarantee that the key or switch will not "hang up" on the bezel when actuated. Figure 11.11 illustrates this important relationship. (1)

Switch Reliability and Switch Life

Switch reliability and switch life depend on the membrane web style chosen, the density of the material in the keypad, and the quality of the material itself. Some switch manufacturers, such as Glolite Sales, Ltd., Pauls Valley, Okla., have developed several grades of silicone rubber compounds which are several times more resistant to fatigue by bending than conventional grades of silicone rubber. Actuation force, snap ratio, and stroke also influence switch life, as does proper curing of the keypad, so great care should be exercised when these parameters are identified and the keypad is manufactured.

Generally speaking, square keys demonstrate shorter life than circular keys because of the stress that is applied to the four corners of the key's membrane web. Circular keys have equal pressure exerted over the entire surface of the membrane web; hence these keys usually demonstrate considerably longer life than their square counterparts. Careful attention should be paid to this phenomenon when the keypad is being designed. All other things being equal, switch life is reduced as higher durometer (hardness) material is used, and switch life is also reduced as actuation force is increased.

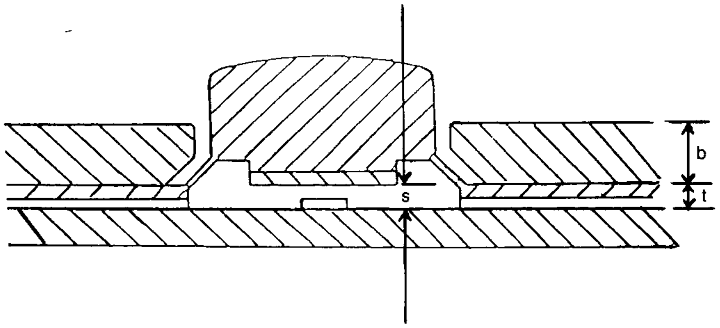

FIGURE 11.11 The minimum height of any switch or key is determined by adding the following values: base thickness (t) of keypad + bezel thickness (b) + stroke (s) + 0.02 in (0,5 mm). (*Courtesy of Glolite Sales, Ltd., Pauls Valley, Okla.*)

A commonly accepted definition of *mechanical life* is that the switch is considered functional until its initial actuation force degrades by 20 percent. The test condition and parameter associated with this definition of life is that the switch is continuously activated at the rate of 2 times per second at a force of 5.3 oz (150 g). By contrast, a commonly accepted definition of *electrical life* is that the contact resistance of the switch cannot exceed 200 Ω. The test condition and parameter for this definition of life is that an actuation force of 5.3 oz (150 g) is applied against a gold-plated contact on a PCB. As noted elsewhere in this chapter, several different types of contacts are available for use in rubber keypads, and each exhibits unique electrical characteristics.

Additionally, it should be noted that contact resistance for rubber switches varies depending on the plating used on the PCB. Conductive rubber switches can be used with gold-plated, nickel-plated, and screened carbon PCBs with high reliability, but the contact resistance will be different for each board. Gold-plated PCBs demonstrate the lowest contact resistance (less than 100 Ω), while screened carbon PCBs consistently measure much higher contact resistances (typically 1000 Ω). The use of tin-lead solder-plated PCBs is not recommended with conductive rubber switches because the carbon-filled conductive pills are not abrasive enough to keep the contact on the PCB sufficiently clean for reliable contact.

Key Rocking

Key rocking is a condition of conductive rubber switches wherein a key, when pressed by a human finger, has a tendency to tip, or rock, to one side or the other during its stroke. In order to minimize this undesirable feature, the following design suggestions should be given careful consideration:

A. Minimize keystroke: Specify travel within 0.03 to 0.04 in (0,8 to 1,0 mm) for switches with tactile feel.

B. Design keys to incorporate slightly concave tops: Concave keytops give a more solid feel than flat keytops.
  1. If a concave keytop is used, be certain that the radius of the concavity is not overly severe if it is to be printed with some type of graphics.
  2. If the radius of the keytop is too severe the printing will become fuzzy because the ink will have a tendency, during application, to run to the center of the key. In addition, it will be very difficult for the manufacturer to control the consistency of the graphics because of the severity of the key slope.

C. Limit height of key: Keytop should not be higher than 0.100 in (2,5 mm) above the faceplate (bezel) surface.

D. Add antirocking pins (stabilizing pads) to the bottoms of all keys:
  1. Antirocking pins are frequently added to the inner surfaces of keys to negate key rocking. The pins are molded as part of the base silicone rubber material of the keypad.
  2. Make certain that the height of the antirocking pins does not interfere with the switch contact.
  3. Incorporate antirocking pins for switches that have a stroke of 0.04 in (1,0 mm) or more.

E. Design the conductive rubber contact to stabilize the key:
  1. Try to design the contact so that it conforms to the key shape. Multiple contacts can be used for large keys, and the availability of different-shaped contacts (i.e., circular, oval, square) from the potential manufacturer should be investigated.

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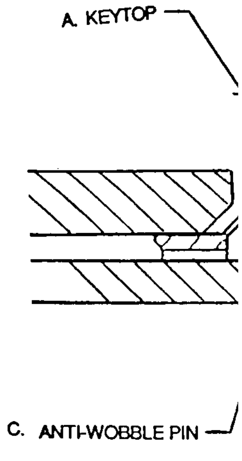

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2. As a general rule, design the contact under the key to cover approximately 50 percent of the key area. This will promote switch stability and help ensure reliable switch contact. If this general rule cannot be followed because of space limitations on the PCB and the switch contact area is less than 50 percent of the key area, it is even more important to incorporate antirocking pins into the keypad so that reliable contact can be made despite the use of undersize contacts.

Figure 11.12 depicts the incorporation of antirocking pins on a typical conductive rubber key. It is important to note that a minimum clearance of 0.020 in (0,5 mm) must be maintained from the bottom inside edge of the membrane web of any key to any other feature on the inner surface of that same key. This rule applies whether that feature is a conductive contact or antirocking pins. This clearance is critical to ensure that the conductive rubber "puck" comes into contact with the PCB in the correct manner.

Typically, antirocking pins are approximately 0.04 in (1,0 mm) in diameter. The antirocking pin must have a height that is smaller than the height of the conductive contact itself so that the pins do not prevent the contact from reaching the PCB.

Printed Circuit Board Design. Conductive rubber keypads are reliable and versatile; however, the environment in which the keypad will be used must be considered in determining the type of plating applied to the PCB which will enhance the long life and trouble-free operation inherent in this technology.

As previously discussed, the type of PCB plating that offers the lowest contact resistance is gold over nickel. However, other viable options exist depending on the application.

The type of plating used for switch contacts on the PCB should be carefully considered to maximize switch life. Most manufacturers recommend that only gold plating be used on the switch contacts. Nickel, tin-lead, and bare copper are

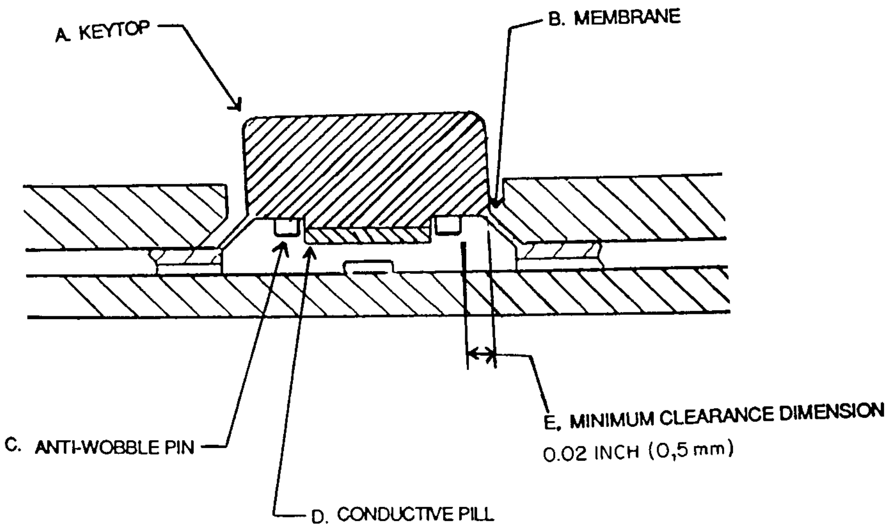

FIGURE 11.12 Antirocking pins are incorporated into the molded rubber. (*Courtesy of Glolite Sales, Ltd., Pauls Valley, Okla.*)

not recommended due to the inherently poor wiping action of the silicone rubber carbon contacts. Surface oxides can quickly build up on these metals, causing a sharp increase in electrical contact resistance. This can lead to intermittent functioning of the switch and eventual switch failure.

As an alternative to expensive gold plating, some suppliers of conductive rubber switches offer conductive carbon ink which can be applied directly on a hard PCB substrate using a simple screen printing and heat curing process. One manufacturer, Advanced Connector Technology, Ventura, Calif., offers a product called Carbon Ink #2000 to be used in conjunction with silicone rubber switch PCB's to increase switch life. The manufacturer recommends that the entire PCB switch contact be composed of conductive carbon ink only (no etched metal) and that the carbon ink overlap only the metal land areas (usually copper) connecting the PCB switch trace patterns. The carbon ink will not oxidize, is etch resistant, and can withstand immersion in a 500°F (260°C) wave solder bath with no switch contact deterioration. According to the company, replacement of gold-plated PCB switch contacts with conductive carbon ink can result in PCB cost savings of as much as 50 percent! In addition, switch life is usually increased since the PCB carbon contacts remove fewer carbon particles from the conductive silicone rubber switch contacts than do PCB metallic contacts such as gold. One caution should be observed, however; because of their abrasive action, edgeboard connectors and metal dome switches (Chap. 9) are *not* recommended for use with carbon contacts on PCBs.

It should be noted that conductive carbon contacts used in conductive rubber switches demonstrate very stable contact resistance and long life (at least 50,000,000 cycles). Contact problems with conductive rubber keypads are often related to selection, or application, of the plating on the PCB, and extra care should therefore be taken in PCB design. Consultation with a reliable conductive rubber switch manufacturer, as early in the system design stage as feasible, concerning selection of materials and plating for the PCB will provide benefits by way of long-term dependable performance of the keypad.

Design of PCB Contact Pads for Conductive Rubber Switches. Contact pads on PCBs should be equal to or up to 1.25 times larger than the conductive contact on the rubber key. The minimum distance between contact fingers on the pad and the minimum size of the pad traces should be 0.010 in (0,25 mm). In most cases, the recommended maximum spacing between the fingers on the pad is 0.015 in (0,38 mm). Figure 11.13 depicts some common pad patterns for conductive rubber keypad PCBs. Although no particular pad pattern is recommended by switch manufacturers, the pad pattern selected for a particular application should offer as many *shorting paths* as possible to guarantee switch operation.

FIGURE 11.13 Common pad patterns for conductive rubber switches. (*Courtesy of Shin-Etsu Polymer America, Inc, Union City, Calif.*)

Keypad Colors and Graphics

Keypad Colors. As previously indicated, silicone rubber formulations that begin as translucent or grayish-white material can be easily pigmented for color matching of the basic keypad to a selected color standard. The Pantone color system is commonly used in the industry as one of these standards, and conductive rubber manufacturers can do a remarkable job of matching keypad colors to this

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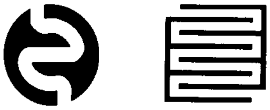

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criterion. Another color standard sometimes used in the rubber keypad industry is the FED-STD-595 system, a government specification developed to standardize color selection for military products, although this is less widely used than the Pantone system. Most conductive rubber switch manufacturers can also match to special color chips provided by the user.

Although it is obvious that the keys of the keypad are usually molded in the same color as the basic keypad, a unique characteristic of the molding process allows individual keys or groups of keys to be color-coded to contrast with or complement the base color or other keys. This feature, when combined with the nearly unlimited graphics capabilities of printed keypads, permits production of keypads which are attractive and easy to operate. This, along with the flexibility of design, color matching capabilities, and cost effectiveness of conductive rubber switches, make them a favored switch technology for industrial designers, particularly for products destined for the consumer marketplace.

Keypad Graphics. Almost all keypad legend and graphics information applied to rubber keypads is *surface printed* (silk-screened) using a special silicone ink that, after curing, becomes permanently bonded to the base silicone rubber material during the manufacturing process. A specially formulated silicone ink is used in the printing process and is a true rubber ink, rather than a paint. Silk screening provides sharply defined graphics, and the process is ideal for keypads containing multiple colors, as each color is applied separately with a different screen.

Once the keypad has been screened with this special ink the keypad is put into a high-temperature oven for curing and bonding of the ink to the keypad. After curing, the ink and keypad are, in effect, "one material," and it is very difficult to remove the graphics from the keypad.

Silk-screen application of graphics successfully meets the needs of most keypad applications, but additional means of extending the durability of graphics life have been developed by conductive rubber manufacturers.

One method, called *overcoating,* involves coating the graphics layer with a translucent silicone ink (providing either a matte or a shiny finish) and curing the overcoat in the same manner as the graphics layer, during which time it becomes, as the graphics layer did, an integral part of the keypad. Overcoating typically doubles the life of silk-screen graphics and is especially useful in applications where the keypad is exposed to very harsh conditions, such as when an operator wears gloves during operation of the keypad or even when the keypad is expected to endure an excessive number of operations (i.e., the ENTER key of a numeric entry keypad). In some cases, two overcoatings may be applied to even further protect the graphics from abrasion. Because of the additional labor involved in applying the overcoating, a keypad with this feature will be more expensive than one without, but the user may decide that the extra cost is worth the security of knowing the graphics are well protected.

A second method of protecting graphics from abrasion is called the *diffusion* process in which the graphics are sublimated *below* the surface of the silicone rubber switch material itself. The depth of this special diffusion printing is typically 0.004 to 0.006 in (0,10 to 0,15 mm) below the top surface of the keypad and typically lasts three to four times longer than silk-screen printing. The abrasion resistance of diffuse printing can be further enhanced by the application of an overcoat similar to that applied over silk-screened graphics layers. However, diffusion printing can be done only on flat keytops and on keys without radii. Additionally, diffusion printing will also require that the keytops be a minimum height, typically 0.275 in (7,0 mm), to allow for the special tooling necessary to perform the diffusion process. Because of this special tooling and the details of the process itself, the user can expect keypad unit price and tooling charges to be higher than the standard silk-screen–overcoat process. If the specifying engineer decides the operating environment of the proposed keypad is harsh enough to justify consideration of diffusion printing, potential switch manufacturers should be questioned about their ability to process diffusion printing (many can't) and their experience with the process. Securing samples of the switch manufacturer's previous *production* processing of diffusion printing can assist the user in determining the quality capabilities of the manufacturer. (1)

To satisfy the demands for an immortal legend for products in constant contact with cloth, gloves, pencil erasers, sharp instruments, dirt, and grit, Conductive Rubber Technology, Bothell, Wash., offers the *engraved printed legend.* The legend, engraved 0.012 in (0,3 mm) below the surface of the key and filled with a contrasting silicone ink, has 100 times the abrasion resistance of the surface printed legend, with a minimum line width of 0.015 in (0,4 mm). Immortality doesn't come cheap, however, as this process costs approximately 50 percent more than surface printing. (5)

Once the graphics process has been decided, it is recommended that the specifying engineer and the switch manufacturer identify an acceptable abrasion test, for inclusion in the switch specification, that the graphics on the keypad can be expected to meet. One abrasion test common in the industry states the number of times the graphic layer will be subjected to back-and-forth rubbing by a rubber eraser and at what force the eraser is applied to the graphics during the test. The acceptance criterion might be that more than 50 percent of the graphics must be visible after the test to be considered successful or that the graphics can still be read under certain lighting conditions, even though faded, after test completion. The point to be emphasized is that the results of an abrasion test can be interpreted in a number of ways and the best time for the supplier and the user to decide on acceptance criteria is when the specification is written, not after the keypad is delivered to the user.

Some examples of abrasion tests included in specifications include:

1. Resistance to abrasion:
   - *a.* *Test:* Rub the printed surface with a plastic eraser under a 17.6-oz (500-g) force.
   - *b.* *Failure criteria:* Graphics cannot be read, from a distance of 18 in (457 mm) under normal office lighting, after 1500 cycles.
2. Resistance to key striking:
   - *a.* *Test:* Strike the keytop with a device approximating the texture and density of the human finger with 7-oz (200-g) force at a rate of 3.5 times per second.
   - *b.* *Failure criteria:* Graphics cannot be read, from a distance of 1 ft (304,8 mm) under normal office lighting, after 500,000 cycles.
3. Resistance to peeling:
   - *a.* *Test:* Apply adhesive tape to printed surface and peel off.
   - *b.* *Failure criteria:* Graphics display any type of peeling prior to 100 applications of the tape test.
4. Resistance to fingerprint liquid:
   - *a.* *Test:* Liberally apply synthetic fingerprint liquid on printed surface and leave for 240 h at 104°F (40°C), 95 percent RH.
   - *b.* *Failure criteria:* Graphics display easily detectable changes in printing quality.

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5. Resistance to ultraviolet rays:
   a. *Test:* Apply 20-W sterilizing ultraviolet ray to printed surface from distance of 6 in (152 mm) for 72 h.
   b. *Failure criteria:* Graphics demonstrate changes from original color when compared with color chip (or with graphics of a nonexposed keypad).

Some basic design suggestions to follow for conductive rubber keypad graphics artwork are:

1. Supply positive image artwork to the switch manufacturer:
   a. If the specifying engineer chooses to supply artwork for keypad graphics to the switch manufacturer, the format for the artwork should be agreed upon beforehand. Normally, switch manufacturers request positive image artwork, but it is always best to check with the selected manufacturer.
   b. If the specifying engineer prefers that the switch manufacturer supply final artwork for the graphics, the engineer should specify preferences for font style, print style, and print size, and should *always* insist on artwork review and sign-off prior to any production parts being supplied.
2. Finalize artwork for the keypad before production tooling has been completed:
   a. Artwork charges (if done by the manufacturer) and silk-screen charges are always part of the original tooling charges quoted.
   b. Any and all changes in artwork will require new and additional silk screens, translating to additional tooling charges. (1)

Figure 11.14 depicts the various limitations, tolerances, and spacings required to silk-screen graphics on rubber keypads.

Recommended Design Dimensions

Figure 11.15 depicts recommended design dimensions standard for the conductive rubber industry. Deviations from these dimensions and the tolerances shown in Table 11.2 should be discussed with potential switch suppliers as early in the design phase as possible.

Backlighting. Conductive rubber keypads can be backlighted in a number of ways, the most common being that depicted in Fig. 11.16*a, b* and *c.* LEDs (radial lead, formed and surface mounted) are frequently used to achieve backlighting because of their low operating temperature and relatively small size.

Diffused backlighting can be achieved only by using translucent silicone rubber (refer to Table 11.3) and a light pipe or by using the base material of the keypad itself as a light pipe (Fig. 11.16*c*). Regardless, it must be remembered that conductive rubber keys cannot be screened or printed on the sides, so light will escape from the side of the key as well as be emitted from the top surface of the switch. A small number of conductive rubber manufacturers have developed methods of spraying opaque silicone inks on the sides of keys to block light in this manner, but the additional cost is significant.

Both positive image and negative image legends can be backlit when translucent material is used for the keypad's construction. Attention to the following notes will help the specifying engineer achieve the best results:

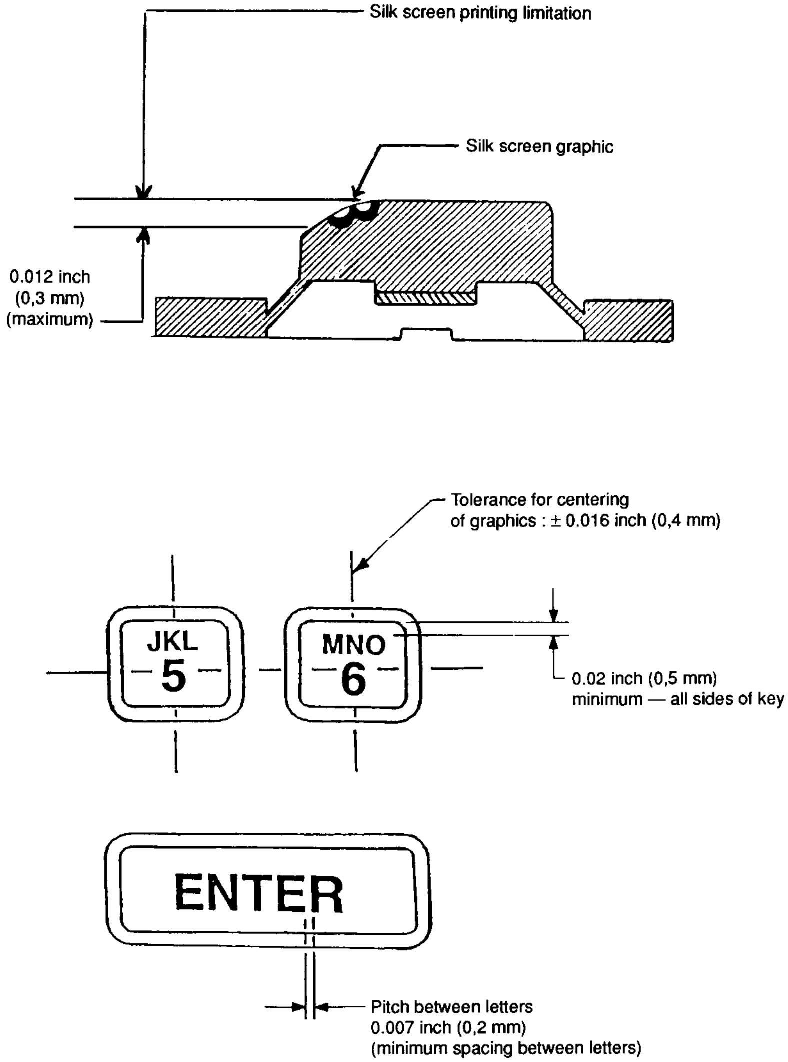
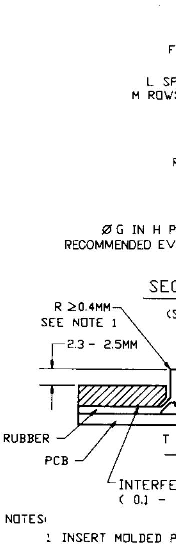


FIGURE 11.14 Limitations, tolerances, and spacing for graphics on rubber keypads. (*Courtesy of Glolite Sales, Ltd., Pauls Valley, Okla.*)

- The bottom of the base material of the keypad can be screened white to enhance backlighting capabilities. If the bottom of the keypad is screened white, no light will be lost to the PCB.
- Discuss with the manufacturer any additional costs in having the conductive pill silk-screened white prior to molding. This is done so that no dark spots or shadows appear during backlighting.



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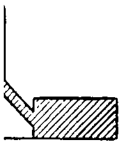

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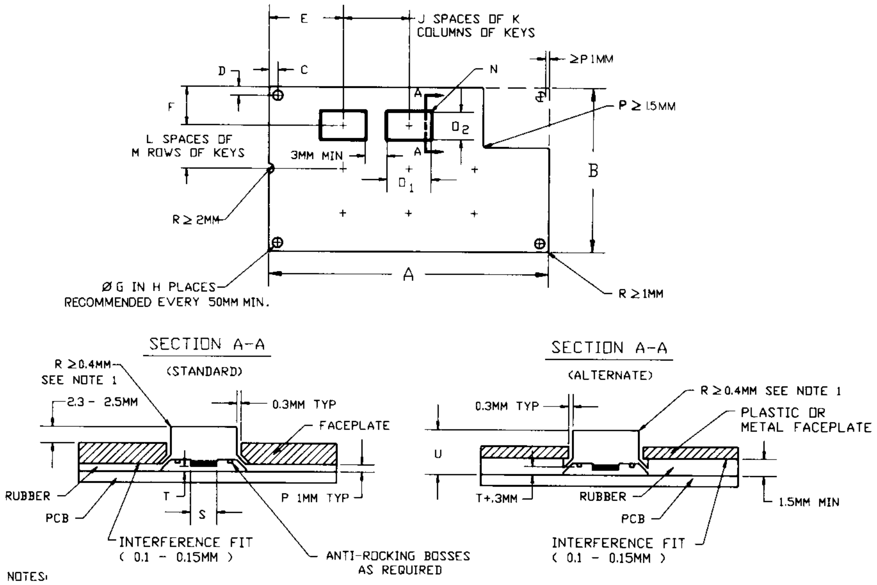

NOTES:
1 INSERT MOLDED PRINTING REQUIRES R=0MM.

FIGURE 11.15 Standardized design dimensions for conductive rubber switches. (*Courtesy of Conductive Rubber Technology, Inc., Bothell, Wash.*)

- Discuss adding a small amount of white diffuser material to the base translucent material to prevent hot spots during backlighting, particularly if using individual lamps as the light source. (1)

Additional methods of backlighting include EL (electroluminescent) lamps and woven fiber-optic lamps. These methods are discussed further in Chap. 10.

GLOSSARY

Actuation force. The minimum force required to compress the membrane web of the conductive rubber switch so that contact is made with the PCB. Generally, larger keys require higher actuation forces than small keys.

Air channel. Air path from key to key or to the outside of the keypad which allows the keys to "breathe" and return to normal position after actuation. Keys should be vented to each other and not to the outside if the keypad needs to be watertight.

Alignment hole. A hole in the rubber keypad that is used for aligning keypads that are typically more than 3 in (76,2 mm) in length. The alignment holes mate with pins protruding from the rear of the bezel.

Base. The silicone sheet material that forms the apron of the keypad which joins all keys together.

Bezel. The faceplate, typically made of plastic or metal, that covers a keypad.

Conductive contact (conductive puck, conductive pill). The current-carrying contact, manufactured from silicone rubber impregnated with amorphous carbon, permanently

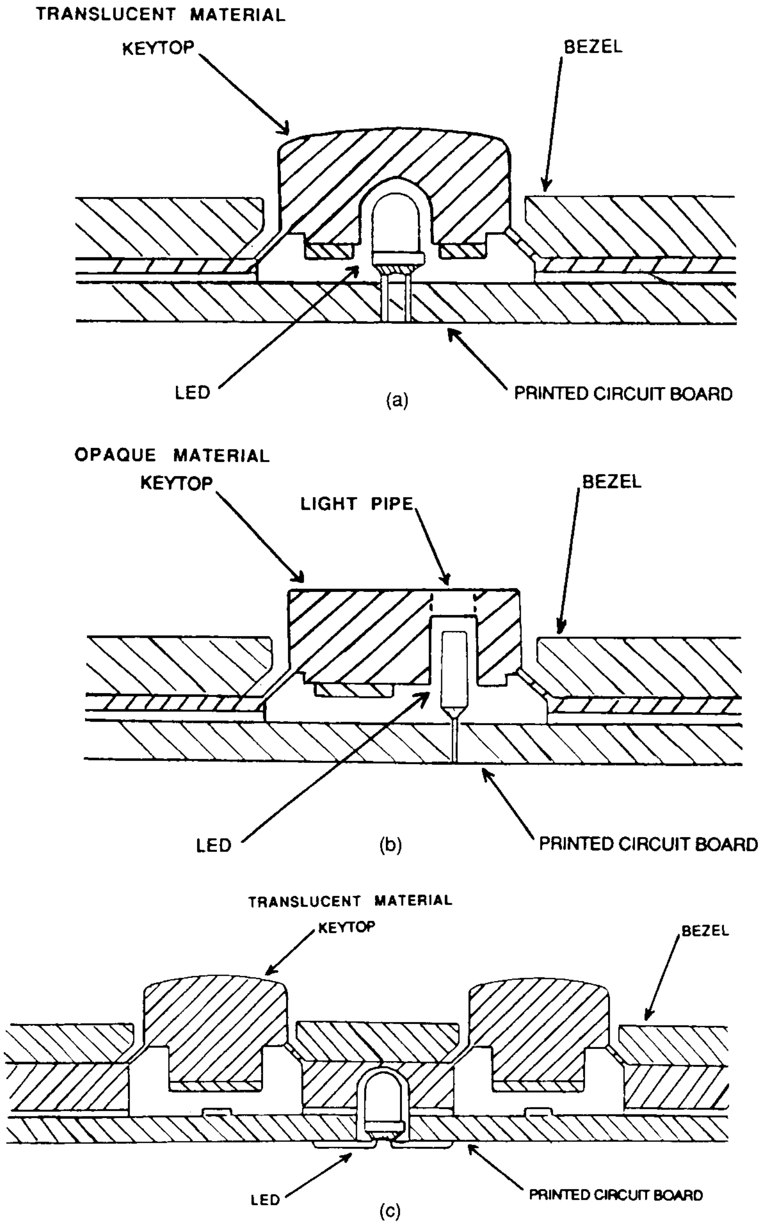

FIGURE 11.16 Typical conductive rubber backlighting techniques: (*a*) Centralized lamp, (*b*) lamp under light pipe, and (*c*) indirect lighting. (*Courtesy of Glolite Sales, Ltd., Pauls Valley, Okla.*)

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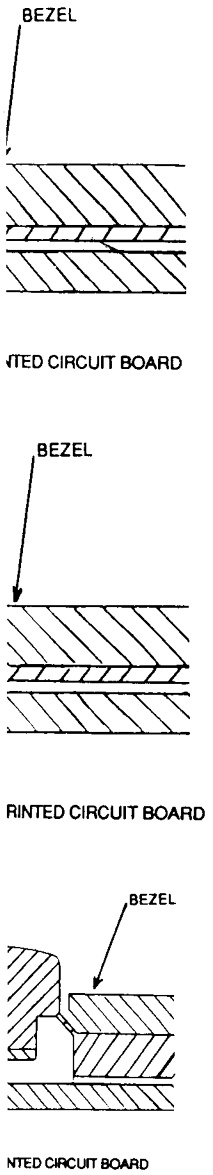

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molded into the basic keypad rubber at each key location. Usually produced in a cylindrical shape, the conductive contact completes electrical connection with the PCB when the keytop is actuated.

Contact force. The force a switch typically realizes when contact is made with the PCB.

Contact resistance. The resistance realized between the surface of the conductive contact of the switch and the contact pad on the PCB when the switch is actuated.

Durometer. A measurement of the hardness of rubber materials. The higher the durometer reading, the harder the rubber.

Membrane web. The nonconductive skirt attached between the key and the apron of a conductive rubber switch which provides the tactile feel and stroke characteristics of the switch. The membrane web shape is always designed by the manufacturer to provide the stroke, actuation force, and return force required by the switch specification.

Mounting boss. An alignment feature that is molded on the bottom of a keypad to help align the keypad with its PCB at assembly.

Return force. The force a switch typically realizes after contact has been made with the PCB.

Snap ratio. The difference between the actuation force (F_1) of a switch and the contact force (F_2) of the same switch divided by the actuation force (F_1):

$$\frac{F_1 - F_2}{F_1}$$

Snap ratio is important since it has direct influence on tactile feel and the life of the keypad.
Tactile feel
A subjective term used to describe the perceived response of a conductive rubber switch during actuation travel and at switch contact. In conductive rubber switches, tactile feel is controlled by the shape and thickness of the membrane web of each switch position and is the most critical process in manufacturing rubber keypads.

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