CONSTRUCTION OF VACUUM-FORMED CONTROL AND DISPLAY MOCKUP PANELS

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FOREWORD

This report was prepared by the International Business Machines (IBM) Corporation, Electronics Systems Center, Owego, New York, under Contract No. AF 33(615)-3739, Project No. 7184, "Human Performance in Advanced Systems," Task No. 718404, "Advanced Systems Human Engineering Design Criteria," between March and July 1966. Claude V. Deats and Gunnar Nielsen were the principal investigators for the IBM Corporation. The task is administered for the 6570th Aerospace Medical Research Laboratories by Charles Bates, Jr. Steve A. Heckart, Performance Requirements Branch, Human Engineering Division, Behavioral Sciences Laboratory, served as contract monitor.

This technical report has been reviewed and is approved.

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ABSTRACT

This report describes a process for vacuum-forming thin sheets of plastic material into control and display panel mockups. The description includes techniques for fabricating controls and annunciators plus requirements for drawings, tools, equipment, and materials. The vacuum-forming process, which is well established in the plastics industry for fabricating parts in large quantities, is fast and inexpensive. In this report, the fabrication of a typical mock-up panel is used to illustrate the vacuum-forming process.

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INTRODUCTION

This report describes a process for vacuum-forming thin sheets of plastic material into control and display panel mockups. The vacuum-forming process has been used to produce control console mockups for aircraft and space capsule crew stations, with control panels ranging in size from 1 by 5 3/4 inches to 12 by 12 inches. A typical mockup is shown in figure 1 and an assortment of panels is shown in figure 2. A step-by-step process for vacuum forming a mockup panel is shown in the Appendix.

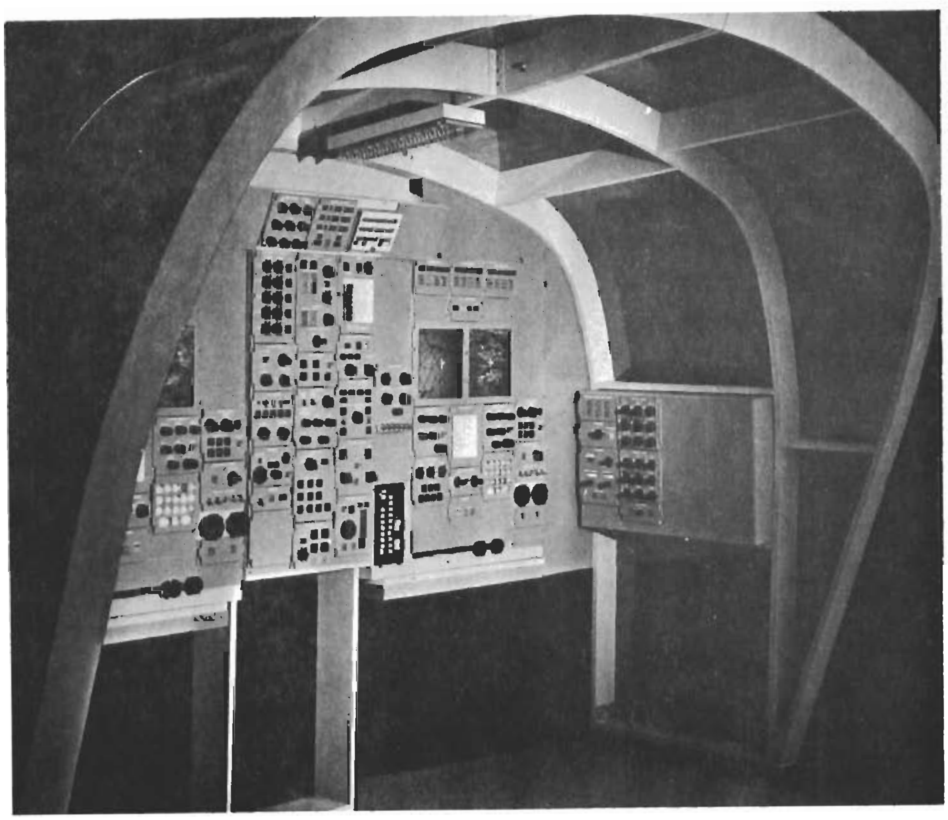


Figure 1. Typical Mockup

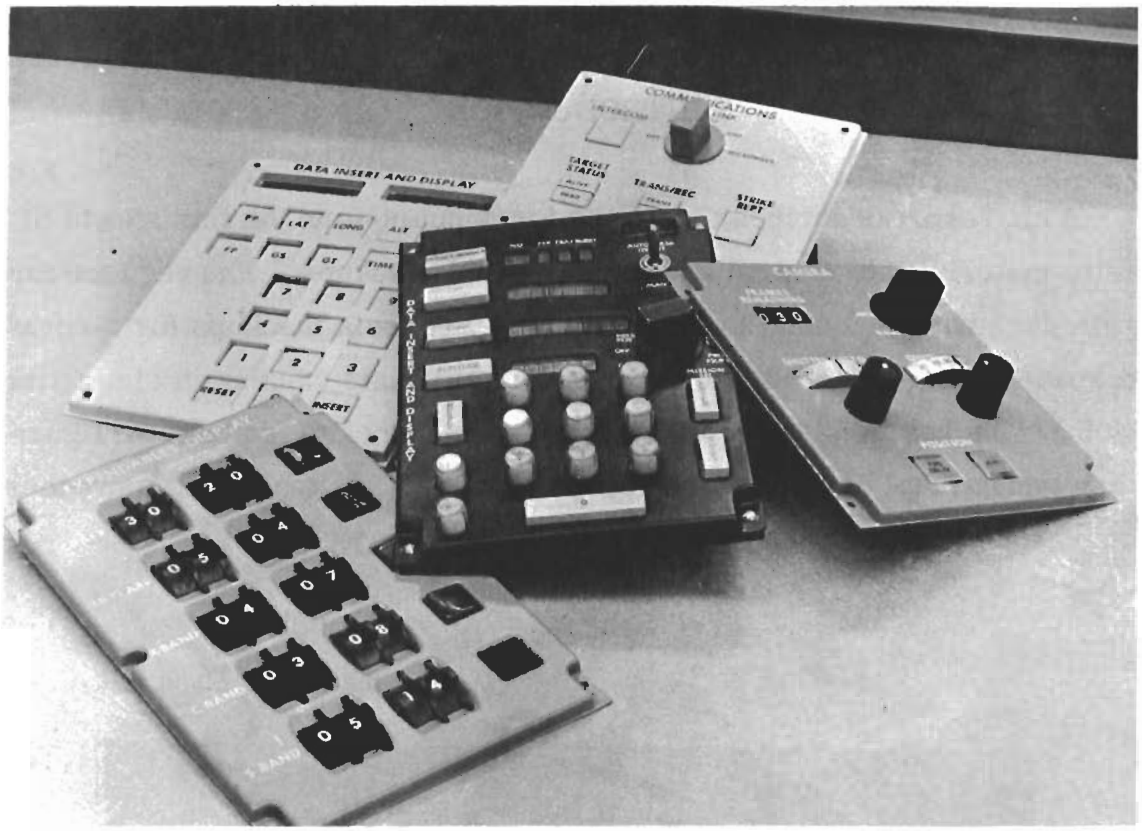


Figure 2. Panel Assortment

Section II

PROCESS DESCRIPTION

1. USE

The development of control consoles or similar equipment requires an integrated effort by several groups such as System Engineering, Human Factors, and Packaging Engineering. During the early stages of a development program, the equipment is developed using sketches, drawings, paste-ups, magnetic mockups, etc. At some time in the program, it is desirable to see the actual equipment. It is then that the vacuum-forming process can be used to produce a three-dimensional mockup at a nominal expenditure of time and money.

The schedule for a development program normally allocates very limited time for fabricating a mockup. Consequently, the fabrication process must be simple. Every possible shortcut should be utilized, and as few people as possible should be involved in the process.

2. FEATURES AND LIMITATIONS

Vacuum-formed panels offer advantages in each of the following areas which should be considered when building a mockup:

- Details that can be shown
- Realistic appearance
- Fabrication time
- Cost.

The simplest plastic mockup is one that conveys a three-dimensional concept under static conditions. Such a mockup can be used as a model for photographing and for demonstrating space allocation. In some cases it is desirable to have an operator perform certain operations on the mockup for time-line analysis. For these purposes, such features as operable controls can be included. These features will also help to introduce realism into the mockup. Further sophistication can be obtained by adding annunciators and indicator lamps that light when appropriate controls are operated. The vacuum-formed panels can be readily adapted to include these features.

The vacuum-formed panels look real, which often leads to commitments for panels that are expected to have more capabilities than they should. This situation should and can be avoided by remembering that a static, three-dimensional mockup is the initial intent.

3. BASIC PROCESS

The first step in the vacuum-forming process is to prepare plywood or masonite molds of the panels and controls. The panels and controls are then vacuum-formed over molds using transparent or opaque plastic sheets. Following this operation, the molded pieces are trimmed to size and the desired holes and cutouts are made. Press-on lettering can be used for labels on the panels and annunciators. Lights and switches are then mounted on the panels, and the desired wiring is installed. At this stage, the panels are not rigid; therefore, they must be mounted on individual backer plates or an overall console plate to provide additional stiffness and support. The only special equipment required for this process is the vacuum-forming machine, and the only special material is the plastic.

4. VACUUM-FORMING EQUIPMENT

Clamping, heating, and applying the vacuum are the major operations in a vacuum-forming process. The plastic sheet, which is relatively rigid at room temperatures, is clamped along its edges in a clamping frame and then heated until it becomes soft and pliable The mold and heated plastic are then brought into contact and some initial draping takes place.

To completely shape the plastic to the mold, additional forces are required. These forces are obtained by supplying a vacuum to each cavity in the mold. The vacuum is supplied by a vacuum pump through a storage tank that is connected to the vacuum platen on which the mold is fastened.

The plastic is heated to the correct temperature by a heater which is normally controlled by a timer. If the plastic is heated too much, it becomes too soft and uncontrollable. Whereas, if the plastic is not heated enough, it is too stiff and is not capable of taking the desired form. Factors influencing the required heating time are the size of the heating element, thickness and type of plastic, and to some extent, the color and surface finish of the plastic.

Suitable equipment can be built, or commercial equipment with a wide range of features and conveniences can be purchased. When purchasing equipment, the factors to consider are convenience, size,and production rate. Several machines are available that are specially designed for general purpose use such as sample and pilot runs. These are small machines with work areas of about 10 to 12 inches square and with timer control. These machines are well suited for the type of panels and controls considered in this report.

Larger machines with adjustable platens, compressed air assistance, larger mold depth accommodation, and heated mold provisions contain features that are not utilized for panel fabrication. These machines are more complicated to set up. They also use more raw material and require more time to perform a given small job.

A typical machine for vacuum-forming panels is shown in figure 3. The operator in this photograph is attaching the mold for a test panel onto the platen. The machine, which cost approximately $800, has a 12- by 12-inch platen, accepts 13- by 13-inch plastic sheets, and has automatic resetable timers for controlling the heating and vacuum cycles.

5. PLASTIC MATERIAL

Two basic materials have been used almost exclusively for fabricating mockup panels. Opaque parts are made of·styrene (polystyrene) and transparent parts of rigid vinyl (polyvinyl chloride). Both of these plastics are thermoplastics, i.e., plastic materials that retain their ability to be repeatedly formed by pressure and heat.

The plastic is normally available in 3- by 6-foot sheets in a wide range of thicknesses. High impact and super high impact grades of styrene are stronger and form easier than medium impact grades, but the cost is slightly higher. Tables I and II show typical commercial catalog information for styrene and vinyl respectively.

Thicknesses of 0.040 inch can be used in most cases. If additional rigidity is required or if there are many closely spaced cavities, thicker material such as 0.060 inch will be required. Small parts such as windows, pilot lights, etc. may be made from 0.020- to 0.030-inch thick material. The governing factor is the ratio of original surface area to final surface area. For 0.030-inch thick material, a ratio of 2:1 will produce an average finished thickness of 0.015-inch. In some cases, the final thicknesses in some areas might be only 0.003-inch,but further reduction in the thickness usually results in the plastic rupturing.

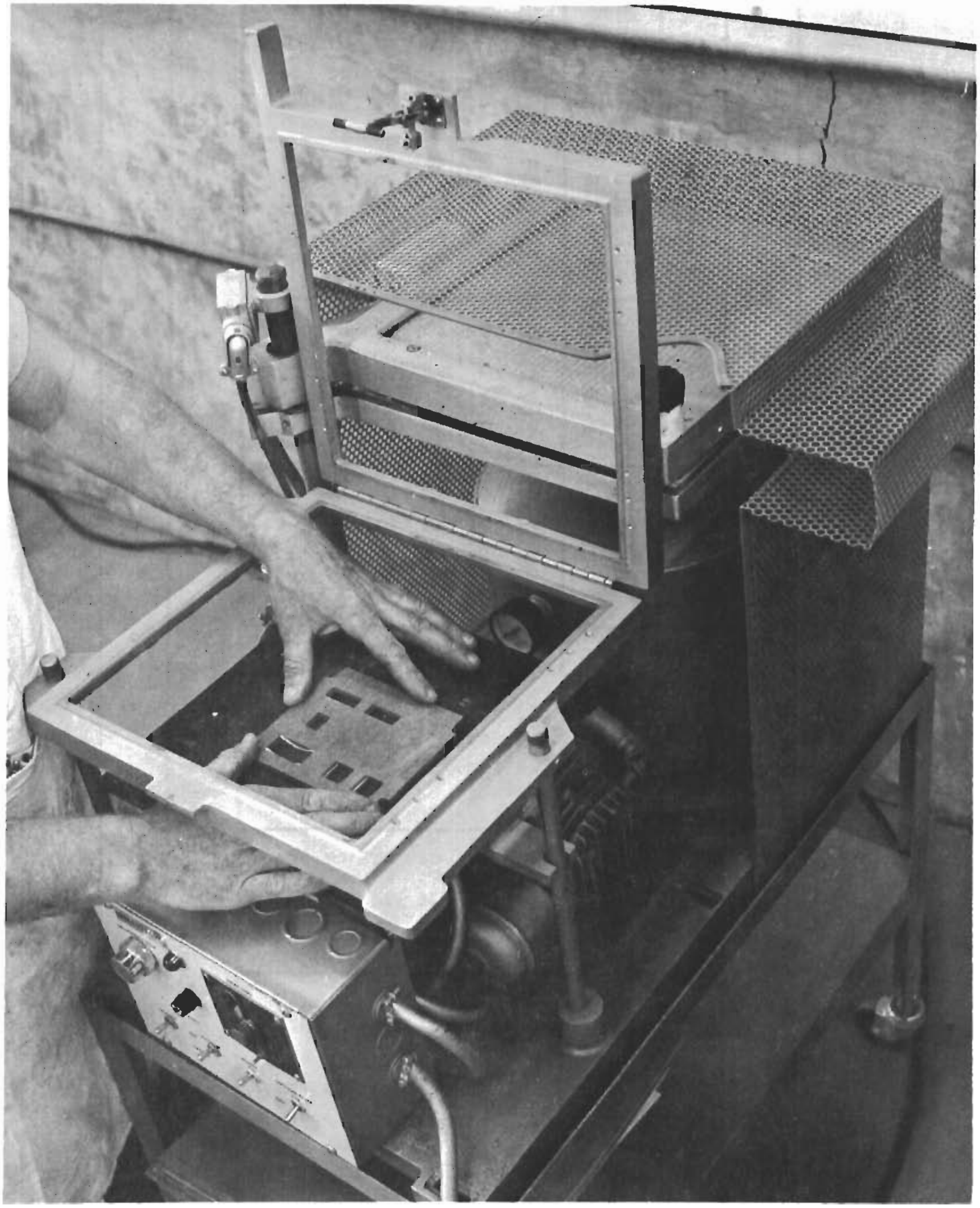


Figure 3. Vacuum-Forming Machine (Mold Being Mounted)

Table I

TYPICAL CATALOG INFORMATION FOR POLYSTYRENE

Thickness (inches)	Weight per Foot (pounds)	Size (inches)	Sheet Weight (pounds)	Price per Pound/per Sheet			
				1-25 Pounds	26-50 Pounds	51-200 Pounds	201-500 Pounds
0.020	0.09	36 x 72	2	$.96/1.92	$.80/1.60	$.77/1.54	$.72/1.44
0.030	0.172	36 x 72	3.11	.96/2.99	.80/2.49	.77/2.33	.72/2.24
0.040	0.230	36 x 72	4.15	.96/3.98	.80/3.32	.77/3.20	.72/2.99
0.060	0.345	36 x 72	6.22	.96/5.97	.80/4.97	.77/4.79	.72/4.48
0.080	0.460	36 x 72	8.29	.96/7.96	.80/6.63	.77/6.38	.72/5.96
0.125	0.720	36 x 72	12.96	.96/12.44	.80/10.37	.77/9.97	.72/9.33

Colors available: White, Translucent, White Opaque, and Natural.

Table II

TYPICAL CATALOG INFORMATION FOR POLYVINYL

Thickness (inches)	Price per Sheet						
	1 to 24 Sheets	25 to 49 Sheets	50 to 149 Sheets	150 to 199 Sheets	200 to 999 Sheets	1000 to 4999 Sheets	5000 and Over Sheets
0.020	$ 4.26	$ 3.91	$ 3.57	$ 3.34	$ 3.22	$ 2.88	$ 2.76
0.025	5.37	4.93	4.50	4.21	4.06	3.63	3.48
0.032	6.36	5.85	5.33	4.99	4.82	4.30	4.13
0.040	7.77	7.14	6.51	6.09	5.88	5.25	5.04
0.050	10.18	9.35	8.53	7.98	7.70	6.88	6.60
0.060	11.84	10.88	9.92	9.28	8.96	8.00	7.68
0.080	15.73	14.45	13.18	12.33	11.90	10.63	10.20
0.100	19.70	18.11	16.51	15.44	14.91	13.31	12.78
0.125	24.79	22.78	20.77	19.43	18.76	16.75	16.08

Clear — Special Size 36 x 72 Inches

For economy, opaque plastic material may be purchased in the natural gray color. Other colors are obtained by painting the part with a lacquer-base paint after forming and trimming. Colorless transparent plastic is purchased, and felt-tipped markers are used to color the back side of the formed parts. Both types of materials are readily available from plastic supply firms. The McGraw-Hill Book Company, Incorporated, publishes an encyclopedia, "Modern Plastics Encyclopedia," that is an excellent source for information on plastic materials and machinery. The same company also publishes a trade magazine, "Modern Plastics."

Section III

FABRICATION OF A SAMPLE PANEL

The panel shown in figure 4 was selected as an average sized representative panel. It has four small and two large indicator lamps, two annunciators, two toggle switches, one rocker switch, one seven-position selector switch, and two push-button switches. The panel in figure 4 is fastened with four screws to an individual backer plate. The recessed areas at the corners are convenient for mounting screws and also help to give the panel a more realistic look.

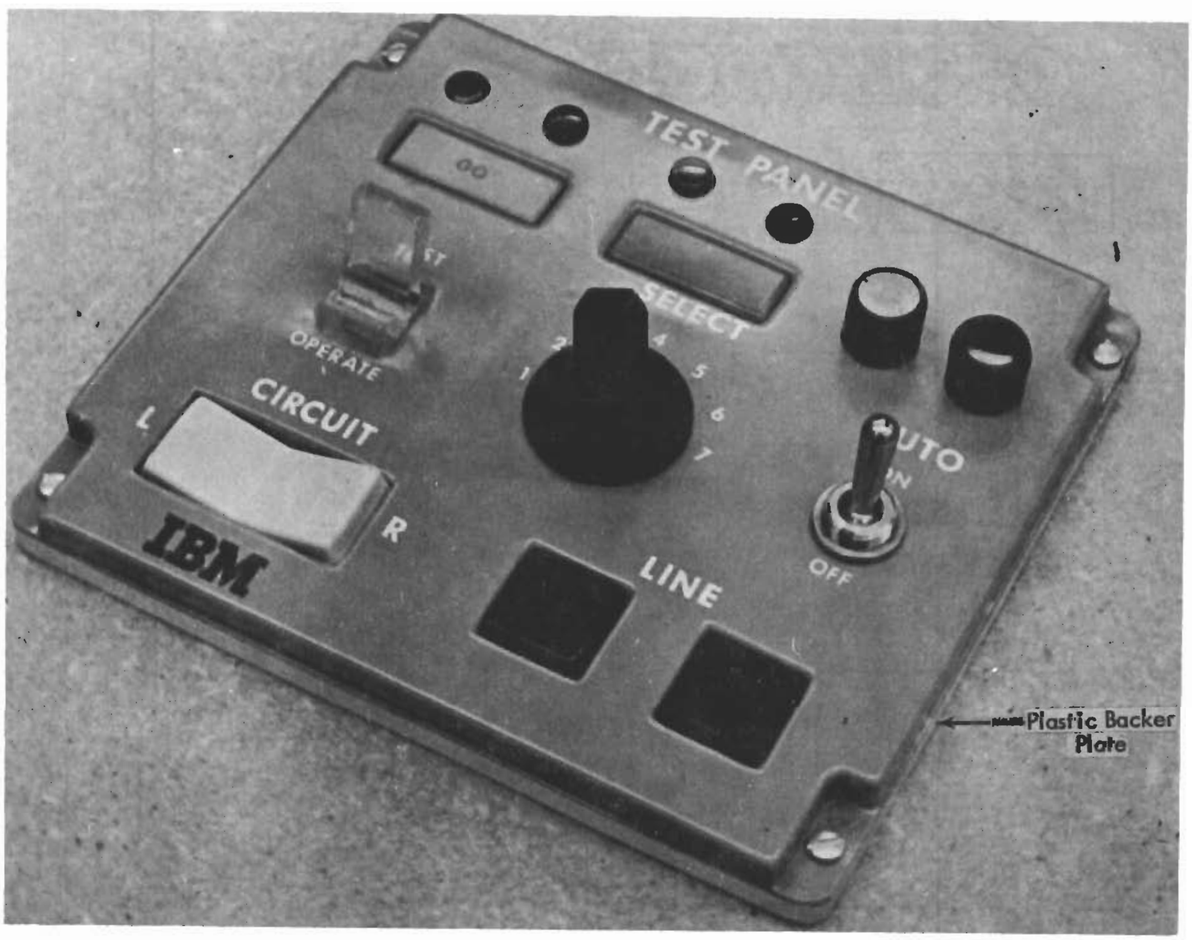


Figure 4. Test Panel with Plastic Backer Plate

1. ENGINEERING SKETCH

The first step in the vacuum-forming process is to prepare an engineering sketch (see figure 5) showing the requirements for the panel. This sketch should include the following information:

- Description and approximate location of each control
- Labels to be included on the panel and controls
- Color and opaqueness of the plastic material
- Illumination requirements (where and when).

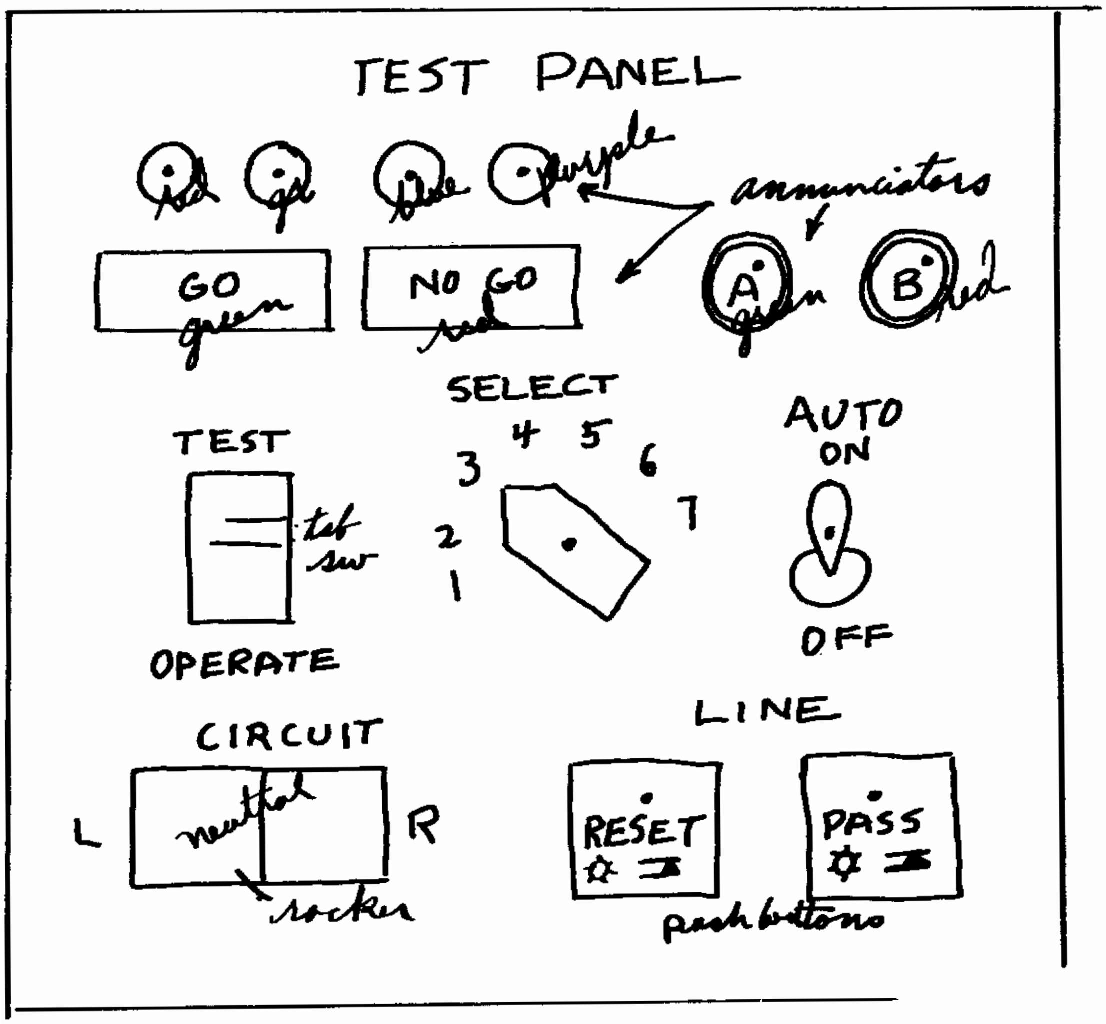


Figure 5. Engineering Sketch

Several schemes for presenting this information on the preliminary sketch are possible; however, the most expedient method seems to be simply to specify the information as shown in figure 5. The following ground rules were used to prepare this sketch:

- The labeling is depicted by printed letters in the approximate desired location.
- The color is handwritten on each control and in a corner of the panel.
- The control type is handwritten next to each control. For toggle and rotary switches, the illustration will suffice.
- A heavy dot indicates the control must be operable.
- An illuminated control is denoted by a symbol for a small light bulb.
- A switch contact is depicted by a symbol for an electrical contact.

The wiring within the individual panels and within the overall mockup is specified on a separate schematic diagram or other document. This wiring is not an essential part of the panel fabrication process.

In some cases all of the information listed here will not be available when the panel fabrication is started. However, the process can be started as soon as the controls and their location have been established. Details such as colors and labeling can be added later.

2. SCALE DRAWING

On the basis of the engineering sketch just described, a person experienced in fabricating displays and controls prepares a full-scale layout of the panel as shown in figure 6. This drawing is a front view of the panel

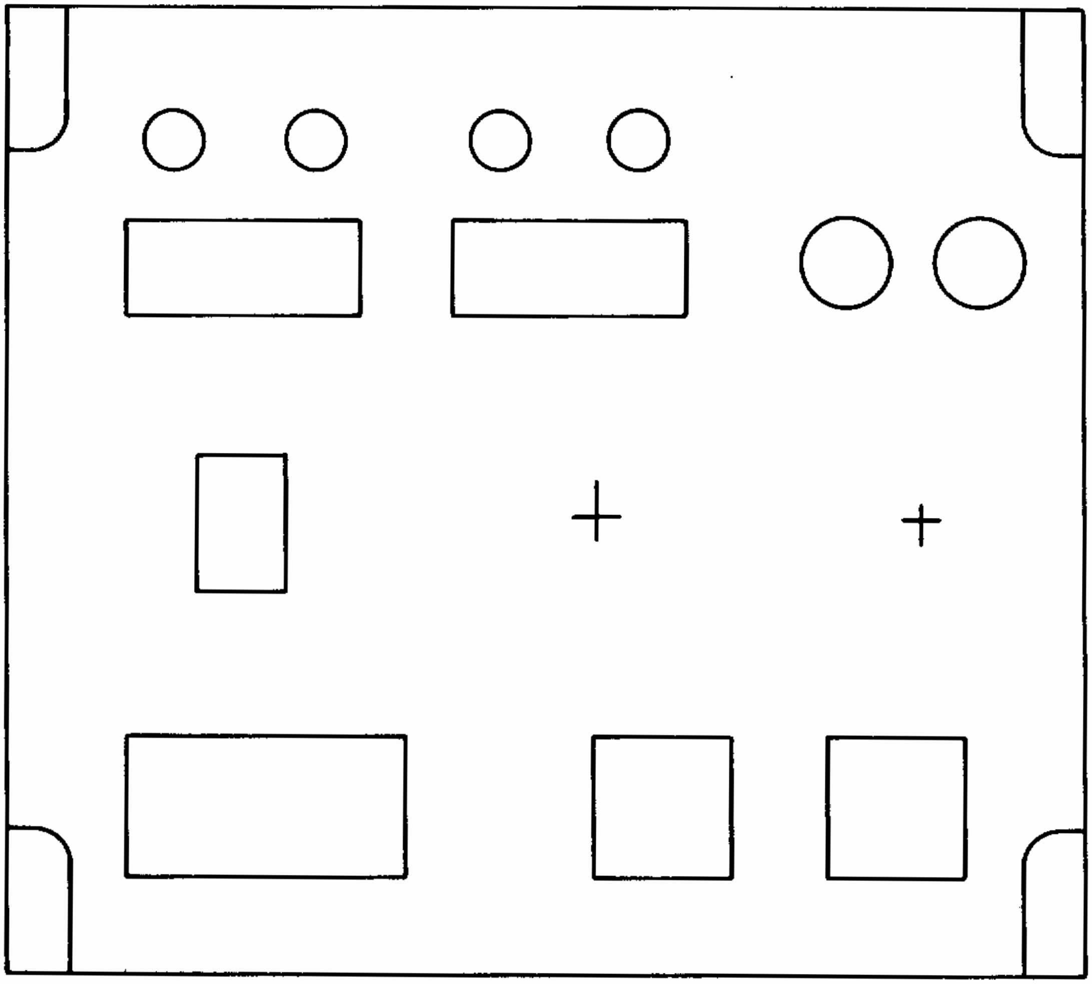


Figure 6. Full-Scale Layout

showing the overall size plus the sizes and locations of all controls. The following advantages result from drawing the panel full scale:

- A copy of the drawing can serve as a cutting guide by pasting it directly onto the mold material. This eliminates the need for layout work by the shop.

- The lettering sizes and locations can be established on a print of the panel. This aids in achieving the proper balance and distribution.

- No dimensions are required on the drawing. All measurements are in fractions to the nearest 1/16 inch, so scaling of the drawing is very simple.

After a sufficient number of copies of the layout drawing (figure 6) have been obtained, the drawing is completed by adding lettering, knobs, switches, etc. as shown in figure 7. A copy of this drawing should be approved by the originator of the engineering sketch before parts are ordered.

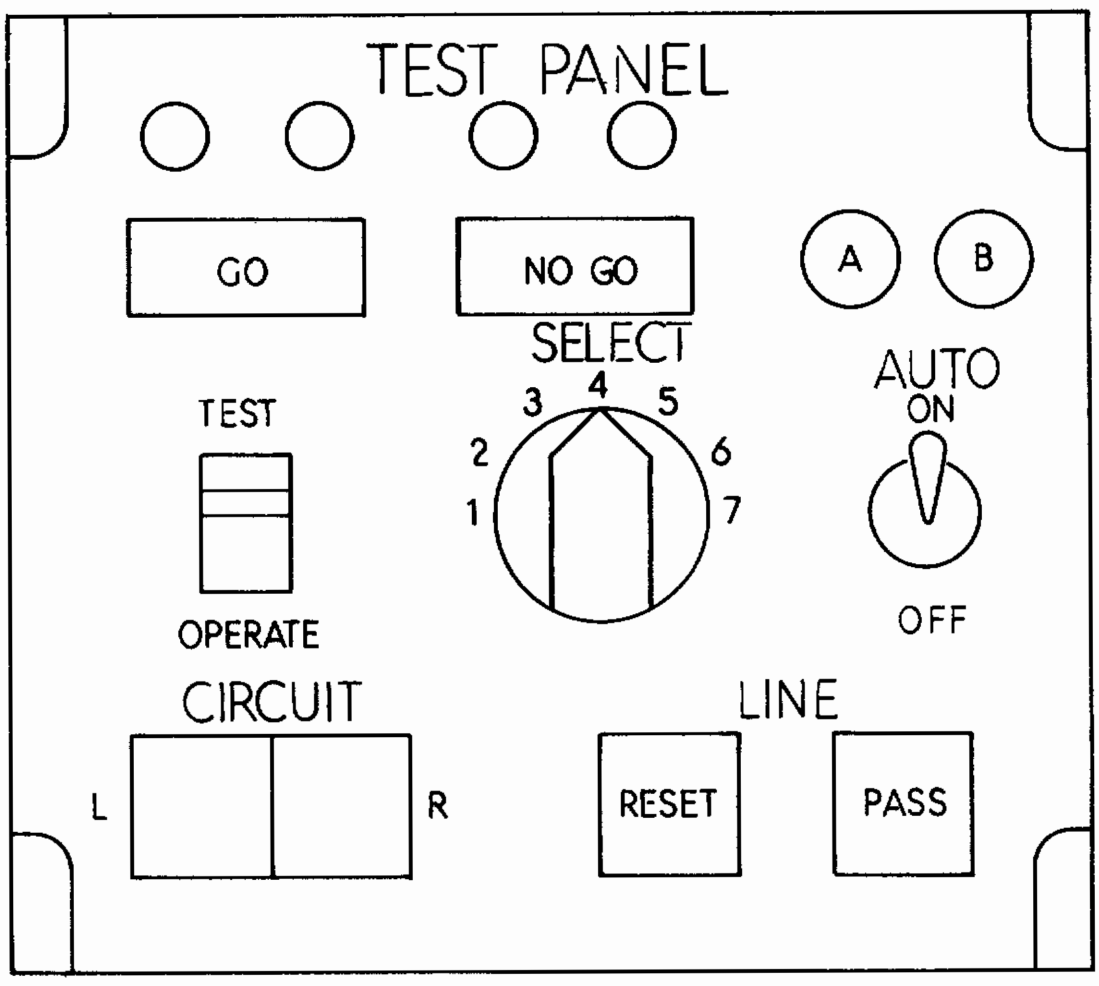


Figure 7. Complete Panel Drawn to Scale

3. MOLD FABRICATION

a. Mold

Panels molded to 1/4-inch depths have been realistic looking and have not been difficult to vacuum form. Since only a few panels are normally required, the molds should be designed to be as quick and economical to produce as possible. Extremely detailed molds cannot be justified unless production runs are to be made.

The mold for the sample test panel is shown in figure 8. This mold is made of tempered Masonite. Plywood can be used for molds, but it has a tendency to produce a chipped edge when fast and rough cuts are made. Also, the grain pattern of the plywood will sometimes transfer to the plastic, producing an undesired texture. If an extremely smooth-finished part such as a clear window is desired, plexiglass is recommended for the mold. Plexiglass is more expensive than the other materials mentioned and requires additional care to eliminate surface flaws.

The first step in fabricating the mold is to cement a drawing of the panel layout onto the smooth surface of a sheet of 1/4-inch Masonite. Double-faced tape or white cement have proved satisfactory for this purpose.

The next step is to cut the outline of the panel and the openings for the controls in the mold material, following the lines of the layout drawing. The final size of the panel and the openings can be varied slightly, depending on how accurately the lines are followed. The panel will be oversize if the drawing line is left after the cut and undersize if the drawing line is completely cut away. The centers of any round holes to be cut in the plastic after forming are marked with a center punch; the center punch mark will be transferred to the plastic.

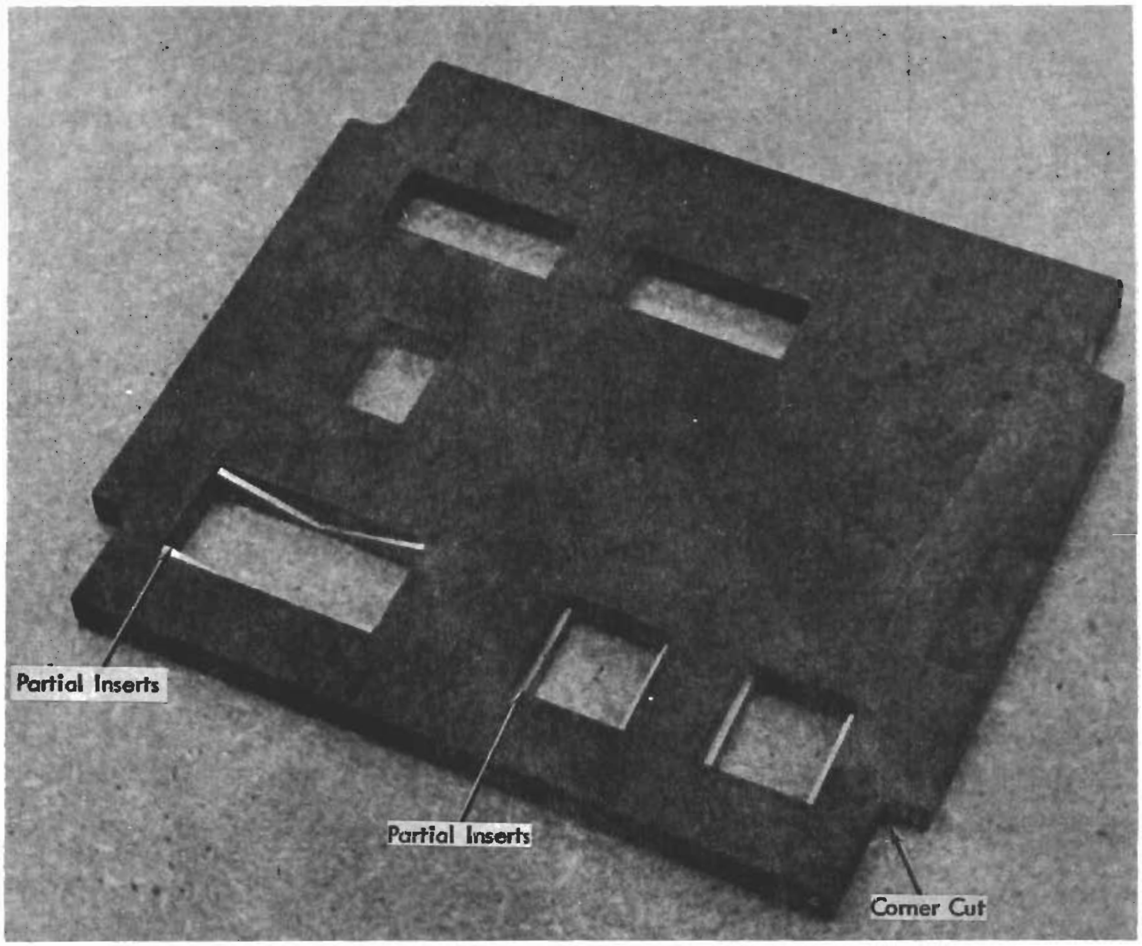


Figure 8. Test Panel Mold

Openings for the controls can be cut with common shop tools such as drill presses, jig saws, band saws, sabre saws, punch presses, or milling machines. The cut surfaces are smoothed with sandpaper or a file, and the edges are left sharp. Note that the mold represents the inside of the panel and that the minimum radius of an outside edge on a final panel will be roughly equal to the thickness of the plastic material. This turns out to be a desirable radius that gives the panel a finished look.

For some panels, the full 1/4-inch molding depth is not desired in all openings or in part of an opening. Different depths can be obtained by either cutting the full openings through the material and then cementing partial or thinner inserts back into the openings or by machining to the desired depth. Partial inserts are shown in figure 8. These inserts serve as a cutting guide for openings to be cut in the plastic to retain the pushbutton. In this panel, the insert is made of aluminum.

b. Bleed Holes

Depressions in the panel are formed by the vacuum that is applied to each cavity through a small bleed hole in the mold. For full depth cavities, the holes in the platen are sufficient. For partial depth cavities, usually one bleed hole is sufficient for each cavity. The bleed holes should be drilled near the corners of the cavities and should be approximately 0.30 to 0.50 inch in diameter. If a bleed hole is located on an otherwise flat surface, a small "pimple" will be formed on the back of the panel and a small depression will be visible on the front.

4. VACUUM FORMING

The most important factor in the vacuum-forming process is having the plastic heated to the proper temperature (200° to 250°F), depending on the material). It is very difficult to measure the temperature of a sheet of plastic suspended in a clamping frame. Therefore, the temperature is not measured. Instead, the plastic is exposed to a uniform heat source for a controlled length of time. To achieve uniform results, the heating element is raised to its stabilized temperature by preheating it for about 15 minutes. This time is dependent upon the equipment used.

The vacuum platen is a flat plate having a series of small holes connecting to the vacuum source. In most cases the mold will not completely cover the platen. The platen holes that are not covered by the mold must be blocked off with some material such as plastic adhesive tape.

The mold can be laid directly on the platen. However, if several parts are to be molded, it is more convenient to fasten the mold to the platen with a few strips of double-faced tape. The bleed holes and openings in the mold should not be covered by this tape. The platen presses the mold in a perpendicular direction against the plastic, so that forces that might tend to shift the mold horizontally are minimized.

The mold should be sprayed with a release agent. In many cases this is not required; however, it is a simple operation that provides a safeguard against overheated plastic sticking to the mold. Good results have been obtained with Fluorocarbon No. 122. This release agent is available in aerosol cans. A light coating of the release agent can be sprayed on the mold when it is made or at the time it is used. It is not necessary to spray the mold after each cycle — the release agent remains effective for several cycles.

Commercial vacuum-forming machines are designed to accept a blank sheet of plastic of a certain size. The sheet must be clamped along all four sides as shown in figure 9. Improper clamping will result in wrinkles and distortions. To conserve material, a small panel can sometimes be molded from an undersize sheet clamped only on three sides or possibly two opposite sides. A nominal degree of success has been achieved using this technique. A better technique is to fit more than one panel on the platen at one time, thereby achieving full utilization of each blank.

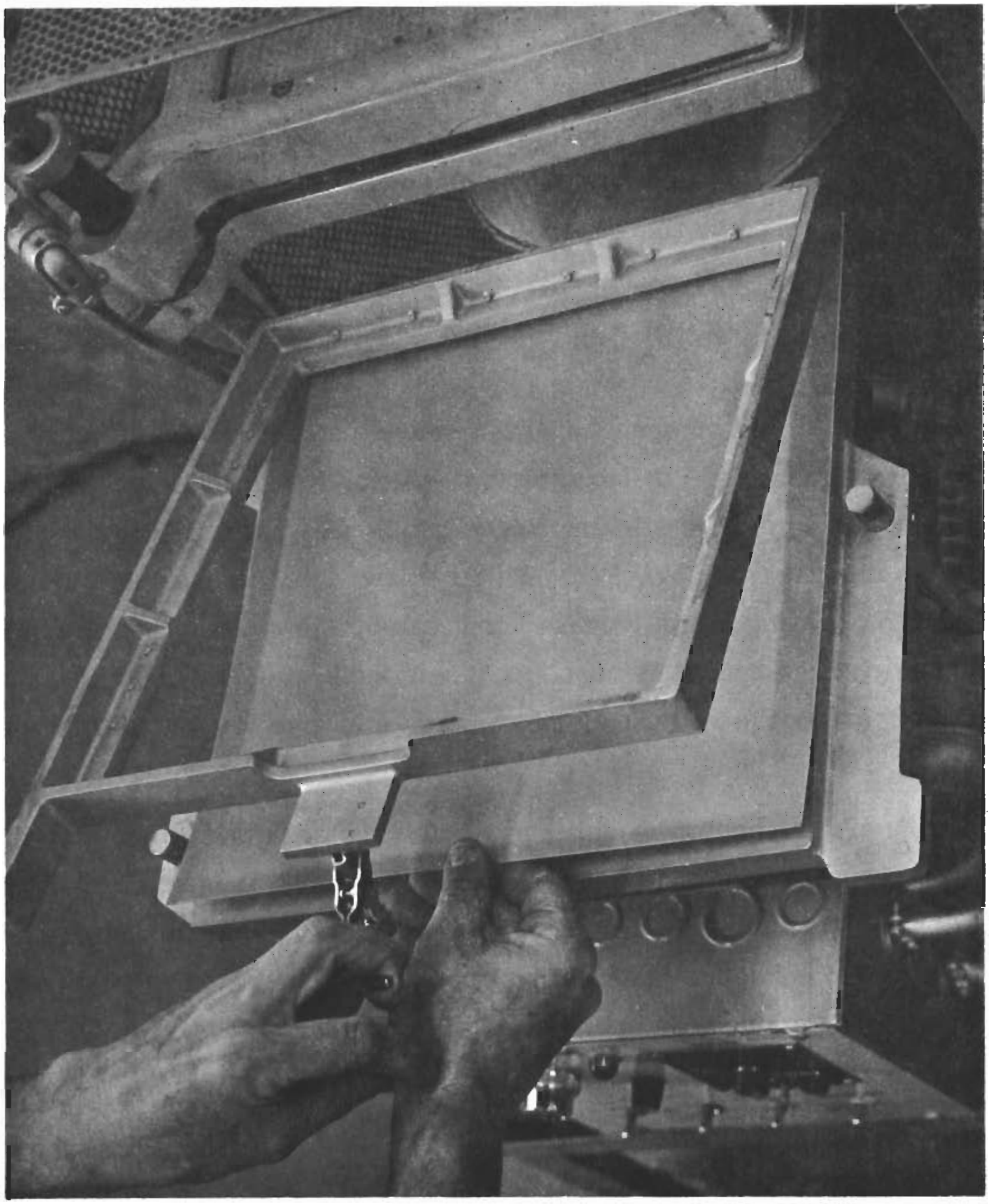


Figure 9. Blank Plastic Sheet Being Clamped into the Machine

In most vacuum-forming machines the automatic timer starts when the heater is brought into position over the plastic. After the prescribed time has elapsed, either a bell sounds and the operator takes over or the remaining steps are performed automatically. The required time is set into the timer by the operator after a few trial runs. Typical times are as follows:

Plastic Sheet	Typical Heating Time (seconds)
Vinyl, 0.030 inch	20
Styrene, 0.040 inch	25
Styrene, 0.060 inch	35

Normally the heater is mounted on a two-position swinging gate, such as is shown in figure 10. or on a sliding carriage. The heater has two positions, one aligned over the clamping frame and the other stored out of the way. When the heater is moved into position over the plastic, it actuates a switch which starts the heater timer. As the plastic is heated, it will start to deform and buckle. When the plastic reaches the proper temperature, the buckles will disappear, and the plastic will have sagged to a smooth curve.

At the end of the prescribed heating time, the heater is returned to its stored position. It is not enough to simply turn the heater off. The heat remaining in the heating element is more than sufficient to melt the plastic; therefore, it is important to remove all the heat inertia by returning the heater to its stored position. On automatic vacuum-forming machines, the next cycle is started when the heater is returned to its stored position where it activates a switch to start the vacuum forming.

Immediately after the heater is removed, the platen must be raised. The platen is manually or automatically raised forcing the mold part way into the suspended heated plastic. The platen stops when it reaches a predetermined point, which is set by stops. When the mold comes in contact with the plastic, the contact areas are instantly chilled, limiting further forming of these areas.

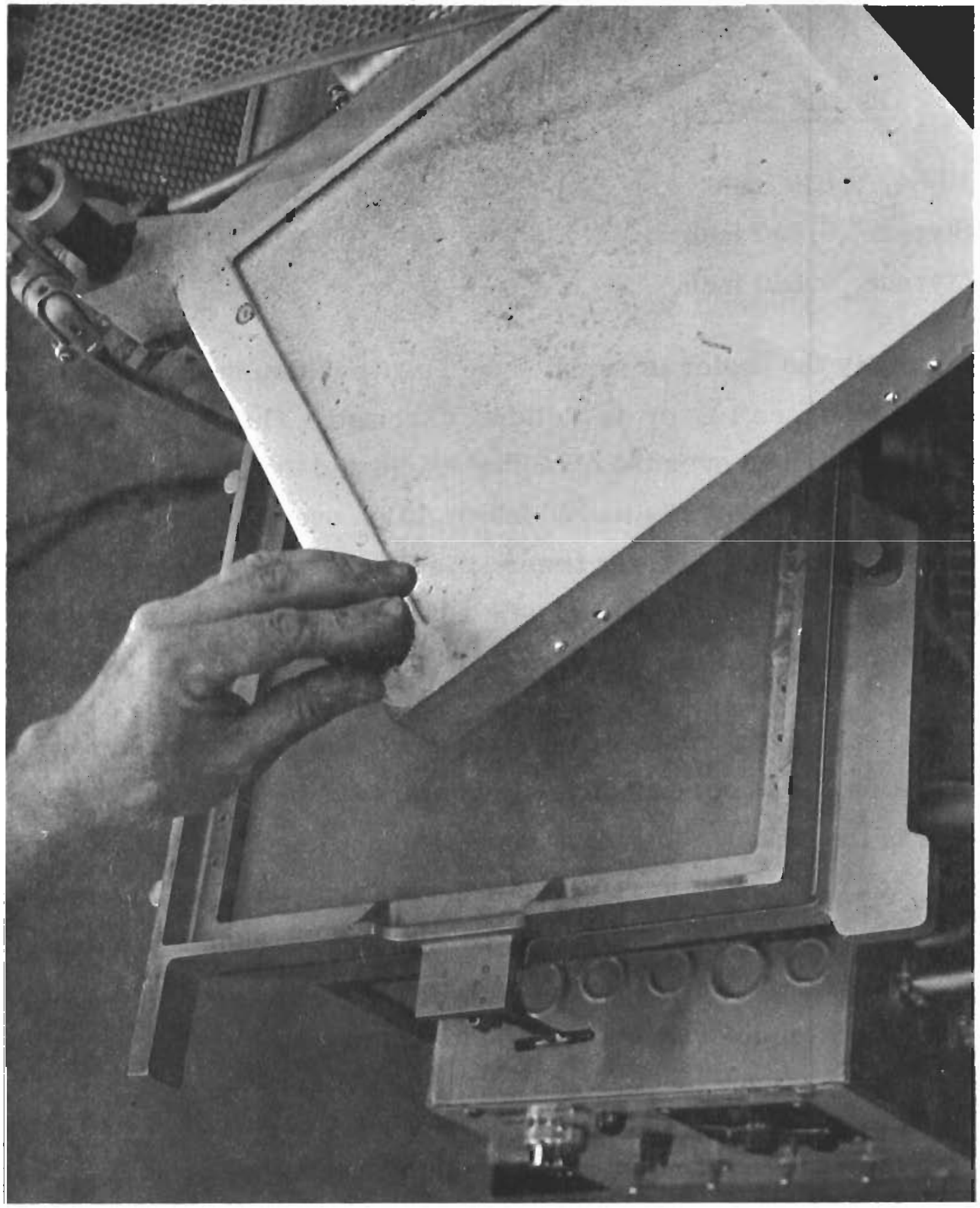


Figure 10. Heater Being Positioned

The vacuum is applied through a manually or automatically operated valve the instant the platen is raised into its operational position. The vacuum is normally supplied from a vacuum tank that is automatically maintained at a specific level of vacuum by a vacuum pump. The plastic in contact with the mold rapidly cools to below its forming point, and only the plastic over the cavities remains hot enough to stretch. After 10 to 20 seconds, the plastic over the cavities has cooled to the point where no additional forming takes place, regardless of any reasonable increase in vacuum. Figure 11 shows the molded panel at this point in the process. The vacuum is turned off at the end of the cycle, and the pressure of the vacuum tank is pumped down in preparation for the next cycle.

Before the clamping frame is released and the molded part with its "skirt" is removed from the machine, the plastic must be cooled to a temperature low enough for the material to hold its shape. Compressed air may be used to speed cooling. If cooled too long, the plastic shrinks making it difficult to remove from the mold. Releasing the clamping frame before the plastic has cooled sufficiently will result in the panel warping or developing undesirable distortions.

A panel molded at the ideal temperature will contain all of the details of the mold. Examining the molded panel for these details will enable the operator to determine whether adjustments in the heating time are required.

5. FINISHING THE PANEL

The molded plastic panels can be sawed, drilled, sheared, and machined much like other rigid plastics, and ordinary wood-working tools can be used. The outside edges of the panels can be cut most conveniently using machine shears as shown in figure 12. The best results are obtained when the edges are trimmed as shown in figure 13.

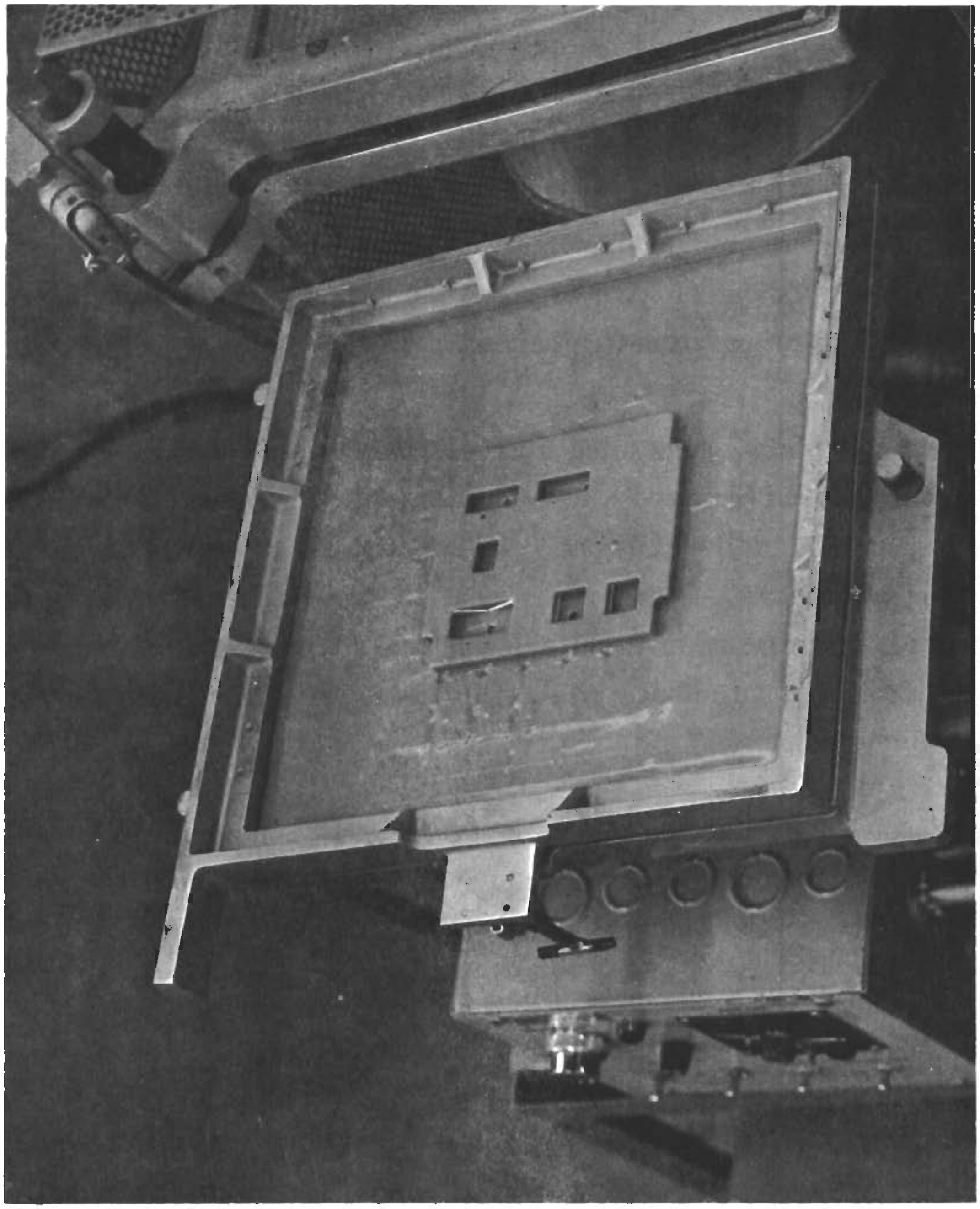


Figure 11. Formed Panel (Still in Clamping Frame)

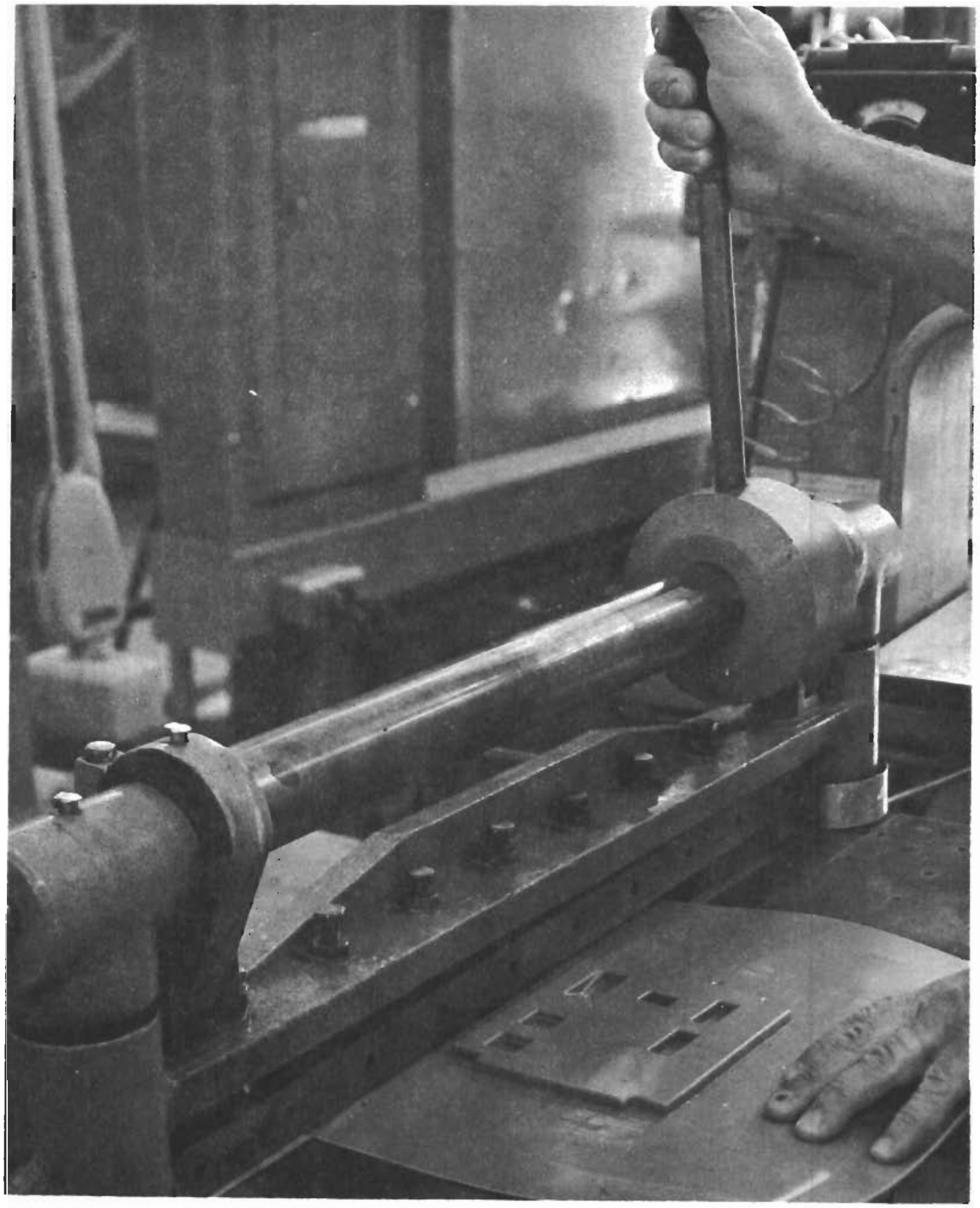


Figure 12. Edge Trimming

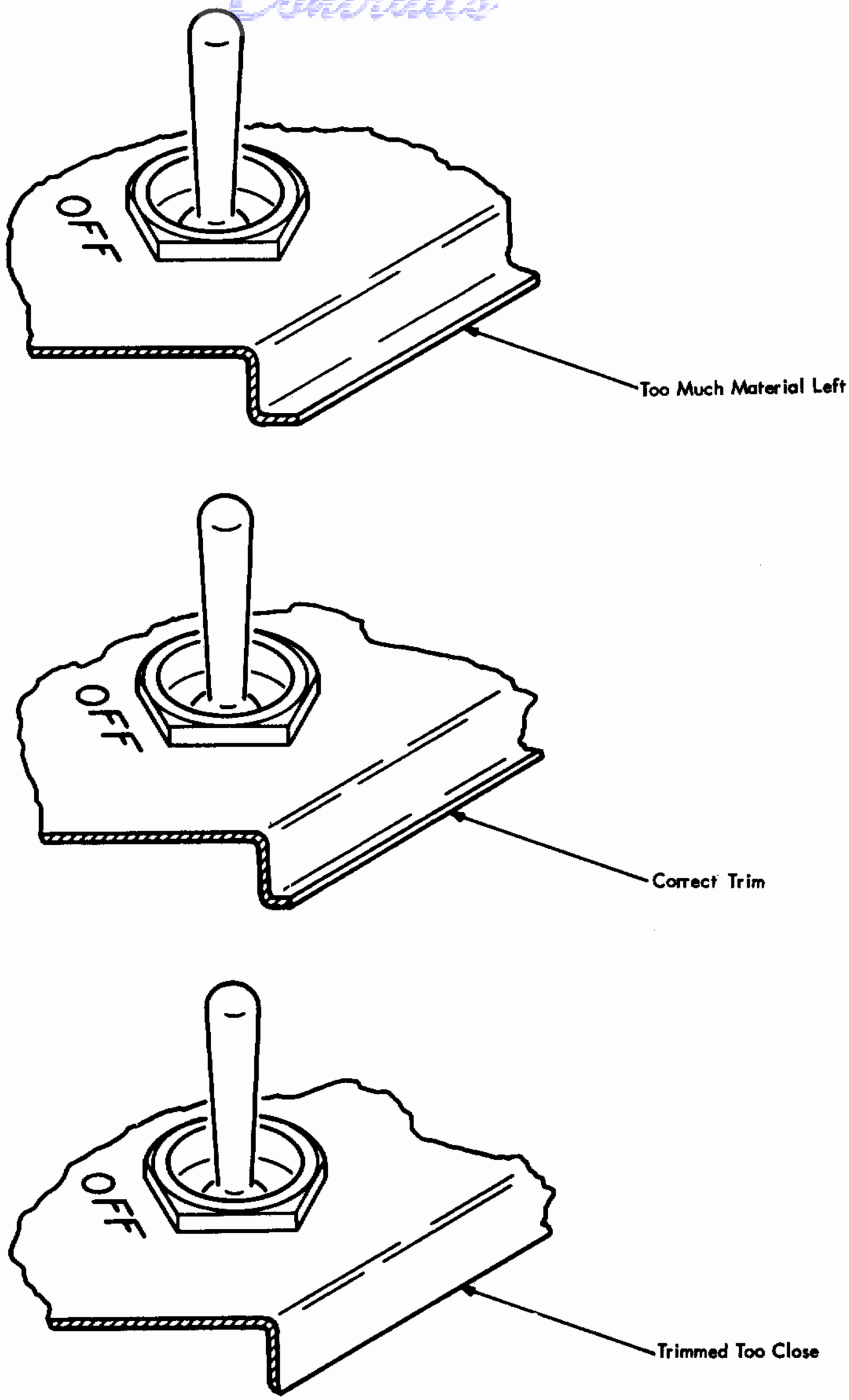


Figure 13. Correct Edge Trimming

The specific openings required for individual controls are described in Subsection 6. Round holes are drilled and square holes are drilled and then shaped with a file or knife. However, an assortment of punches, and a single-station punch press, such as shown in figure 14, can simplify this operation and save considerable time. If the proper size punch is not available, considerable time can still be saved by using an undersize punch to nibble out the material. This will produce a hole that requires a minimum of filing and fitting. Trimming and cutting a few panels will soon show the mockup maker the benefits and savings resulting from including center-punch marks, scribe-lines, and cutting guides on the mold. If many different panels are to be made at one time, raised identification numbers can be included in a location, such as in the bottom of a depression, where they will not show.

Ideally the panels should be molded from a plastic of the color desired for the final panel. However, the panels can be painted with a laquer base paint. Paint sprayers or aerosol cans are recommended. Handpainting with a brush is possible, but it is very difficult to eliminate brush marks.

The panels can be lettered by hand, but the best results are obtained using press-on or transfer letters. These letters, which are available from various vendors under different trade names, are attached to a transparent sheet of paper. The desired letter is aligned over the proper location and then transferred from the transparent paper to the panel (see figure 15) by applying pressure with the rounded point of a hard pencil or a similar object. Extra protection for these letters, which become scratched and chipped quite easily, can be provided by coating them with a light spray of matte transparent protective coating of a type that will not dissolve the letters. Press-on lettering may slightly increase the cost of the panel, but the lettering will improve the appearance of the panel.

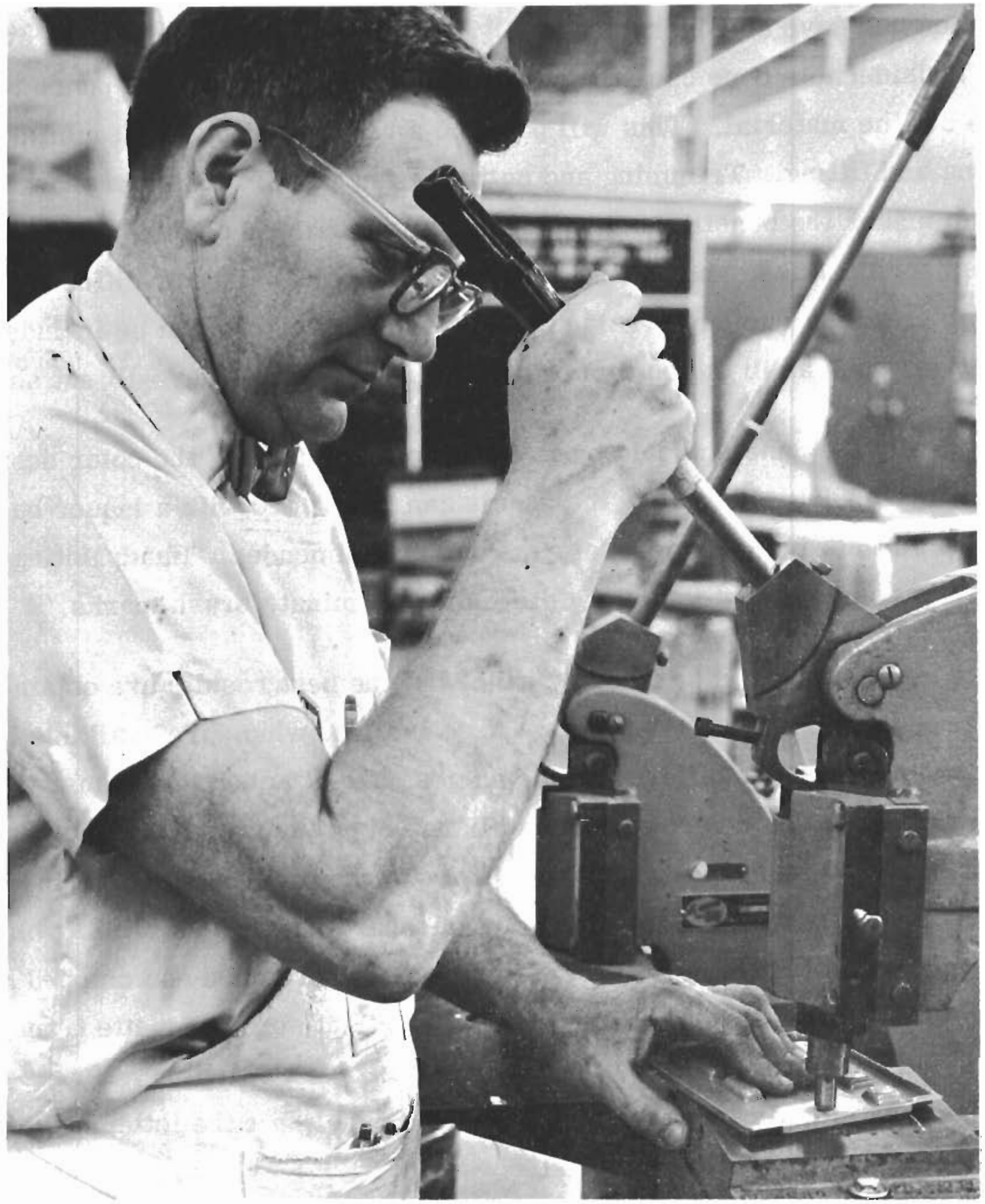


Figure 14. Hole Punching

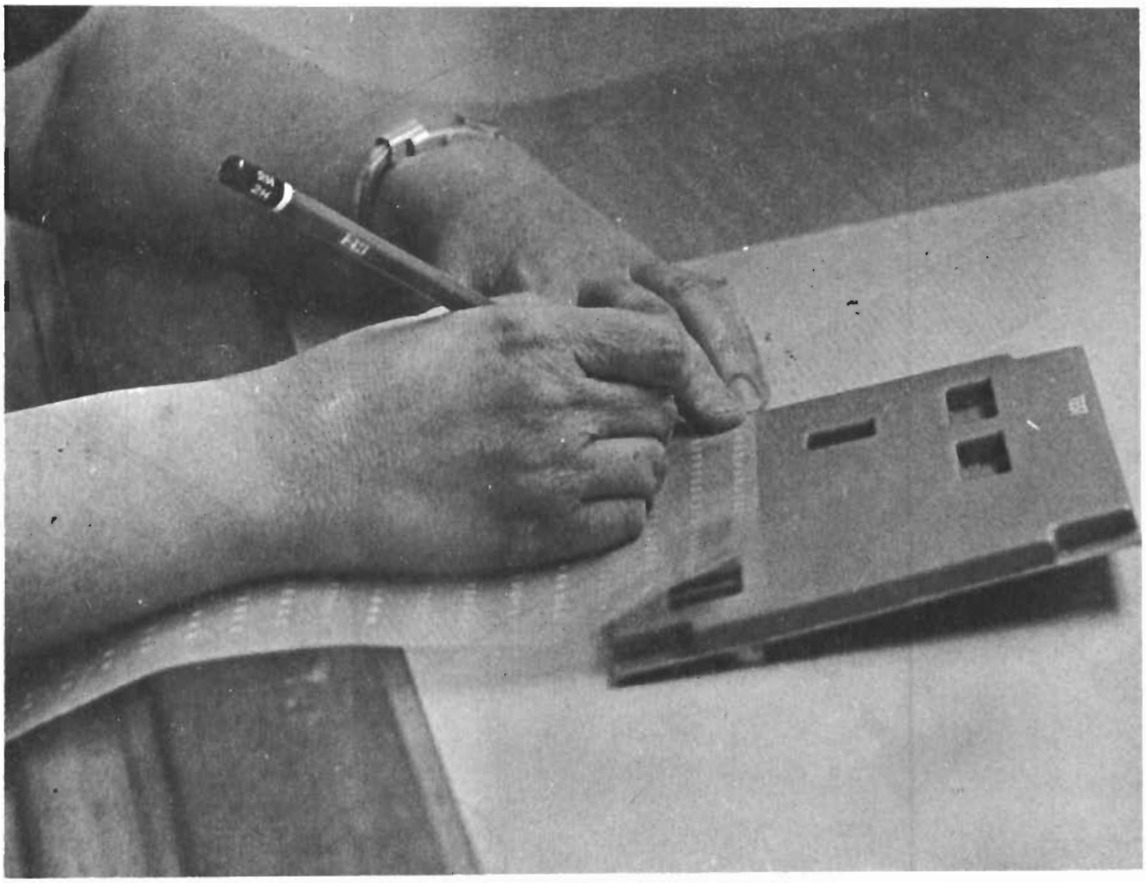


Figure 15. Panel Lettering

After the lettering has been applied, the panel is complete and is ready to accept the different controls. The fabrication and mounting of the controls are described in the following paragraphs.

6. CONTROLS

a. Annunciators

Two types of annunciators, round and rectangular, are included on the selected test panel. The two types of annunciators are shown in figures 16 and 17.

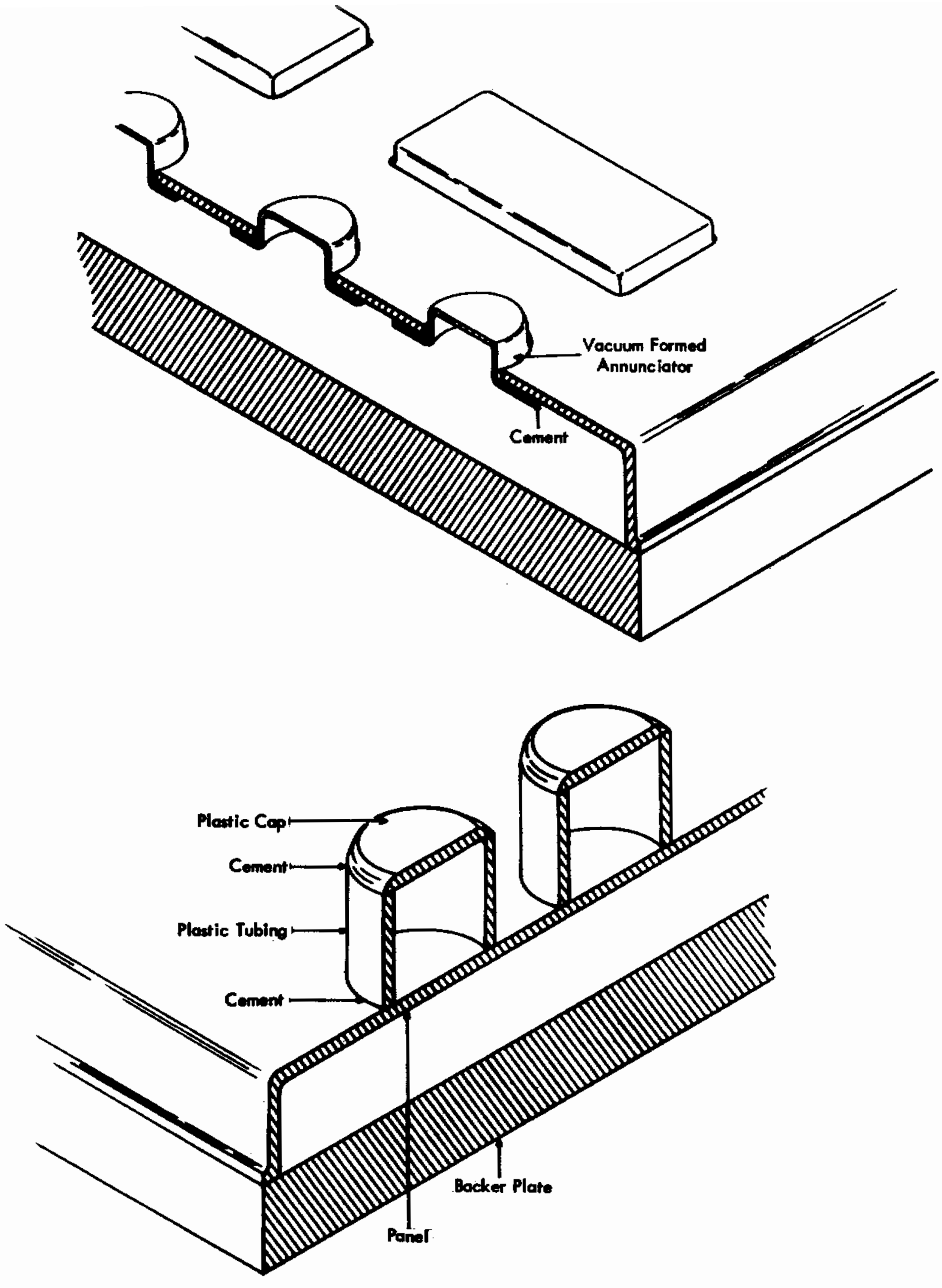
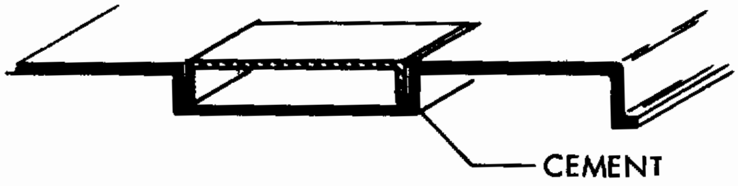
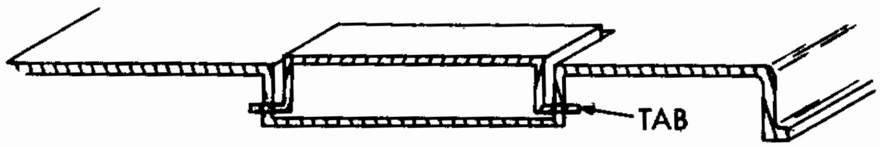


Figure 16. Round Annunciators



ANNUNCIATOR ATTACHED WITH CEMENT



ANNUNCIATOR ATTACHED WITH TABS

Figure 17. Rectangular Annunciator

The small, round annunciators were made by the vacuum-forming process. They were made from clear plastic and were colored on the inside with a felt-tipped marker. These annunciators were inserted from the back into round openings in the panel and then cemented in place with plastic cement. If many annunciators are needed, they can be batch molded in a row, or an entire plastic sheet can be made into annunciators.

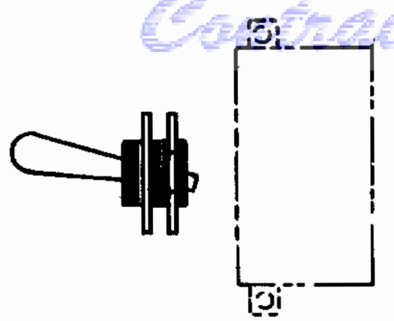
The larger, round annunciators could have been vacuum formed, but in this case they were made by cutting 1/2-inch diameter plastic tubing to the desired length and painting the inside black. A clear plastic disc, colored with a felt-tipped marker, was cemented to the front end of the tubing. The complete annunciator assembly was cemented in place on the front of the panel.

The vacuum-formed rectangular annunciator is shown in figure 17. Cavities to accept these annunciators were molded into the panel. Care must be taken to assure that the annunciator will fit into the cavity. This can be accomplished by making the mold for the annunciator smaller than the cavity in the panel mold by about two times the total thickness of the panel and the control. If the panel is made of 0.040-inch stock and the control is made of 0.020-inch stock, the mold for the control should be 0.120 or 1/8-inch smaller than the opening in the panel mold. (This is a "rule of thumb" which normally results in a loose fit.) Different heights can be used to produce flush or raised annunciators.

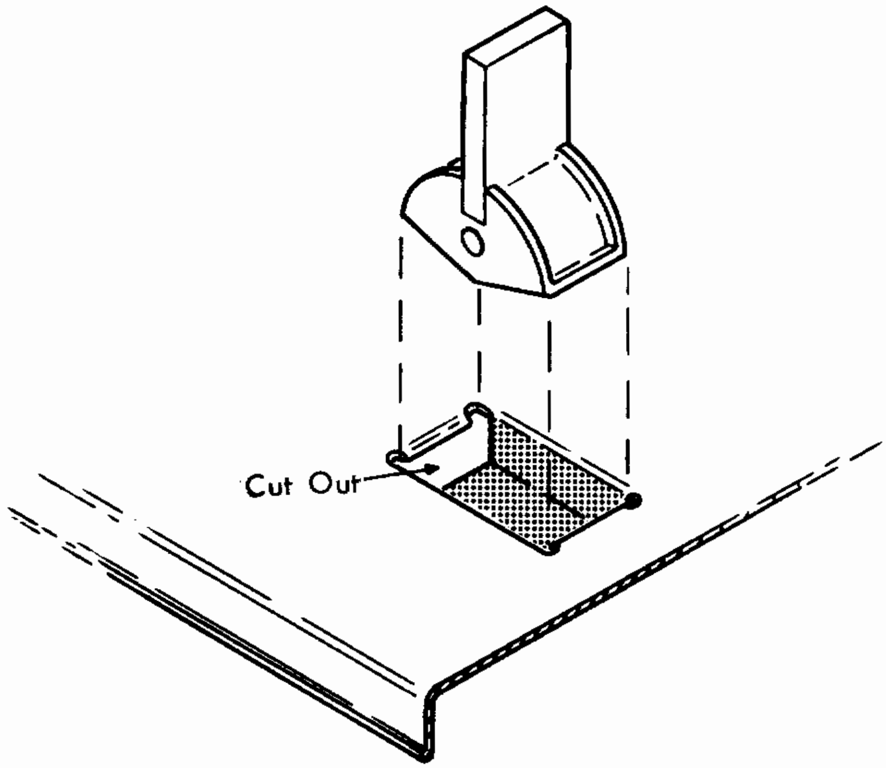
Lettering for the rectangular annunciators was printed on colored or white art board and then cemented in the annunciator. The completed annunciator was cemented in the appropriate cavity in the panel. If it is anticipated that the lettering may be changed, small tabs, such as can be seen in figure 17, may be left on the plastic annunciator when it is trimmed. The tabs can be inserted into slots cut in the bottom of the cavity to hold the annunciator in the cavity. The annunciator can then be removed to change the lettering.

b. <u>Toggle Switches</u>

Two toggle switches are included on the test panel. The switch on the right of the test panel is a conventional toggle switch, and the switch on the left has a special tab configuration. To keep the back of the panels flush, part of the conventional toggle switch was cut off leaving only the threaded sleeve plus the activator and its pivot point as shown in figure 18. The diameter of the mounting hole in the panel is equal to the outside diameter of the thread on the switch. The switch is mounted with a conventional hexagonal or knurled nut.



Modified Conventional Toggle Switch



Tab Switch

Figure 18. Toggle Switches

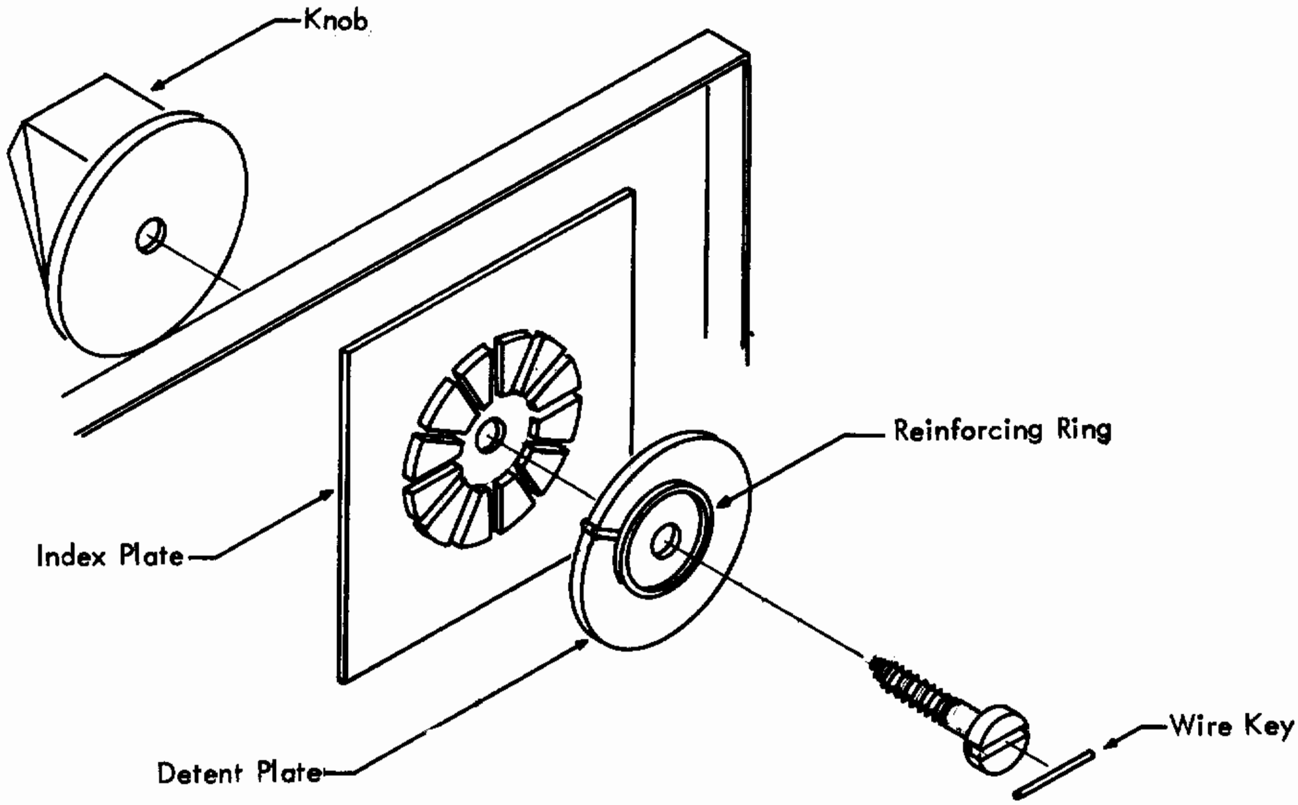
The tab switch is a sample of a new concept switch that was fabricated from pieces of solid plastic. Transparent plastic was used to permit experiments with built-in labels and illumination. This switch actually rocks on the bottom wall of the panel cavity. The switch is mounted in the panel opening, which is equal to the width of the switch in the horizontal direction and slightly smaller than the switch in the vertical direction. With the proper size opening, the switch can be snapped into place and will not come out during normal operation. Neither switch has toggle action.

c. Selector Switch

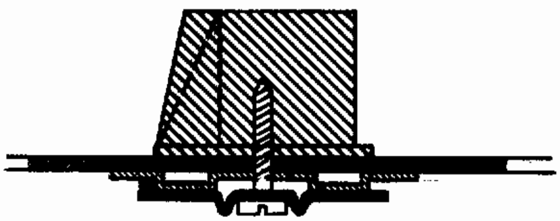
The selector switch can be merely a knob fastened to the panel with a screw. However, a more realistic effect is created by using the design shown in figure 19. The detent positions are established by two vacuum-formed parts, an index plate and a detent plate. The index plate has small, raised, pie-shaped sections with radial grooves between the sections. This plate is cemented to the back of the panel and acts as a stationary index plate. The index plate can be centered with relation to the panel by drilling holes for the switch shaft in both the panel and plate and then holding the two pieces together with a screw while they are being cemented. For this application, the switch shaft is a No. 8, 5/8-inch long sheet metal screw. Locating these holes is a good illustration of how the center punch mark in the mold eliminates the need for repeated layout work.

The detent plate has a single raised radial section and a raised reinforcing ring with a hole in the middle for the screw. The inside diameter of the reinforcing ring should be just big enough to accept the outside diameter of the screwhead. Also, the height of the ring and the screwhead should be the same.

To assemble the switch, the screw is inserted through the detent plate, the index plate, and the rear of the panel in that order. The screw is then screwed into the knob and tightened to provide proper spring action of the detent plate. The screw is keyed to the detent plate by a piece of wire that is fitted into the slot of the screw then pressed into the reinforcing ring on the detent plate using a hot soldering iron (see figure 19). The wire is then cemented into the slot of the screw. Care should be taken to align the knob and index mark before heatsealing the keying wire to the detent plate.



Exploded View



Assembled View

Figure 19. Selector Switch

Figure 20 shows how several selector switch parts can be molded in one batch. Here, four 12-position and four 18-position index plates plus eight detent plates are molded at the same time. The index plates provide detented switch positions at 30- and 20-degree intervals; only the desired positions are labeled on the front of the panel.

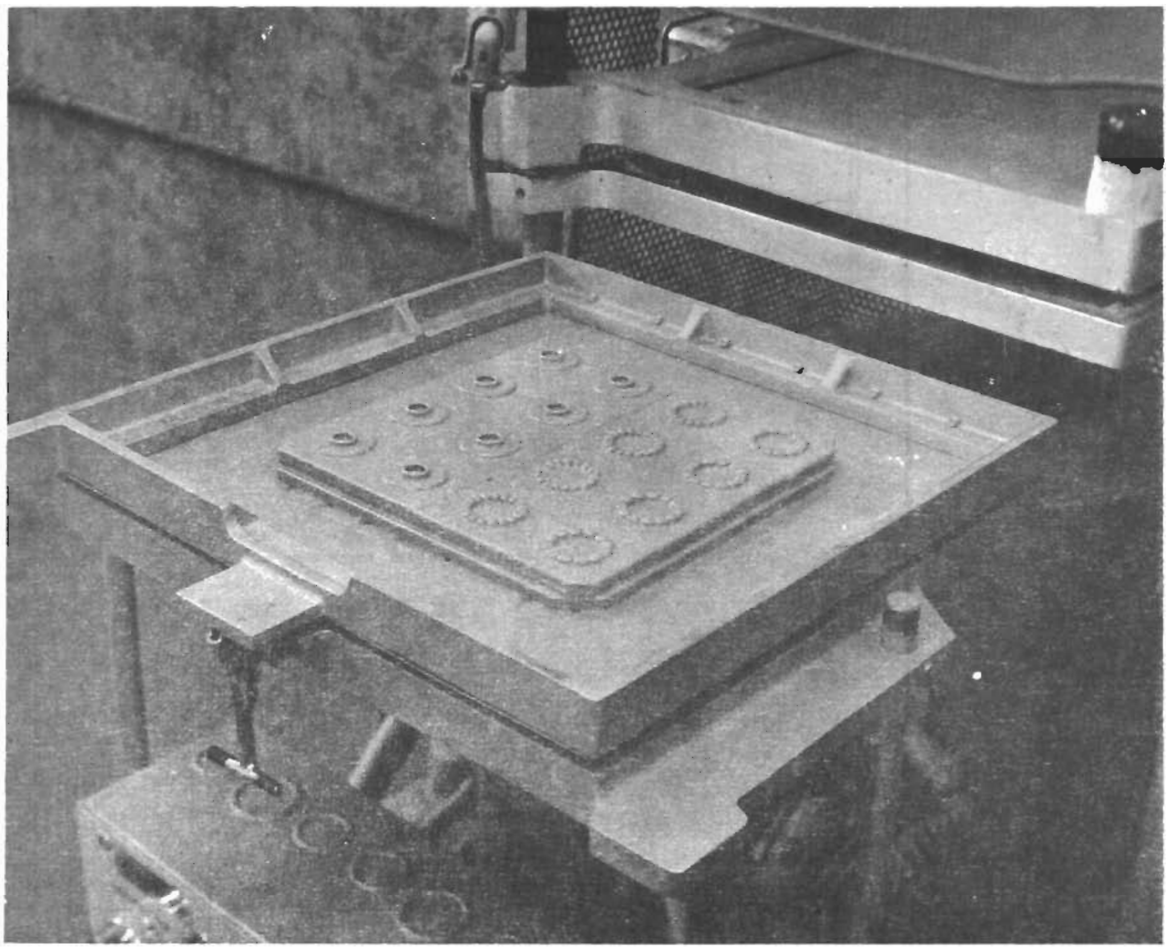


Figure 20. Batch Molding Selector Switch Parts

d. Rocker Switch

The rocker switch is a vacuum-formed part. Figure 21 shows the mold for the rocker switch on the left, the molded part before trimming in the center, and the finished part on the right. The mold is an experimental type having a much larger than necessary backup plate. Batch molding could be used for this switch.

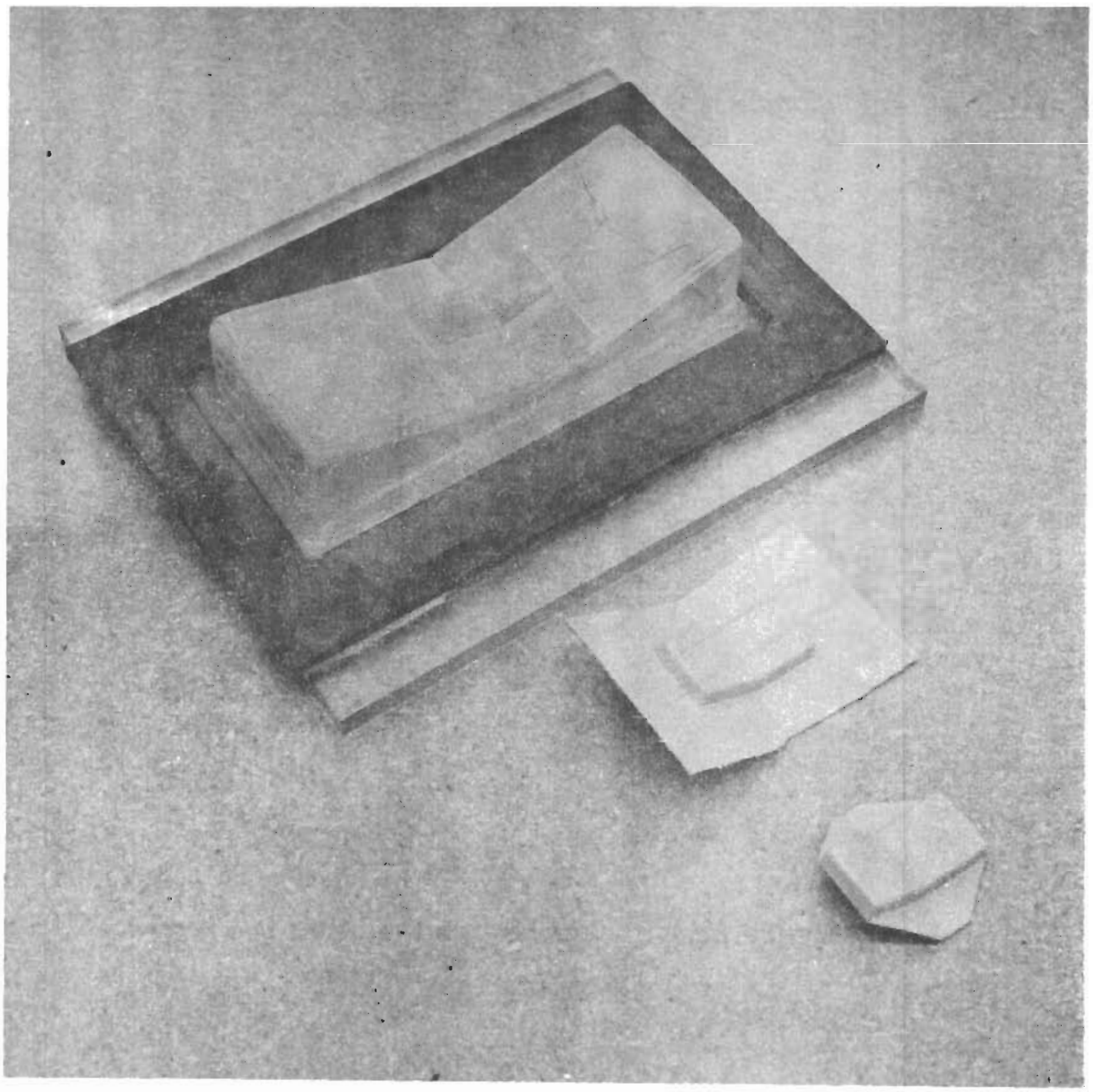


Figure 21. Rocker Switch Mold and Parts

The two sidewalls in the panel cavity for the switch are cut along the molded guides to produce two openings to retain the two button tabs (see figure 22). The switch is mounted by snapping the tabs into the slots; the switch will have some rocking motion but will not have any toggle action.

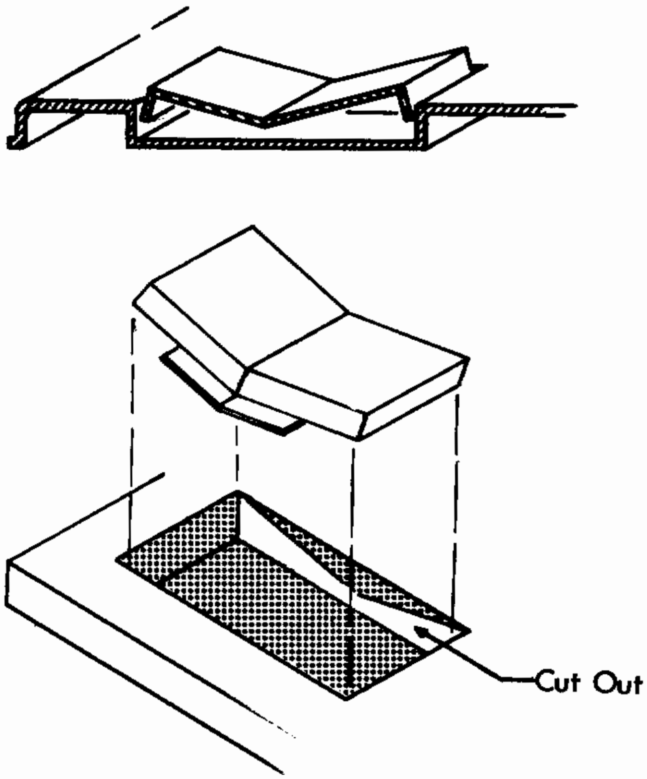


Figure 22. Rocker Switch Installation

e. Pushbutton Switches

The test panel has two pushbutton switches; two possible configurations are shown in figure 23. The buttons for both configurations were vacuum formed using the same mold, but they were trimmed differently.

For the upper switch in figure 23, the molding skirt was trimmed off completely. A small square of plastic foam was then attached to the bottom of the panel cavity using cement or double-faced tape. The button was then cemented to the foam. The foam will cause the button to return to its original position after it is depressed. Flush or raised pushbuttons can be had by varying the thickness of the foam. The stroke length of the button is determined by the height of the button sidewall and depth of the panel cavity.

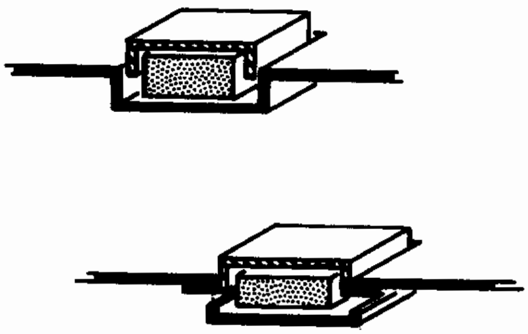


Figure 23. Pushbutton Switches

The pushbutton for the lower switch shown in figure 23 was trimmed so that two retaining tabs remained. The tabs snap into cutouts in the panel, and the foam lies loose inside the button.

Clear plastic can be used for the buttons, and the lettering can be protected on the inside using a technique similiar to that used for the rectangular annunciator. If desired, opaque plastic can be used for the buttons, and the labels attached on the panel or on the front of the button.

f. Illumination

Striking effects can be achieved by mounting grain-of-wheat lamps behind transparent devices such as annunciators and pushbutton switches. Inexpensive imported lamps operating at 12 to 15 volts are available at hobby stores etc. The number of lamps required depends on the area to be illuminated. When illumination is used, a translucent diffusing material instead of white art board should be used as the base for lettering. For round annunciators and pushbuttons, one lamp is generally sufficient; two lamps are required for the elongated annunciators. When lamps are used in pushbutton switches, springs made of folded strips of plastic are used in place of foam (see figure 24).

g. Electrical Contacts

In some cases, metal contacts fastened to the backs of selector switches and pushbutton switches can be used to energize a light, a relay, or other circuitry. One scheme for adding low voltage, low current electrical contacts to a pushbutton switch is shown in figure 24. The resulting switch is a spring-loaded, single-pole, normally open switch. The electrical connections are made by soldering wires to two metal strips that are cemented to the back of the panel cavity. When the switch is pushed, electrical connection is made between the two strips of metal by two office-type staples in the skirt of the pushbutton.

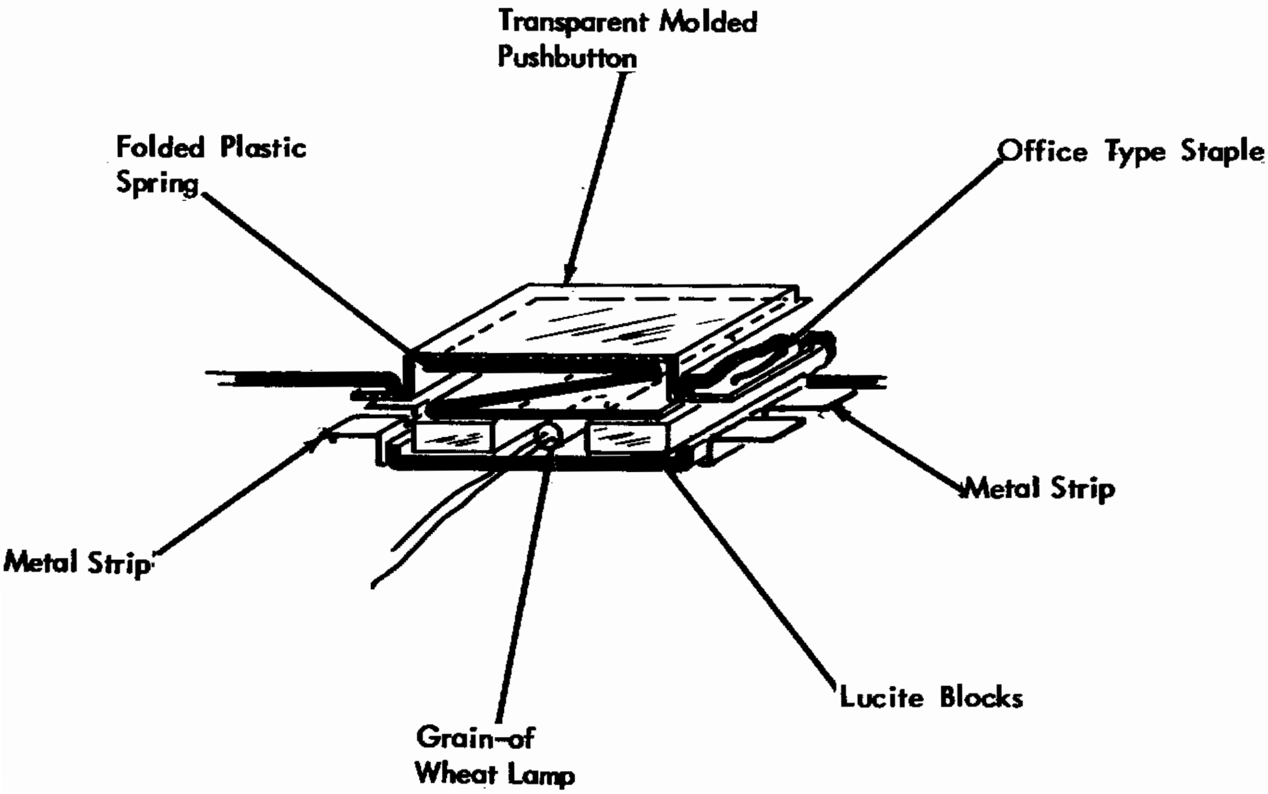


Figure 24. Illuminated Pushbutton Switch with Electrical Contacts

Electrical contacts on the rotary switch can be provided by soldering one wire to a metal insert cemented on the detent plate and soldering the other wires to metal inserts cemented in the grooves of the index plate.

Fabricating these types of electrical contacts can become very tedious and time consuming. If reliable electrical performance is required, use of actual components is recommended.

Section IV

CONCLUSIONS

The test panel and its controls described in the report were selected only as typical examples to explain how the vacuum-forming technique can be applied. Vacuum-forming is an inexpensive fabrication process, and its greatest potential is for jobs which require two or more identical parts. For a single part, the cost of the mold becomes relatively high, but the vacuum-forming process is still less expensive than fabricating all parts of solid material.

The vacuum-forming process can be adapted for use on display devices such as counters, meters, instruments, etc. Also, the process can be a valuable tool in experimental shops and research and development areas for fabricating mock-ups of new ideas and concepts.

1. ESTIMATED FABRICATION TIME

Table III shows estimated times for fabricating the selected test panel. The estimates are for workers who have had related experience and who have performed the process a few times. The estimated times should be used for planning and estimating purposes only. Each panel has its peculiarities, and the amount of detail required on a panel can drastically change the time required to fabricate it.

2. ESTIMATED COST

Most of the basic materials required for making the test panel are purchased in bulk, and the quantity required for each panel is so small that the material cost for estimating purposes can be calculated as less than 5 percent of the labor cost.

Table III

ESTIMATED FABRICATION TIMES FOR THE TEST PANEL

Task	Estimated Time (man-hours)
Prepare full scale layout	1.0
Prepare lettering layout	0.3
Fabricate panel mold	2.0
Vacuum form panel	0.1
Trim and cut openings	0.5
Apply lettering to panel and controls	1.0
Fabricate mold for transparent controls	1.0
Vacuum form transparent controls	0.1
Trim and color controls	0.3
Fabricate mold for rocker switch and detent plates	2.0
Vacuum form rocker switch and detent plates	0.2
Fabricate tab switch	0.5
Fabricate selector switch knob	0.5
Rework toggle switch	0.3
Fabricate backer panel	0.3
Assemble test panel	1.0
Total	11.1

PROCEDURE FOR VACUUM-FORMING PLASTIC PANELS

Step

1. Prepare a preliminary engineering sketch of the panel.
2. Prepare and make several copies of a full-scale layout drawing of the panel.
3. Complete the panel drawing by adding controls, indicators, lettering, etc. to the layout drawing.
4. Cement or tape a copy of the layout drawing onto the mold material.
5. Cut the outline of the panel and openings for the controls in the mold material, following the lines of the outline drawing.
6. Smooth the cut surfaces of the mold.
7. Insert partial inserts in mold openings, if required.
8. Drill required bleed holes.
9. Attach the mold to the vacuum platen.
10. Clamp the plastic sheet into the clamping frame.
11. Block off platen holes that are not covered by the mold.
12. Spray the mold with a release agent. This step can be performed either before or after the mold is placed on the platen. It is not necessary to spray the mold before every mold operation — one spraying will be effective through several operations.

13.* Heat the plastic and remove the heater.

14.* Move the platen to press the mold into the plastic.

15.* Apply the vacuum for the specified time.

16. Cool the plastic to room temperature.
17. Remove the molded panel from the clamping frame.
18. Trim panel and make required openings.
19. Paint panel (if a color different than the color of the base material is desired).
20. Apply lettering.
21. Mount controls.

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* Some vacuum-forming machines will perform these operations automatically.

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13. ABSTRACT

This report describes a process for vacuum-forming thin sheets of plastic material into control and display panel mockups. The description includes techniques for fabricating controls and annunciators plus requirements for drawings, tools, equipment, and materials. The vacuum-forming process, which is well established in the plastics industry for fabricating parts in large quantities, is fast and inexpensive. In this report, the fabrication of a typical mock-up panel is used to illustrate the vacuum-forming process.

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