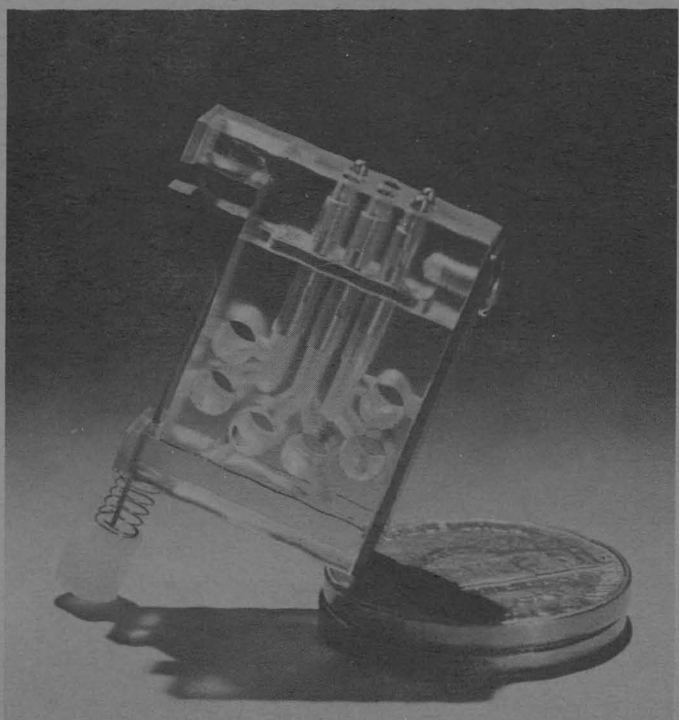
MTR-1951

Development Of A Dynamic
BRAILLE DISPLAY

N. B. Sutherland



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ABSTRACT

The sense of sight is the major channel through which one normally acquires information. The blind, being deprived of this opportunity, must depend heavily upon sighted persons to transform visually-oriented information into aural or tactile form.

Mechanisms are beginning to emerge for capturing machine-generated information and presenting it directly to the blind, but lack of profit incentive because of the small market for such sensory aids has retarded progress.

This report describes the development of a technique for dynamically displaying machine-generated information in braille. The work reported herein represents an eight-month effort which was conducted under the MITRE Independent Research and Development Program.

ACKNOWLEDGEMENTS

As project leader and principle investigator, I would like to express my gratitude to the many people who contributed to this project.

I am indebted to Phil Vance and Lou Thomas for their encouragement and support which led to the initiation of the project. Bob Gildea, with his extensive knowledge of and contacts in the community concerned with blindness, has provided invaluable guidance and assistance.

Although translation of the concept into hardware was indeed a cooperative effort, the success of that activity was due largely to the efforts of Dick Hooper, especially in the development of the pneumatic system and in the design of pneumatic valves. El Wakefield contributed to the development of the braille module, and Leon Cook did the exceptionally fine work in fabricating the prototype modules. Dick LaPorte, Joe Spinosa, and Frank Karkota contributed to the fabrication of the demonstration display, and Frank Karkota did most of the final packaging. Credit for the electronics goes to Ed Palo, with a note of appreciation to Rod McLean for the wiring and to Ray Gamache and Frank Page for assisting me with debugging. The photographs in this report bear the Ed Paradiso mark of quality.

I am grateful for the interest and support which the research committee has shown in making this project possible.

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SECTION I

BACKGROUND

PROBLEM DISCUSSION

The fundamental problem to which this research project relates is that of acquisition by the blind of information which is normally presented for visual consumption. This problem is particularly crucial in education and employment situations, where there is a high degree of dependence upon access to printed or graphic material.

Of necessity, the blind person must depend upon the intervention and assistance of sighted persons to translate visually-oriented information into aural or tactile form. In the former case, the sighted person either reads aloud directly to the blind individual, or records as he reads for later play-back (e.g., talking books). Tactile output most often takes the form of embossed braille, the production of which normally begins with the transcription by a sighted person of printed text into literary braille. This dependence upon sighted persons places severe personal and vocational limitations upon a blind individual, in that he is limited in the quantity and currency of information available to him, and in the degree to which he can function independently.

For the foreseeable future, the blind will continue to rely upon braille books, sound recordings, and sighted readers. However, application of current technology holds the promise of augmenting these techniques in selected areas in such a way as to make information directly and independently available to the blind. Realization of this promise is slow in coming, primarily due to the small market and resultant lack of a profit motive for industry to develop technical aids for the blind.

RELATIONSHIP OF THIS PROJECT TO PROBLEM

A growing volume of visually-presented information originates, or at least exists for a time, in machine-coded form. Examples include the output from computers, electronic calculators, electronically-operated measuring devices, and automated typesetting equipment. This type of coded information appears to be an immediate candidate for automatic processing and presentation to the blind in aural or tactile form. The technical aim of this project is to develop a general purpose capability which will permit the dynamic display of such information in braille.* Development of this capability would add to the range of tools and equipment which could be made available to the blind, and would represent a step toward reducing their dependence upon sighted persons for translation of visual outputs.

HOW THIS PROJECT DIFFERS FROM OTHERS

The idea of automatic presentation of machine code in braille is not new or unique. What does appear to be unique is the concept of treating the braille output as a separable function. Other projects have concentrated on the development or modification of specific pieces of equipment for specific applications. In each case, the output mechanism has been specially designed, often as an integral and inseparable part of the particular apparatus, and therefore not readily transferable to any other application.

The approach represented by this project is the development of a separate, general purpose braille display which can be used in a variety of applications. Since the display is to be general purpose, the required size in terms of number of characters will vary in accordance with the selected application. Therefore, a modular design requirement was adopted, where each module corresponds to one braille character. This modular design permits the construction of a display which is tailored in size to suit the application.

In operation, information from the selected data source would be sent to the display, where its braille equivalent would be created by raising small rods or pins in the braille modules. Instead of embossing paper, the braille equivalent would be read directly from the surface of the modules, and then would be erased or replaced by new information.

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* Braille is a system of raised-dot writing which enables the blind to read using their sense of touch. Braille characters consist of from one to six dots arranged in a 3 x 2 pattern (⠿). A series of braille characters is normally embossed into paper and read by passing the index finger lightly over the braille lines of the page. The literary braille code, which is most commonly used, does not have a one-for-one correspondence with English but, rather, uses a complex grammar of contractions, abbreviations, and special symbols.

SECTION II

TECHNICAL OBJECTIVES

MODULE DEVELOPMENT

As previously stated, a modular design approach was adopted, where each module would correspond to one braille character. At the time this project was funded, a concept for such a module had evolved, based upon a combination of electro-mechanical and pneumatic operation, and an experimental module had been fabricated. Figure 1 is a photograph of the experimental module. An excerpt from a concept paper (M69-64) published in June 1969, describing the operation of the module as then conceived, is appended to this report.

The first objective of this project was to further develop and refine the design of the basic display module.

PNEUMATIC SYSTEM DEVELOPMENT

Since the module operated pneumatically in part, some period of time was planned to determine the pneumatic characteristics of the module, and to design and develop a pneumatic system suitable to operate a group of modules. A key item here was development of a valve to transduce electronic signals into pressure/vacuum states.

DEMONSTRATION DISPLAY FABRICATION

Once a satisfactory module design was achieved and a suitable pneumatic system was developed, a general purpose demonstration display was to be fabricated. This display was to consist of some number of modules (ten, in fact) plus the pneumatic system and electronics required to operate the modules. The display was to accept its input at standard digital logic levels through a single connector plug, to facilitate interfacing with a variety of data sources. An initial design goal was to be able to write the display at teletype speed of ten characters per second.

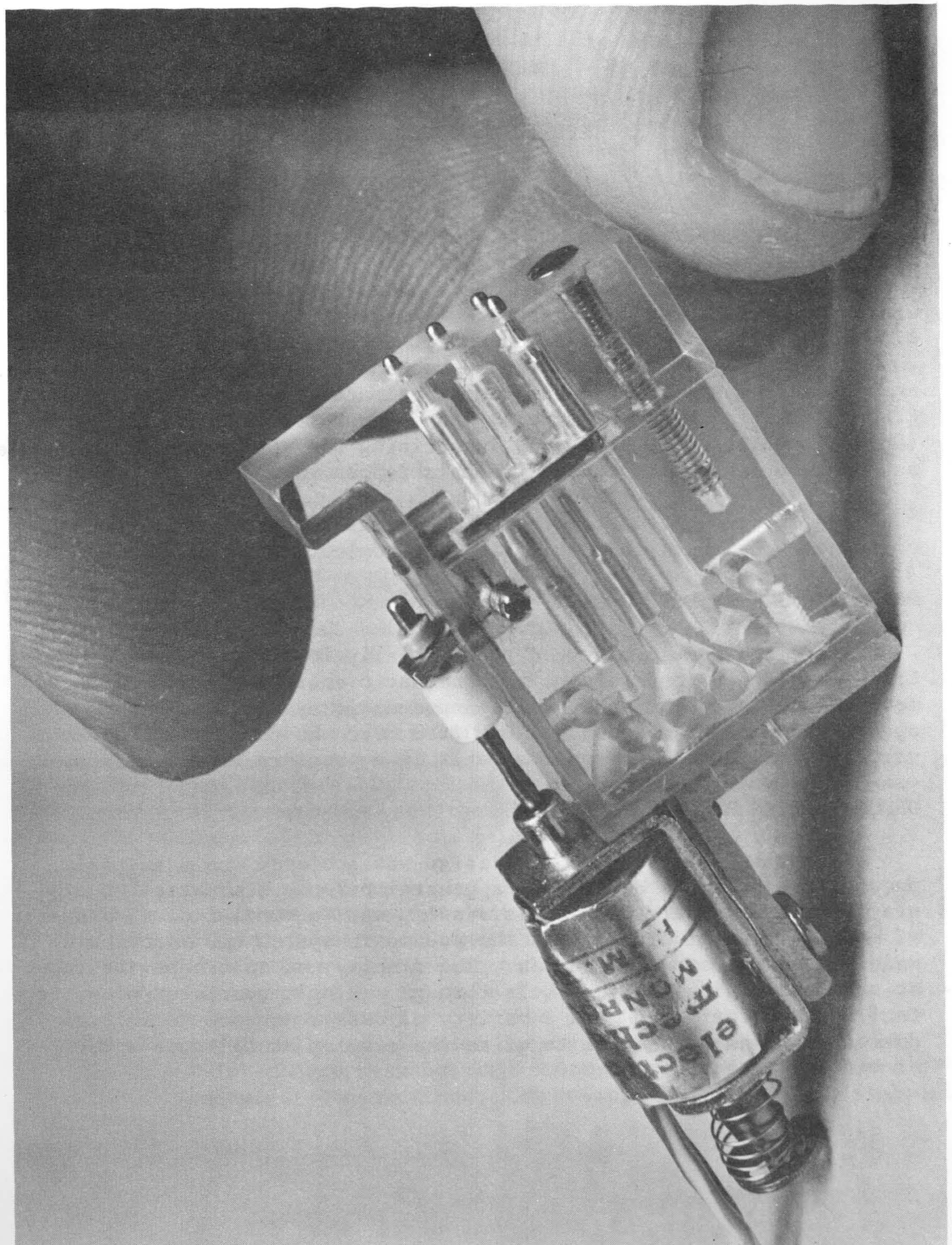

Figure 1. Experimental Braille Display Module

SECTION III

PROJECT SUMMARY

This section gives a brief summary of project activities and accomplishments. A more detailed account, with illustrations and explanations of the operation of the display and its components, may be found in Section VI.

1. Module Redesign. The experimental module was subjected to a number of tests which revealed the necessity for several design changes. Figure 2 shows the redesigned module which was replicated in the prototype display package.

2. Pneumatic System Development. The pneumatic characteristics of the modules were determined, and a pressure system was conceived and assembled. A set of six 3-way valves was required to convert the electrical representations of braille characters into pressure/vacuum states which would raise or lower pins within each braille module. Since a satisfactory commercial valve could not be located, it was necessary to design and fabricate our own (see Figure 3).

3. Display Fabrication. A functional specification of the logic for a ten-character display was prepared. The logic was then wired, requiring approximately 30 integrated circuits and accepting its inputs at standard digital logic levels. A demonstration display consisting of ten modules plus the pressure system, display logic, and power supply was assembled and packaged into an attaché case (see Figures 4 and 5). A keyboard was included to permit manual exercise of the various functions which were implemented in the logic.

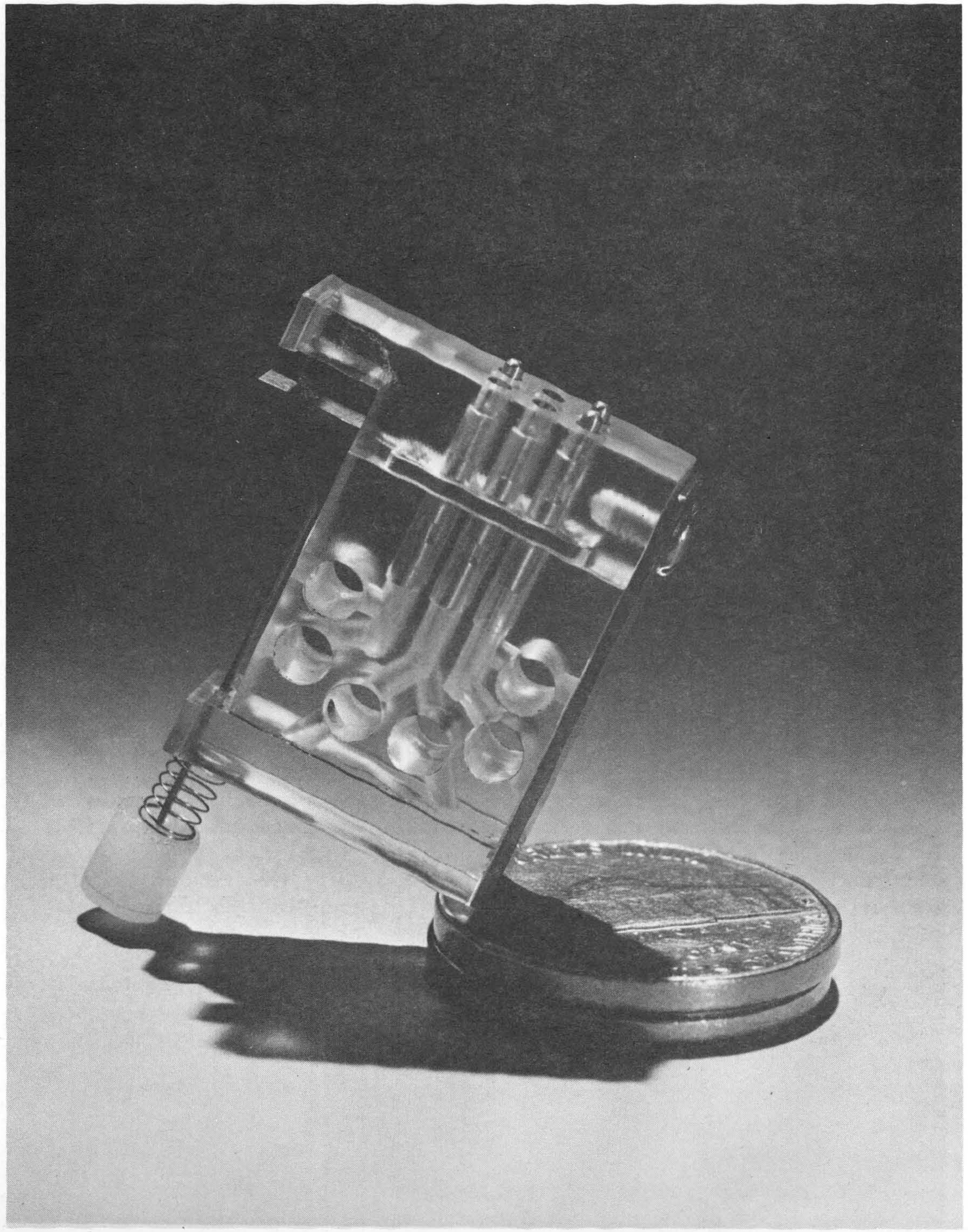

Figure 2. Prototype Braille Display Module

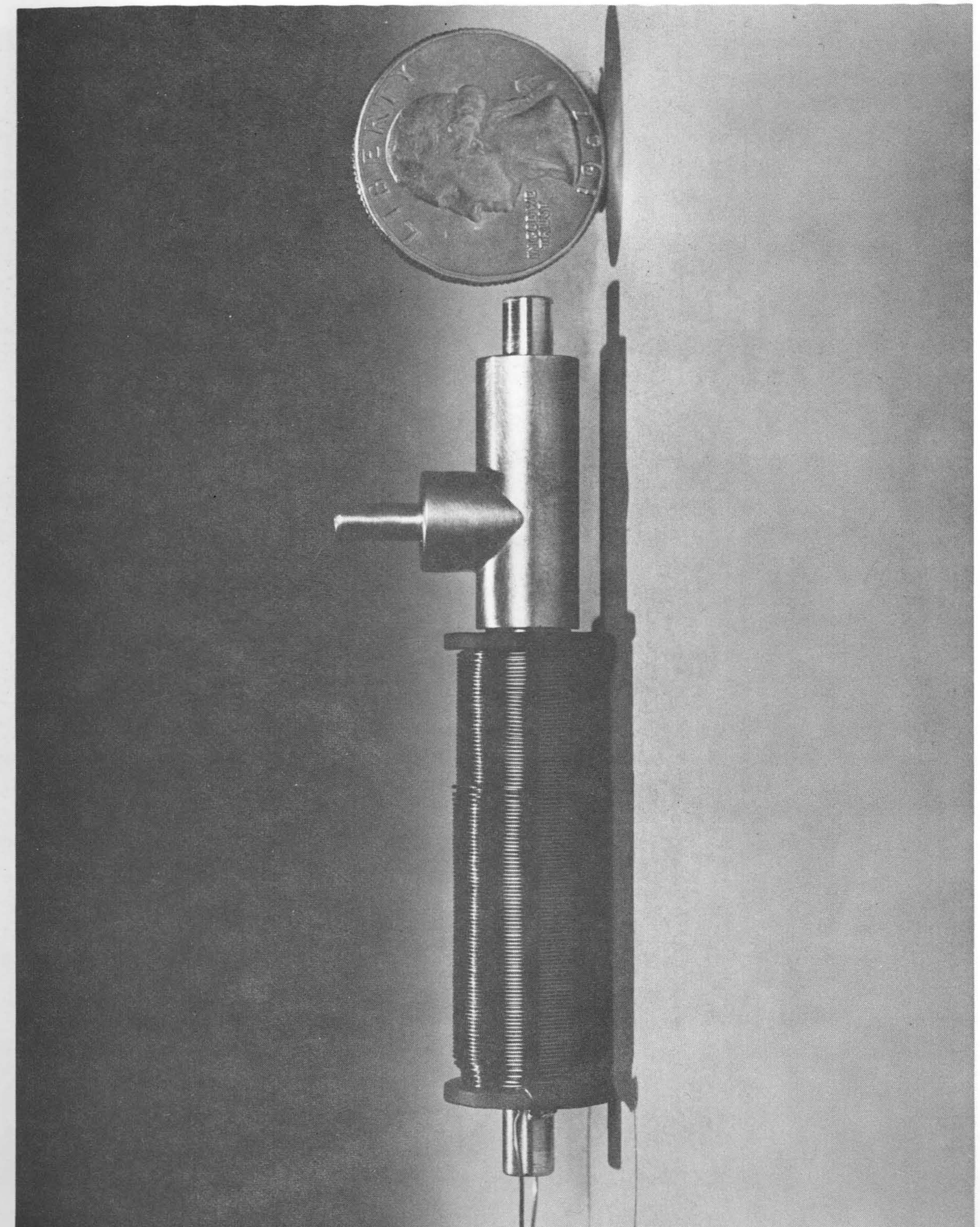

Figure 3. Three-Way Valve Used as Pressure/Vacuum Switch

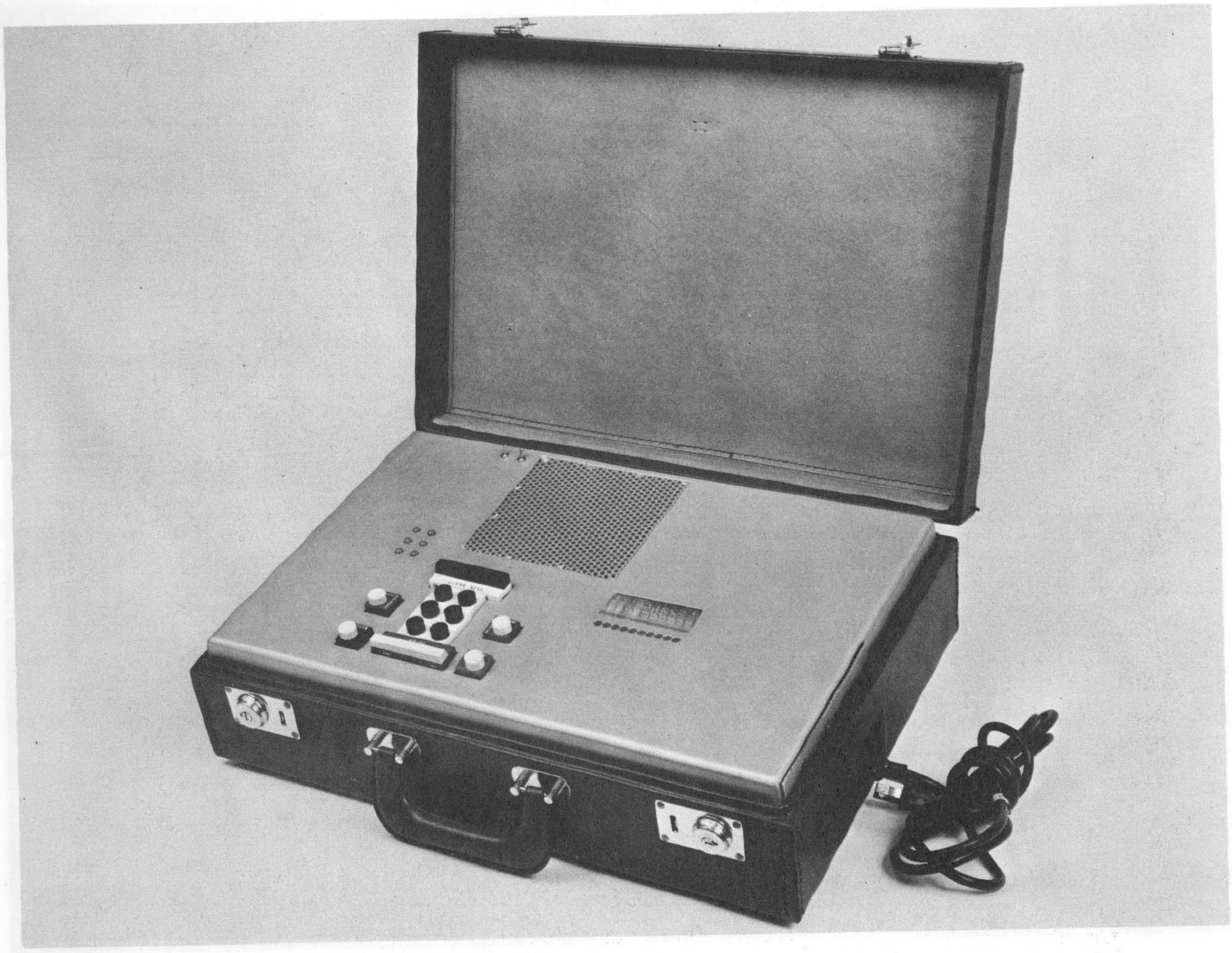

Figure 4. Demonstration Display, Finished Package

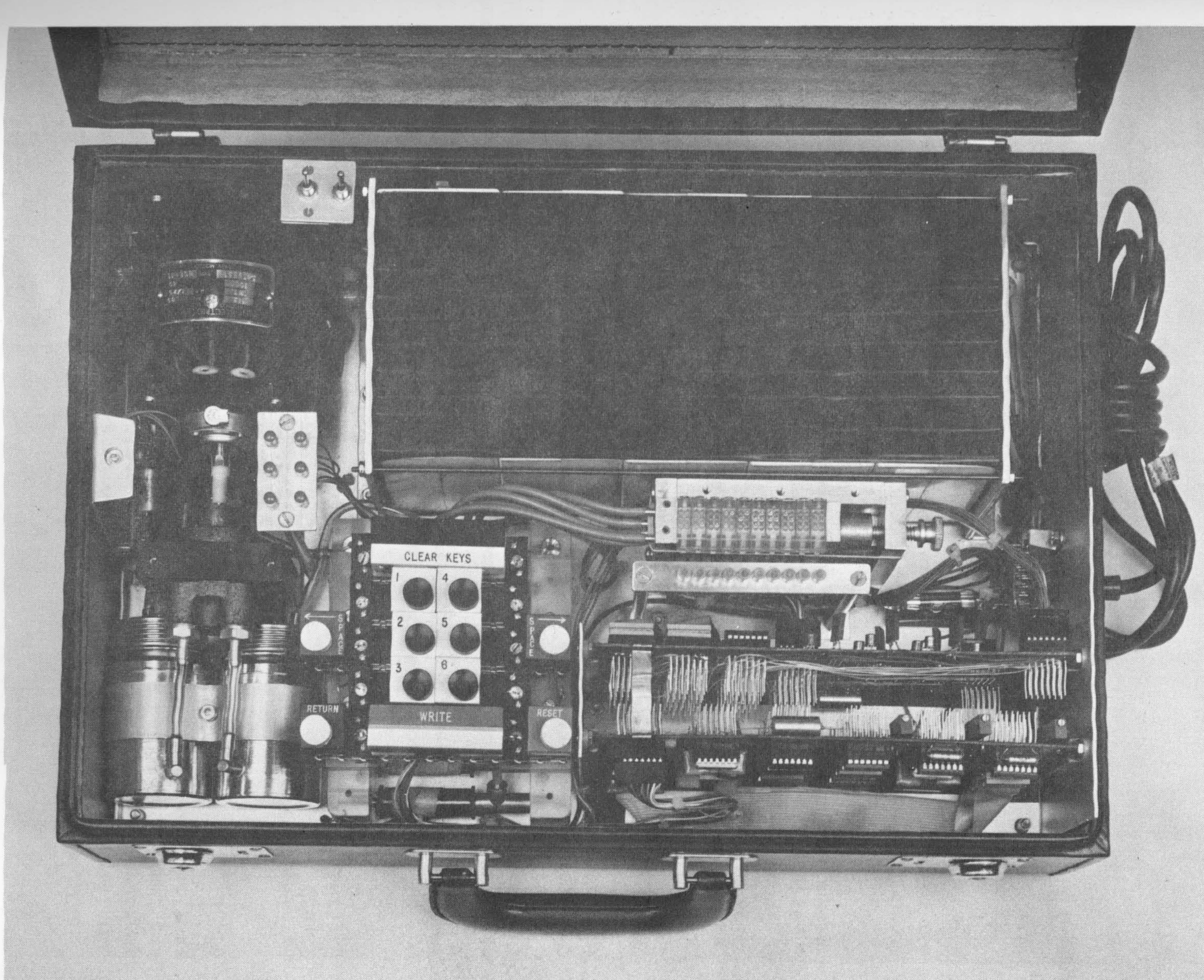

Figure 5. Interior View of Demonstration Display

SECTION IV

EVALUATION*

1. The demonstration package has shown that the pneumatic approach to a dynamic display is feasible.

2. Several blind persons have examined the read surface of the display and have pronounced the quality of the braille which it produces as "excellent".

3. The initial design goal of an operating speed of ten characters per second has been more than satisfactorily met. The display is currently adjusted to operate at fourteen characters per second.

4. The functions which have been implemented in the logic and made available at the connector plug should make the display readily adaptable to a number of applications.

5. Because the braille patterns are firmly locked into place once they are set, it appears to be feasible to obtain permanent copy of displayed information by embossing paper directly from the display surface. Figure 6 shows a possible technique, using a rubber-faced roller to make a paper impression of the display surface. Figure 7 shows the results of the embossing operation.

6. The practicality of the design has yet to be determined, and will require consideration of such factors as cost, design integrity, and performance analysis.

7. Since the display operates at very low pressure (.5 psi), it is a necessary restriction that one keep "hands off" of the display surface until a write operation is completed, to avoid interfering with pins as they are raised and latched.

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* Although the display package is now completed, it has not yet been interfaced to an external data source. There has been neither time nor opportunity to accumulate an operational history for subsequent evaluation. Nevertheless, a number of preliminary evaluative comments may be made.

Figure 6. Illustration of Embossing Technique

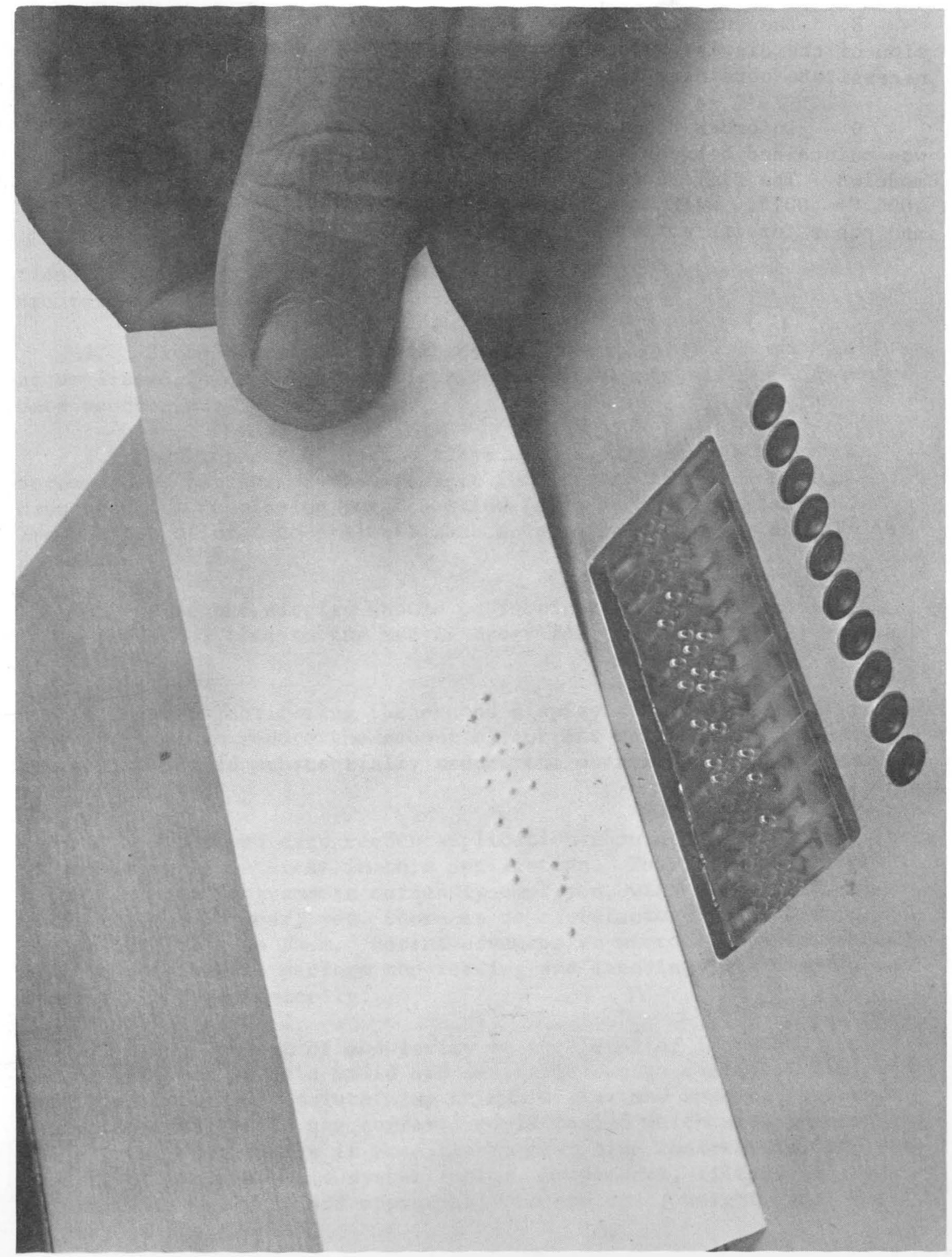


Figure 7. Results of Embossing

8. The current pressure source is limited in capacity. Expansion of the display beyond approximately twenty characters would necessitate obtaining a larger capacity compressor.

9. In order to minimize the air leakage, a very close clearance was maintained between the pins and pin cylinders within the braille modules. The differences in diameters of the pins and cylinders is .004 "$\pm$ .001". With this close a clearance, small particles of dirt and other foreign matter may prove to be a problem.

SECTION V

RECOMMENDATIONS

1. Because of the encouraging results obtained to date, operational evaluation and continued development of the pneumatic design are recommended.

2. Since operational evaluation of the display can only be accomplished in an actual application, an interface with one or more data sources must be developed.

3. Development of an interface with a digital voltmeter is recommended, because of the specific interest on the part of the Massachusetts Commission for the Blind (MCB) in this application. The MCB has offered to evaluate such an application in an actual job situation.

4. A second display should be fabricated and made available for a period of time to the MCB in order for them to properly evaluate it.

5. When fabricating the second display, the 3-way valves should be redesigned to reduce the amount of current which they draw. Such a redesign should substantially reduce the overall power requirements of the display.

6. A punched card reader application should be developed. There is considerable interest in this application. There are some 300 - 400 blind computer programmers currently employed, with another 100 or so being added each year; yet, there is no satisfactory punched card reader available to them. Recent advances in microelectronics should make it possible to perform the reading and encoding into braille both compactly and economically.

7. The concept of modularity to the level of individual braille modules appears to be a valid and desirable design concept. The restrictions imposed by maintaining standard size and spacing when combining modules led to the current module design which uses pneumatics. While this design makes it possible to meet size constraints, the components of the pneumatic system (motor, compressor, filters, relief valves, 3-way valves) add appreciably to the cost, weight, and complexity of the display.

Additional research is recommended, directed towards development of a design which is equivalent in terms of modularity and spacing to the current design, but which is totally electro-mechanical in its operation. That is, modules should respond directly to electrical signals without the necessity of transducing these signals into pressure states.

Elimination of the pneumatic system would greatly simplify the construction of a multi-cell dynamic display.

SECTION VI

DETAILED PROJECT ACTIVITIES

MODULE DEVELOPMENT

The development of a suitable braille module was subject to the constraint that it produce braille of standard size and spacing. Standard spacing within each cell is approximately .1" between dot centers, and standard character spacing is .25" between centers, giving four characters per inch. These spacing requirements rather severely constrain the type of mechanism one might devise in order to create the braille patterns and still maintain the capability of joining or combining modules to yield four-to-the-inch character spacing. It was for this reason that the pneumatic design evolved; air pressure represented a drive force which could be rather easily channeled and directed in order to move small pins and create the tightly-spaced patterns of standard braille.

Early tests with the experimental cell (Figure 1) indicated a need for a number of module changes. Modifications were required to improve the quality of the read surface, to reduce the air flow leakage, to simplify the construction and subsequent maintenance of the modules, and to improve the response times. Figure 8 shows an exploded view of the redesigned module. This is the design which was employed in the fabrication of the ten-cell demonstration display. Operation of the module is explained as follows:

Six pins (Figure 8.B) slide vertically in six cylinders (Figure 8.D). Air pressure is the drive force which moves the pins. Through the middle of the cell an interposer (Figure 8.A) slides back and forth horizontally across the cylinders. The interposer contains six holes; when it is closed, the edges of the holes engage the pins in one of the two notches, locking the pins in place. When the interposer slides forward, it releases the pins. The desired pattern is created by applying either positive or negative pressure to the individual pins while the interposer is open. The interposer is then allowed to close, engaging the pins in either upper or lower notches, and locks the pattern in place.

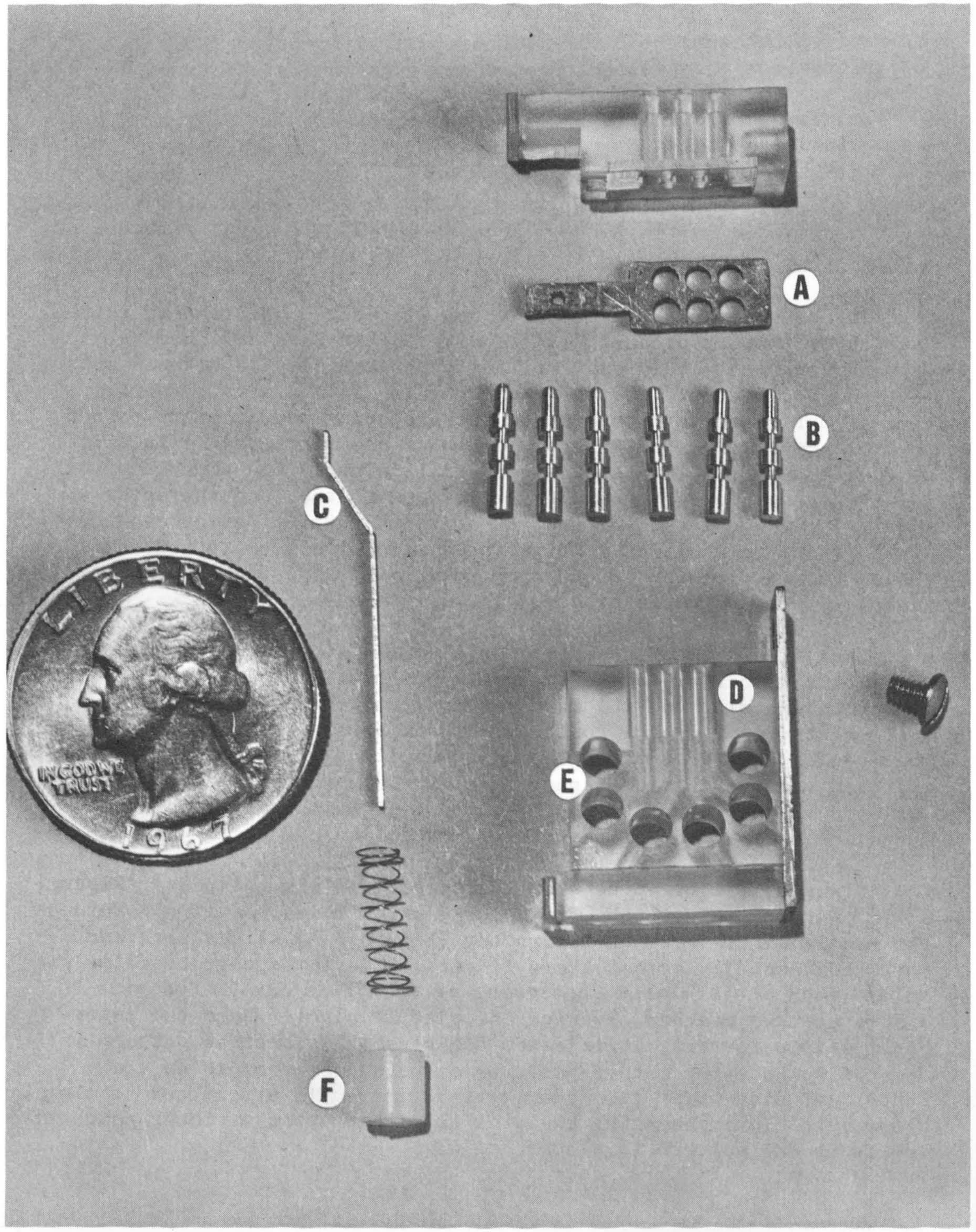


Figure 8. Exploded View of Braille Display Module

The interposer is opened and closed by actuating a small solenoid (Figure 9.D). One solenoid is required per module. The solenoid push rod engages the plastic button (Figure 8.F) on the end of the slant wire actuator (Figure 8.C). The slant wire actuator translates the vertical motion of the push rod into horizontal motion of the interposer. A return spring causes the interposer to close when the solenoid is de-energized.

At the base of each module is a set of six transverse holes (Figure 8.E). Each hole is internally connected to a different pin cylinder. When a number of modules are stacked side-by-side (Figure 9) the transverse holes line up to form six air lines which are common to the row. The code for a given character is delivered simultaneously to all cells in the row (Figure 9.A), but is only set in the module in which the interposer has been actuated to unlock the pins.

Figure 10 illustrates the fact that modules may be easily removed for maintenance or replacement. The cell mount (Figure 9.E) simply acts as a vise. By loosening the knurled knob (Figure 9.F), any module may be lifted out. The modules are free from any electrical connections, and can be cleaned by immersion if it is so desired. (The modules in the demonstration prototype have, in fact, been cleaned by immersing them in freon and placing them in an ultra-sonic cleaner.)

PRESSURE SYSTEM DEVELOPMENT

Determination of Pressure and Flow Requirements

Pressure and flow requirements were obtained through a combination of experimentation and calculation. Tests with the initial experimental cell showed that air leakage around the pins had to be reduced in order to minimize the required size and capacity of the pressure source. Once the cell had been redesigned, a series of tests, together with calculations using empirical equations and charts for flow through close-clearance orifices, indicated a flow requirement of approximately .035 cfm per cell to maintain a pressure of .5 psi. (At .5 psi a pin can be completely raised in less than .01 second, which was judged to be an acceptable response time.) Thus, for a ten-cell display it was necessary to provide a pressure source which could deliver at least .35 cfm at a pressure of .5 psi.

Pressure Source Selection

It was decided that it would be unwise to allow gravity alone to reset pins to the down position. A vacuum reset was judged to be preferable, both from the standpoint of response time and reliability. Therefore, the pressure source must supply both positive and negative pressure.

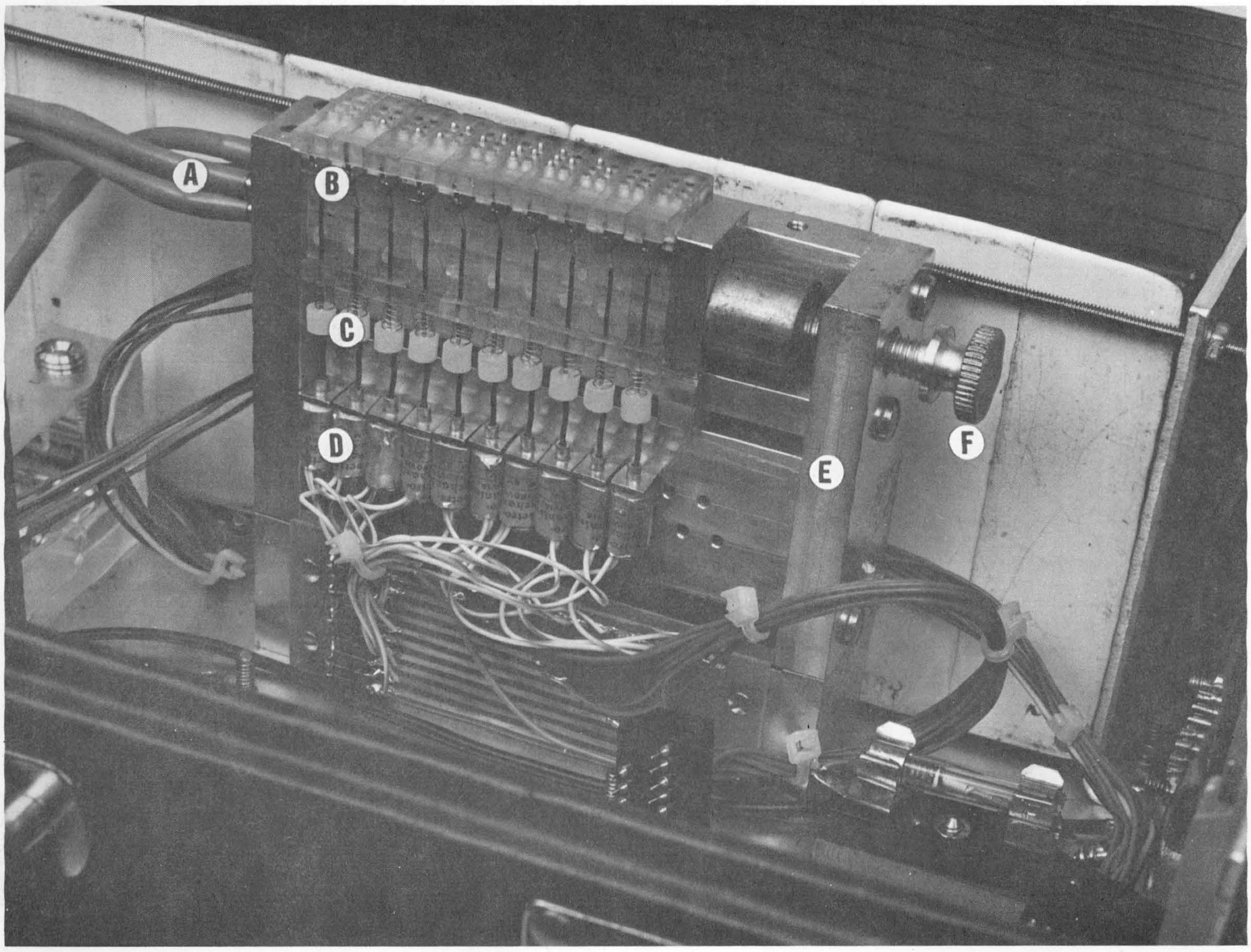


Figure 9. Mount, Containing Ten Braille Modules

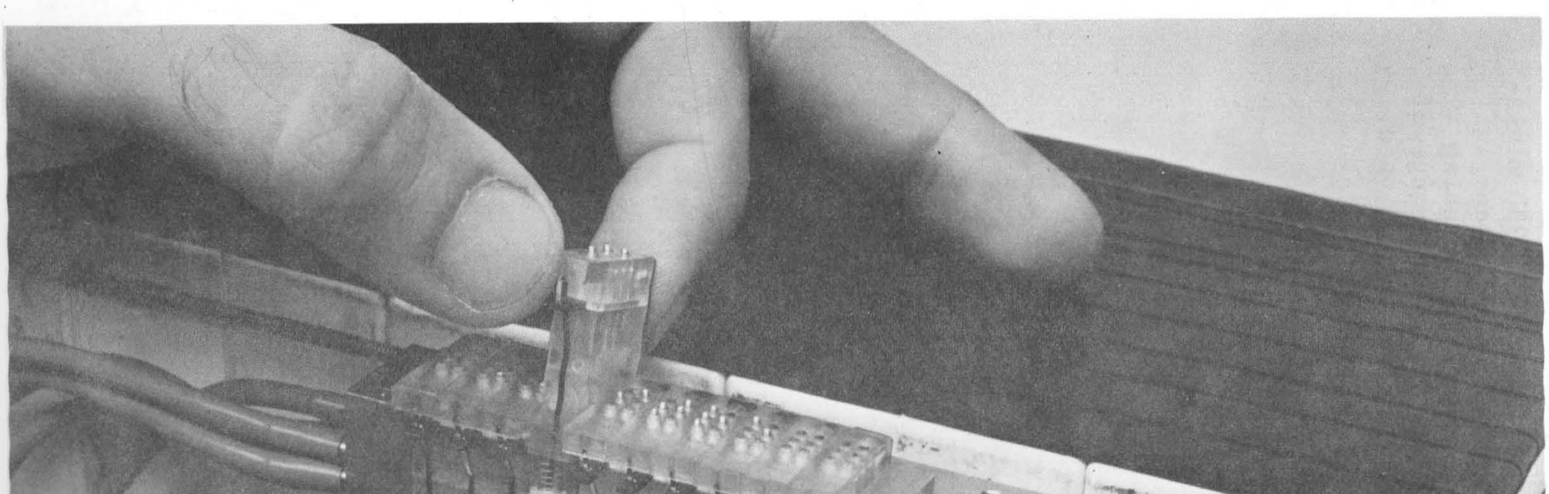
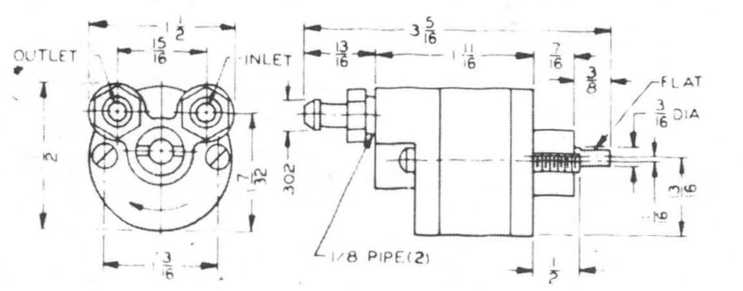


Figure 10. Illustration of Module Replacement

The pressure source which was selected was the Model 0330 miniature rotary-vane compressor from the GAST Manufacturing Company in Benton Harbor, Michigan. This is an oil-less compressor weighing only 11 ounces, with a pressure range of 1-10 psi, a vacuum range of 0-20 inches of mercury, and a maximum flow of .67 cfm running open. Figure 11 shows the dimensions of the compressor.



Model 0330

Figure 11. GAST Model 0330 Miniature Air Compressor

Valve Development

Operation of the modules requires a set of six valves which transduce the electrical signals representing each character into the appropriate positive or negative air pressures to raise or lower small pins within each module. No satisfactory valves could be located commercially, and it was necessary to design and fabricate our own.

Figure 12 shows an exploded view of the three-way valve which was developed to act as a pressure/vacuum switch. Operation of the valve is explained as follows:

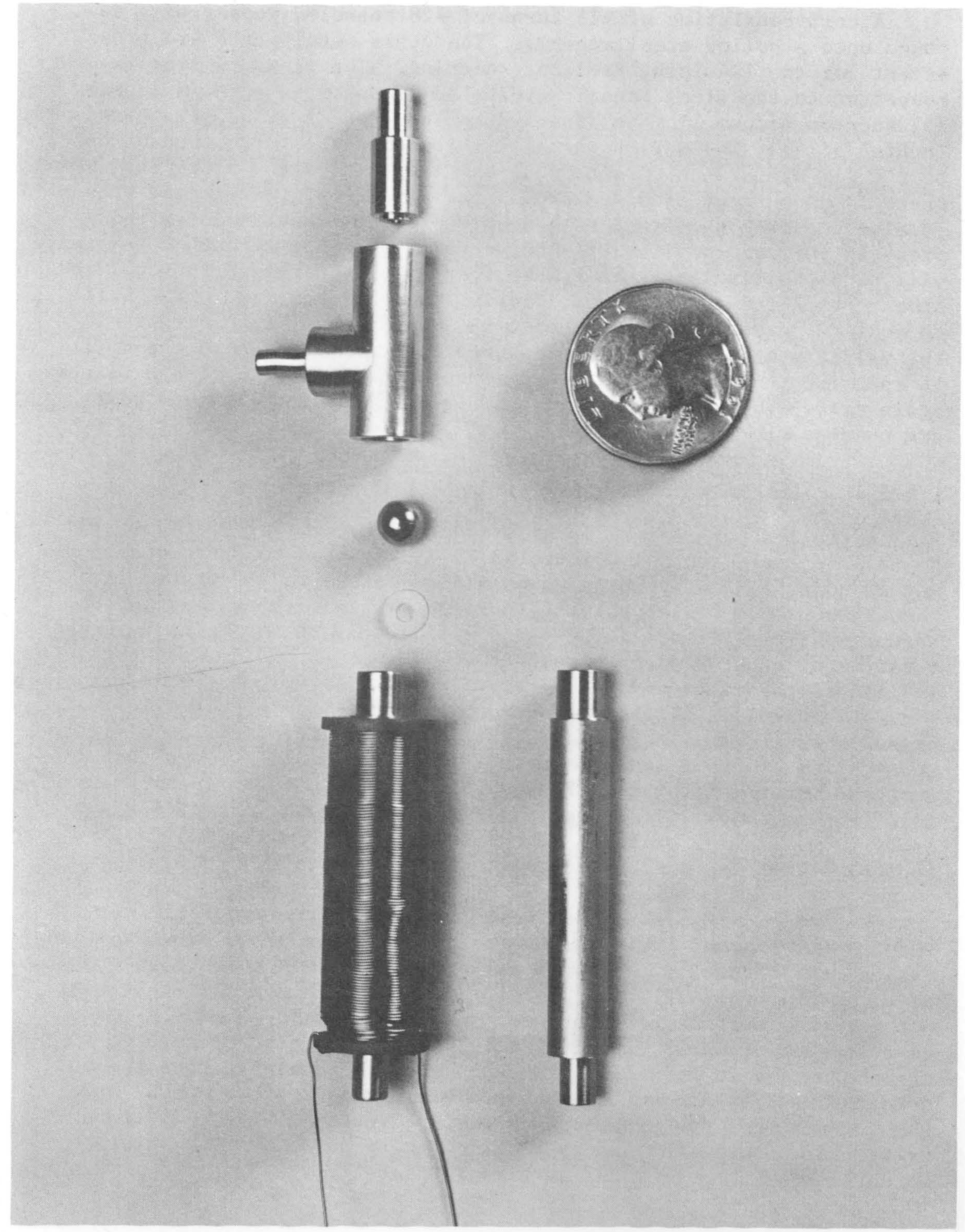


Figure 12. Exploded View of Three-Way Valve

A coil consisting of 925 turns of #28 enameled copper wire is wound onto a hollow steel mandril. The other metal parts are brass, except for the 1/4-inch steel ball bearing. The pressure line is connected to the steel mandril (left-end of valve as seen in Figure 12) and the vacuum line is attached to the brass fitting (right-end in Figure 12). The outlet on the top is connected to the end of one of the six air channels which runs the length of a row of cells. When there is no current flowing through the coil, the pressure and vacuum combine to force the steel ball bearing to the right, opening the pressure port and sealing off the vacuum port. The output of the valve will be a positive pressure. When the coil is energized (6 vdc), the steel core becomes magnetized, drawing the ball bearing to the left to seal the pressure port and open the vacuum port. The output of the valve is then a negative pressure or vacuum as long as the coil is energized. When the coil is de-energized, the pressure and vacuum again drive the ball bearing to the right, closing the vacuum port and opening the pressure port.

Pressure System Explained

A small motor (Figure 13.A) operates the compressor (Figure 13.C). A variable speed control (Figure 13.B) is adjusted to produce approximately .35 cfm flow from the compressor. Intake to the system is through a vacuum relief valve (Figure 14.G) which is mounted in the vacuum manifold (Figure 14.E). The relief valve is adjusted to create a vacuum of about 2.5 cm Hg. within the vacuum manifold and, hence, is applied to the right-end of the six 3-way valves (Figure 14.H). Incoming air, whose flow is slightly reduced because of the vacuum relief valve, passes through a cylindrical can (Figure 14.C) which acts as a filter and muffler. Output from the compressor (Figure 14.A) flows through another filter/muffler can (Figure 14.B) and into the pressure manifold (Figure 14.D). Pressure is applied to the left-end of the six 3-way valves, and a pressure relief valve (Figure 14.F) is adjusted to insure that the pressure does not exceed .5 psi.

When the 3-way valves are de-energized and the compressor is running (the normal state when the display is ready and between write cycles) the output of the 3-way valves which is directed to the row of cells (Figure 14.I) is a positive pressure of .5 psi. If it were not for the interposers in the modules, all pins in all cells would be raised. During a write cycle, valves are energized according to which pins are to be pulled down. Energizing a valve causes the output of that valve to switch from positive pressure to vacuum. Once the valve states are established, the interposer of the cell to be written is opened long enough to allow the pins to be set, after which it closes to lock the pattern in place.

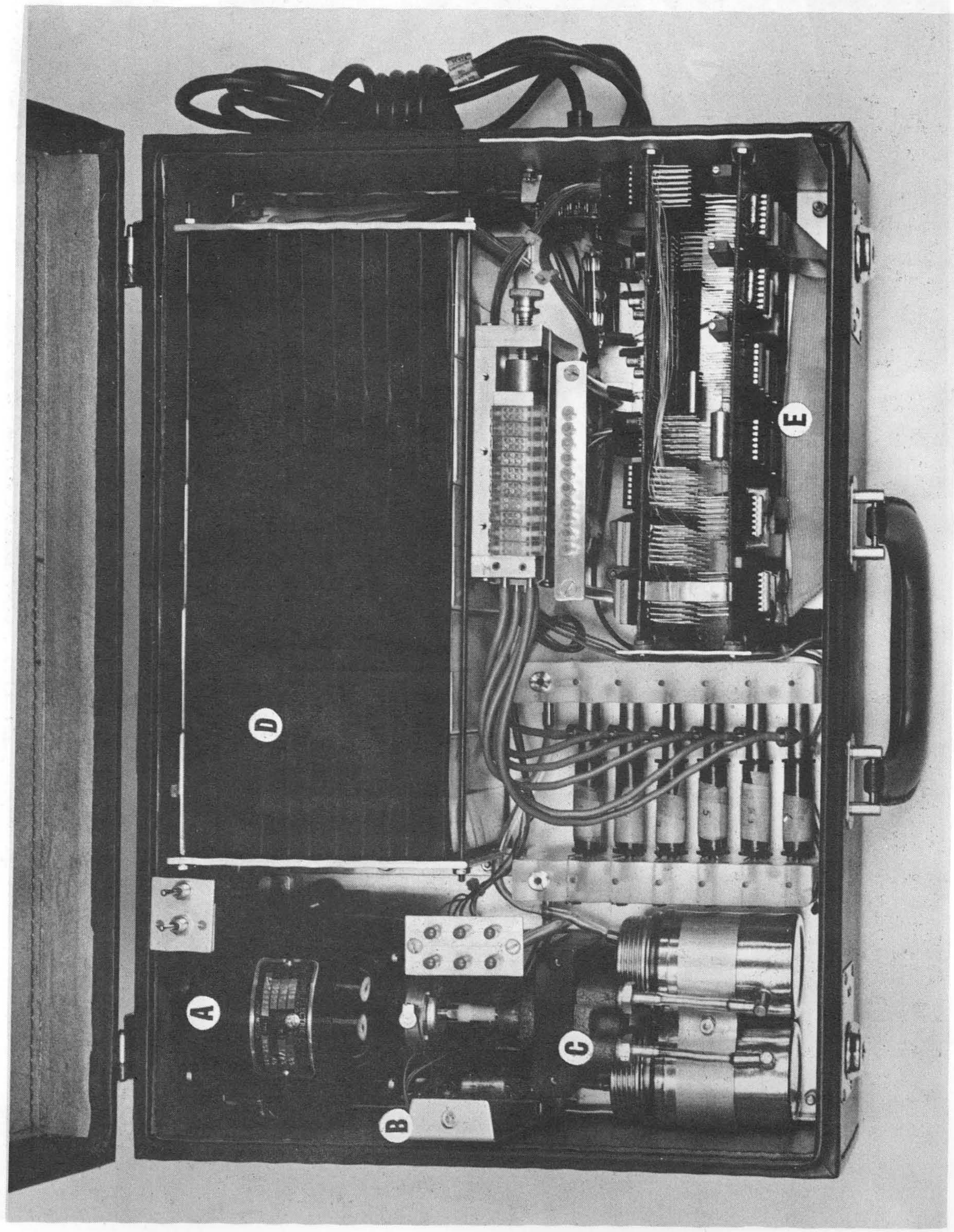


Figure 13. Interior View of Display with Keyboard Removed

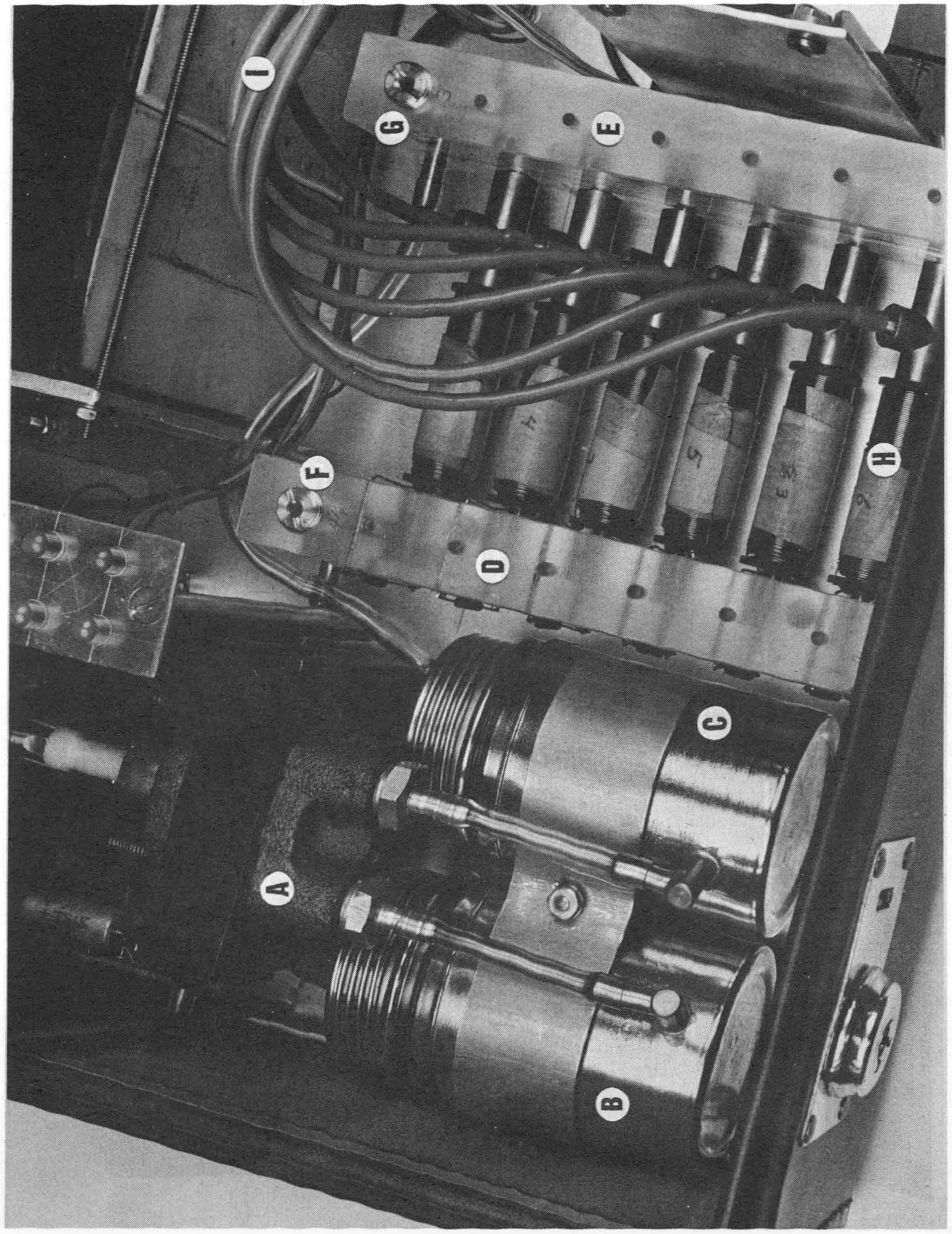


Figure 14. Close-Up of Pressure System

DISPLAY SPECIFICATION AND FABRICATION

Functional Specification

The functional specification was in keeping with the philosophy of a general purpose display. The specification called for a package containing a display surface made up of ten modules, and all of the hardware required to operate the modules, including the power supply, pressure system, and digital logic circuitry. Data input and control lines to the display were to be compatible with standard digital logic, and were to be available on a single connector plug. It was assumed that input to the display data lines would be in accordance with the standard braille convention; conversion from originating code to braille was not included within the display since this conversion would vary according to the data source. Figure 15 illustrates the data and control lines to the display.

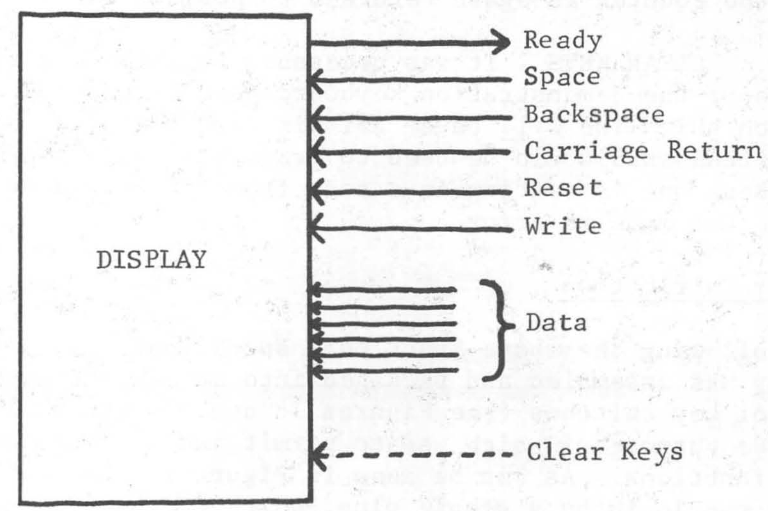


Figure 15. Display Data and Control Lines

A functional description of the data and control lines follows:

1. READY - This line is a logic "1" when the display is ready to receive data, and is a logic "0" when the display is busy performing any of its functions.

2. SPACE - An up-down counter is used to determine which cell is to be written next. SPACE steps the counter ahead one position. If the counter is already in the last (tenth) position, SPACE has no effect.

3. BACKSPACE - Steps the up-down counter back one position. If the counter is already in the first position, BACKSPACE has no effect.

4. CARRIAGE RETURN - Sets the up-down counter to position one.

5. DATA - Each of the six data lines is connected to a flip-flop. A pulse on the data line sets the corresponding flip-flop to a logic "1".

6. WRITE - A write pulse causes the code which is currently stored in the flip-flops to be written into the selected cell. The flip-flops are then cleared to logic "0", and the up-down counter is stepped ahead one position.

7. RESET - The up-down counter is set at position one, and a blank code is then consecutively written into all ten cells, after which the counter is again returned to position one.

8. CLEAR KEYS - It was necessary to include this line only because of the demonstration keyboard (see Figure 16). A positive pulse on this line will cause all six flip-flops to be reset to logic "0". CLEAR KEYS would be used to erase the flip-flop memory in the case where one is setting in a code from the keyboard and realizes that he has made an error.

Display Fabrication

Following the above functional specifications, a ten-character display was assembled and packaged into an attaché case (Figure 14). A set of key switches (see Figures 16 and 17) was built into the package, the purpose of which was to permit manual exercise of the various logic functions. As can be seen in Figure 17, the keyboard is connected to the logic by a single plug, which can be replaced or paralleled by a plug from an external data source. Hence, any function which can be exercised from the keyboard can be initiated from an external device as well.

For demonstration purposes, a row of indicator lights (see Figure 16) was placed under the row of braille cells. One indicator light is turned on under the cell which is selected to be written into next. When the light in the last position is turned on, an audible tone is generated, to inform a blind operator that he has reached the end of the display. The lights, of course, are for the benefit of sighted persons during demonstration.

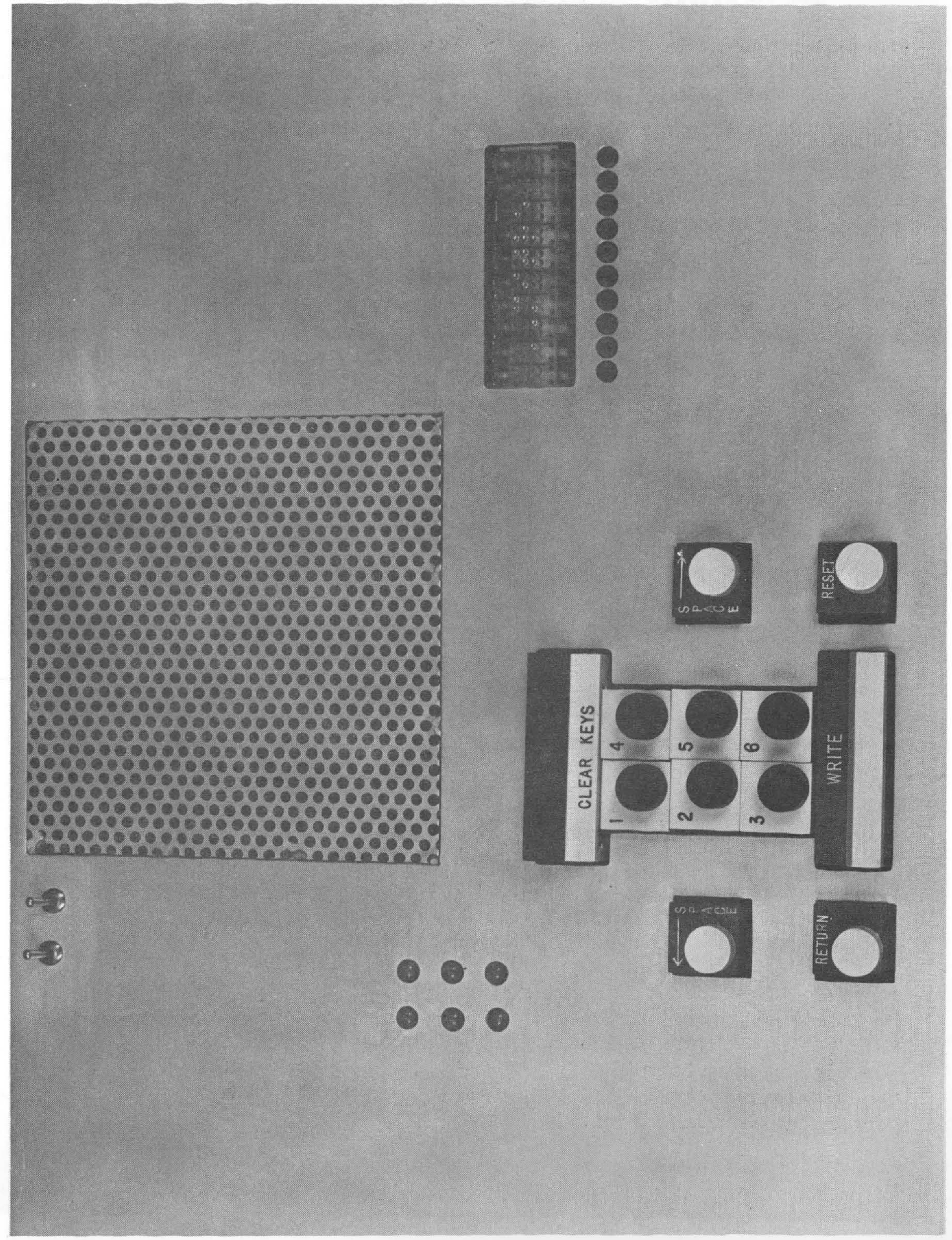
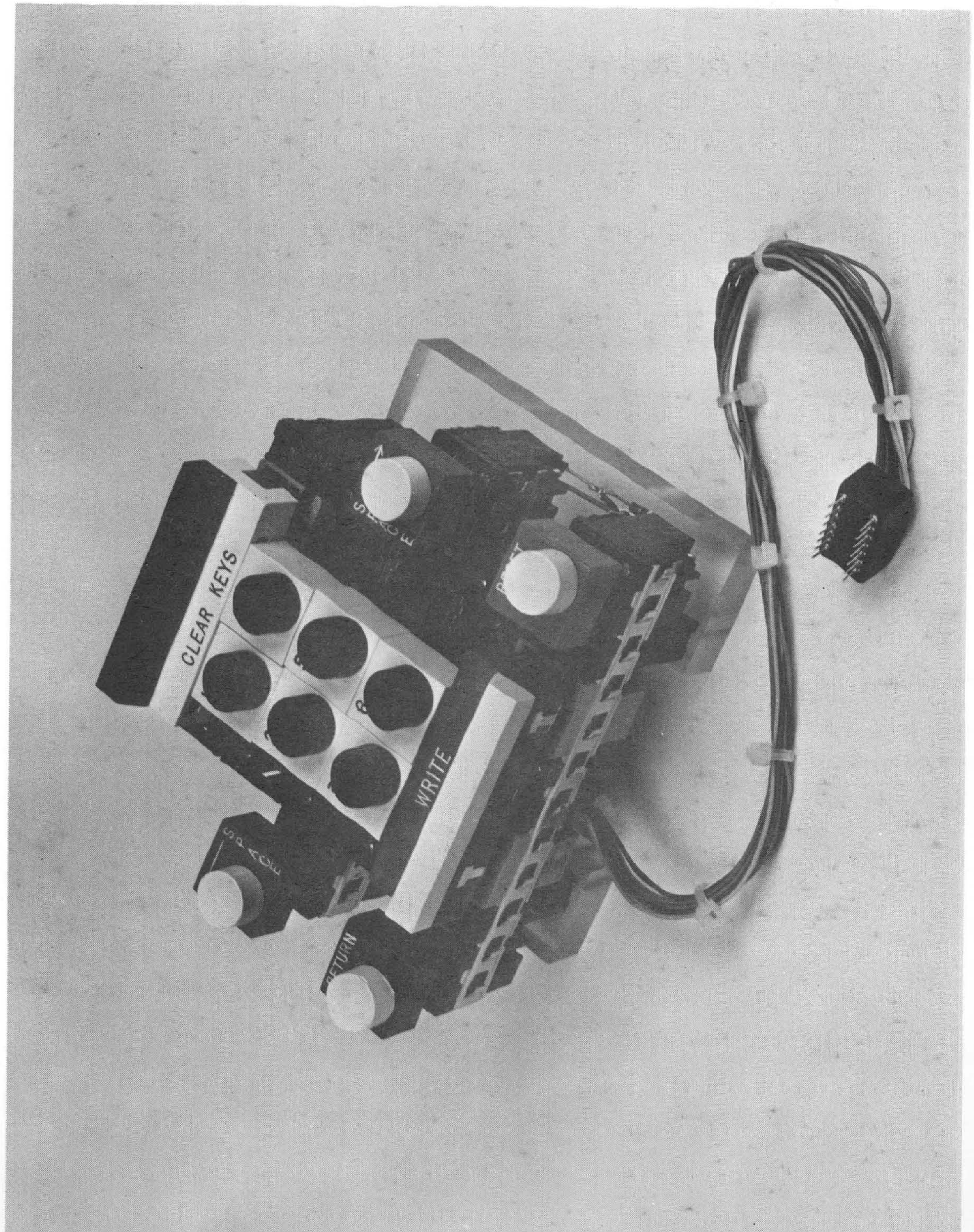


Figure 16. Close-Up of Display Keyboard and Read Surface



Another set of six indicator lights, in the pattern of one braille cell (see Figure 16) was included to show the logical contents of the flip-flop memory. A logic "1" in a given flip-flop causes the corresponding indicator to be lighted. The CLEAR KEYS switch which resets the flip-flops also causes all indicator lights to be turned off.

The logic required to implement the desired functions translated into 31 IC's, mounted on two 3½" x 8" boards (Figure 13.E). Standard TTL integrated circuits were used throughout. The logic requires approximately .5 amperes of current at 5 vdc.

The large coils on the 3-way valves (see Figure 3) operate at 6 vdc, and draw a current of .8 amperes each. The solenoids which operate the cell interposers (see Figure 9.D) operate at 6 vdc and draw a current of .3 amperes each. Thus, the peak current load occurs when writing a blank code, at which time current is required to operate the logic plus six valves and one solenoid. This peak load of 5.6 amperes necessitates a rather substantial power supply. The power supply which was used for the demonstration display (Figure 13.D) consisted of five 1.25 volt rechargeable Nickel-Cadmium batteries. The output from four batteries supplies the 5 volts to the logic, while the output from all five batteries is used to operate the valve and solenoid coils.

Adjustments were incorporated in the logic to permit varying the write cycle timing between 10 and 20 characters per second. The display is currently operating at 14 characters per second; no accurate determination has yet been made of the maximum achievable rate, but it is expected to be somewhat less than 20 characters per second.

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Information Processing

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APPENDIX

EXPLANATION OF MODULE OPERATION

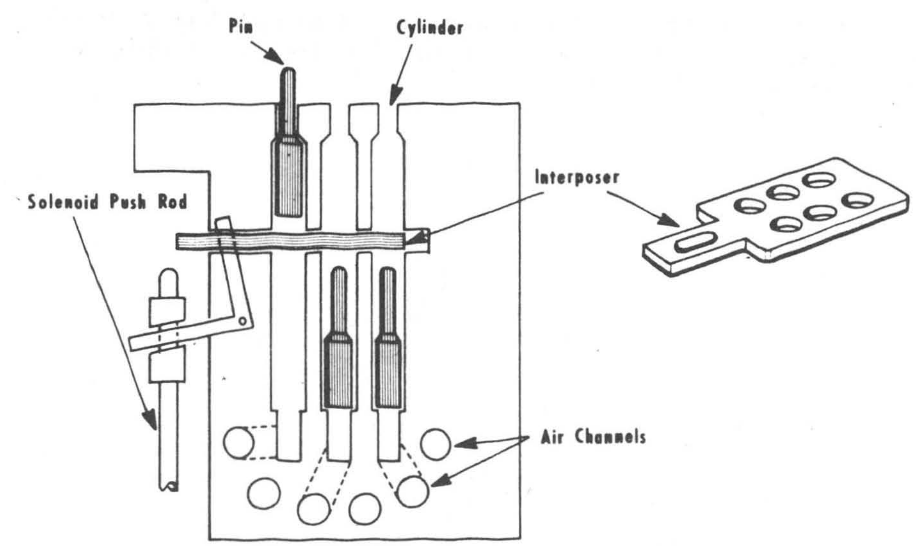
The following two pages are taken from Concept Paper M69-64, June 1969, and describe the operation of the braille module as initially conceived.

APPENDIX

EXPLANATION OF MODULE OPERATION

THE DISPLAY MODULE

The module is operated using a combination of pneumatic and electro-mechanical action. The sketch below gives a cut-away side view of the module.

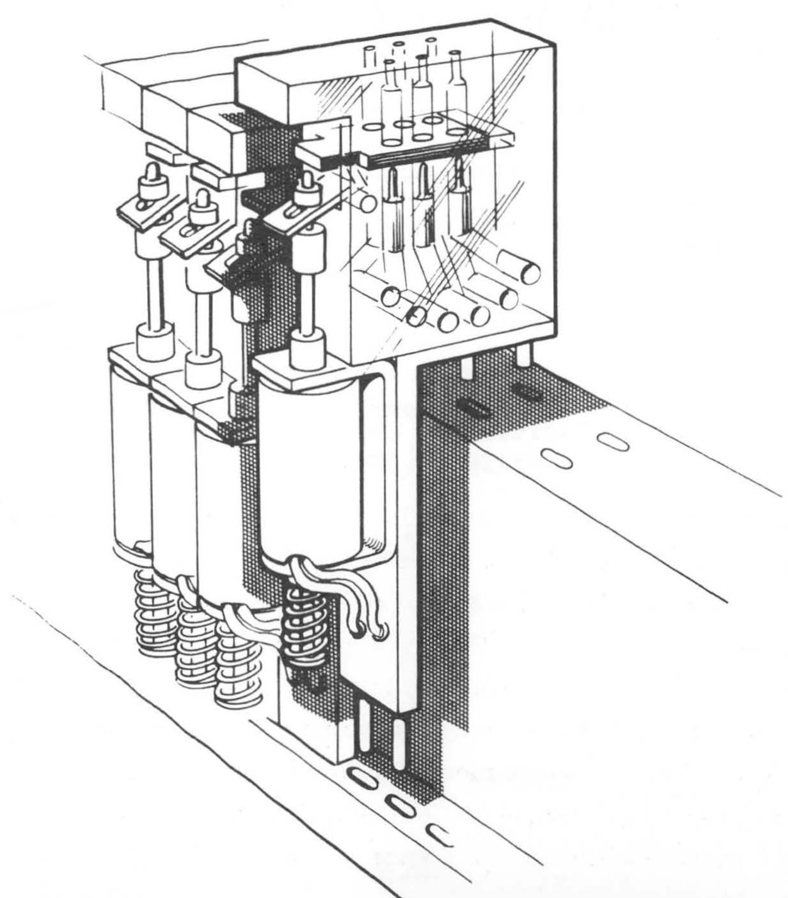


Six pins slide vertically in six cylinders. Air pressure is the drive force which moves the pins. In the middle of the cell, an interposer (see sketch) slides back and forth horizontally across the cylinders. The interposer contains six holes; when it is closed, the holes are misaligned with the cylinders, and the pins which are at the bottom of the cylinders are blocked or held down. When the interposer slides forward the holes align with the cylinders and any pins which receive an air pulse are free to rise to the top of the cylinder. After selected pins have been raised the interposer is allowed to close, and now serves to hold up the selected pins while continuing to hold down unselected pins. The interposer is opened and closed by actuating a small solenoid. One solenoid is required per module.

Looking at the side view, note the six holes arranged in a semicircle around the bottom of the module. These holes go straight through the module, and each one is connected internally to a different cylinder. When a number of modules are stacked side-by-side the holes line up down the row to create six air lines which are common to the row.

The code for a given character is delivered simultaneously to all cells in a row, but is only set in the module in which the interposer has been actuated to unblock the pins.

The modules are designed to be pluggable units, for ease of maintenance and replacement. Modules are 1/4 inch wide, giving standard spacing of 4 Braille cells per inch when stacked to form a row.



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