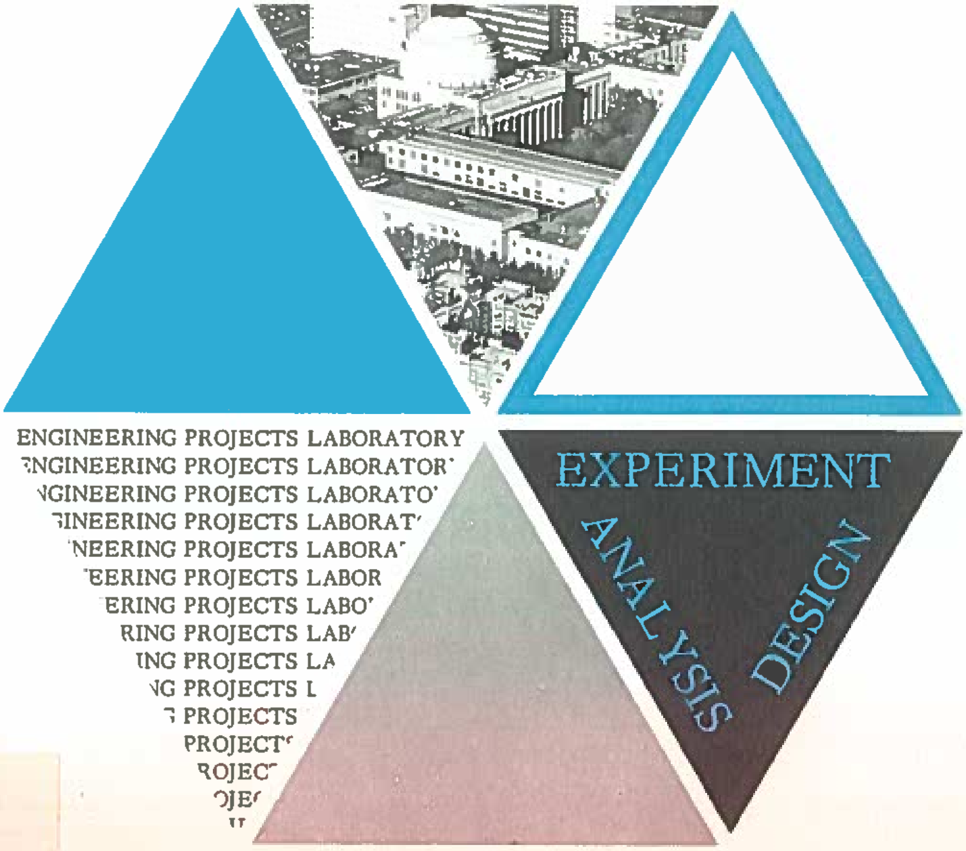
EVALUATION REPORT ON WORK IN PROGRESS ON SENSORY AIDS AND PROSTHETICS

April 1964

Report No. 9211-2
Department of Mechanical
Engineering
Massachusetts Institute
of Technology



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Department of Health, Education and Welfare
Vocational Rehabilitation Administration
Washington 25, D.C.

Contract No. SAV-1011-62

FOREWORD

The Sensory Research Discussions originated and chaired bi-weekly at M. I. T. in the Fall of 1959 by John K. Dupress, at that time Director of Technological Research of the American Foundation for the Blind, influenced several faculty in the Mechanical Engineering Department at M. I. T. to interest themselves and their students in research and development problems associated with human deprivation. Initial investigation were unsupported, conducted entirely within the context of undergraduate laboratory and design projects and thesis work. Subsequently a small grant from the American Foundation for the Blind made possible the fabrication of, and experiments with several research devices. By January 1961 the activity blossomed under the formal support of the Office of Vocational Rehabilitation (now the Vocational Rehabilitation Administration) of the Department of Health, Education and Welfare under contracts SAV-1004-61 and SAV-1011-62, which partially supports the principal investigators, Professors Dwight W. Baumann, Robert W. Mann, and Thomas B. Sheridan, a number of graduate student research assistants in the Engineering Projects Laboratory (EPL), as well as underwriting the work of non-salaried, full-time students engaged in related design and laboratory projects and theses. This report is one of two summarizing the second year's program under VRA-DHEW support through contract SAV-1011-62.

With one exception all projects referred to in this EPL Report No. 9211-2, the Evaluation Report on Work in Progress during the period June 1962 to May 1963, have already been or will be reported in detail in the form of undergraduate or graduate theses. The original of each of these theses is in the public domain in the M. I. T. Library and is available for reference and for photocopy. The Engineering Projects Laboratory retains a reproducible master of all theses from which ozalid copies can be prepared upon request to the the Librarian, EPL Document Room, 3-156, M. I. T.

The exception, "Braille Translation by Computer," is documented in EPL Report No. 9211-1 and is also available from the EPL Librarian.

A bibliography appended to this report identifies reports, theses, projects, and design and laboratory projects conducted under the EPL-M. I. T. Sensory Aids and Prosthetics Research and Development Projects.

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1. AUTOMATING BRAILLE TRANSLATION AND PRESENTATION

Robert W. Mann, Robert C. Gammill

A major part of the current M.I.T. Engineering Projects Laboratory project is directed toward enhancing the availability of Braille material. We desire to increase the scope of ink-print material translated into Braille to include not only popular books and periodicals but also texts, journals, current news, office correspondence, etc., as well as increasing the volume of Braille material in each category. As a second goal we desire to decrease the real-time elapsed between origin of edited material and its Braille counterpart. And finally we desire to automate to a maximum the entire process of acquisition, translation and presentation in order that the resulting schemes be practical and economic.

The previous year's "Evaluation Report on Work in Progress on Sensory Aids and Prosthetics,"[1] described studies on the availability and character of type-composition-tapes which are very widely used in the publishing industry to automate the printing process.

EPL report 9211-1, "Braille Translation by Computer," by Robert Gammill,[2] describes the process by which a particular form of these type-composition-tapes was converted into the standardized Braille Code[3] by means of several computer programs at M.I.T.

The input to the program was the Teletypesetter tape by means of which the Wall Street Journal simultaneously publishes their daily World Wide News column in a number of printing plants across the nation. The original news material is edited in the Wall Street Journal New York City office, and then transmitted by wire to the printing plants where the punched tape operates the Linotype machine to cast the lead type.

In order to use the Teletypesetter tape as computer input, a program using FAP coding was prepared at M.I.T. for the M.I.T. Computation Center IBM 7090 computer which reads the tape information photoelectrically and converts it into IBM cards in a standardized format. The Teletypesetter tape itself is not geometrically compatible with standard computer tape readers. For the purposes of this investigation the Teletypesetter tape was slit to remove unused and incompatible width. For future efforts a compatible tape reader will be necessary

For English to Braille translation a program was written using COMIT (a symbol manipulating language) with the output initially in Grade 1.0 Braille. Since the COMIT language, while proving flexible in the programming, produces only binary codes in its output, the results were left in mnemonic form and printed out in lines conforming to Braille format.

Upon successful testing as a Grade 1.0 translator, the system was upgraded by the insertion of table search for whole words, a few final contractions, and one initial contraction, which are allowed only if they are at the end or beginning of the word. Considerable space saving resulted, but of course less than that provided with Grade 2.0 Braille.

The flexibility of the COMIT translator recommends it for studies of revising of Grade 2.0 Braille rules as proposed in the EPL-M.I.T. thesis of Gerald Staack.[4] Mr. Staack proposed a set of rules which would not allow exceptions or ambiguities and would thus theoretically permit a translation program which would not require continual updating of the "dictionary" in the memory of the computer.

A COMIT translator including provisions for modified Grade 2.0 Braille would permit parallel psychophysical testing of blind subjects on material prepared, in one case, according to strict Grade 2.0 rules and, in the second case, according to the modified rules.

For the World Wide news column translation into standard Grade 2.0 Braille, the program developed by Mrs. Ann Schack[5] of IBM in cooperation with the American Printing House for the Blind in Louisville, Kentucky was converted from its original 704 format into one compatible with the M.I.T. 7090. A number of facilitating changes were also incorporated.

Despite a number of remedial difficulties characteristic of a research investigation of this type, a number of columns of the news were prepared in Braille using the card and tape controlled plate embossing equipment at the American Printing House. The several computer programs introduced only one error in five pages of Braille. Some editing of the original teletype material was necessary to eliminate extraneous copy. For a large-scale effort, it is anticipated that most of this editing can be put under computer control.

The generation of tactile Braille from the computer output can be achieved using the automatic stereotactic equipment at Louisville and now also installed at the Howe Press in Watertown, Massachusetts. Alternatively, the output of the computer program recorded on tape perforated according to a Braille code can be used as input into one of several other devices under development at M. I. T. EPL.

The next section of this report discusses progress on continuous, mechanical Braille displays which use as their input a punched paper tape. The subsequent section reports the current state of our High-Speed Brailler Embosser which is intended to be used as a slave to a standard electric typewriter, driven by a punched tape or other storage-media input, or directly connected to the computer and used as a computer output for the benefit of a blind computer operator.

2. PUNCHED-TAPE-TO-BRAILLE TRANSDUCERS

Robert W. Mann, Ernesto E. Blanco, Alfred H. Bellows

The previous evaluation report[1] discussed possible mechanical elements which could provide a tactile Braille equivalent of Braille cells encoded in punched tape, and described the development of a line-at-a-time device and a continuous device, both based on pins whose vertical binary position is controlled by the presence or absence of holes in a punched tape and whose hemispherical heads constitute the tactile stimuli interpreted by the reader as Braille print.

Brief psychophysical testing of the initial, crude continuous transducer was sufficiently encouraging to justify the building of the model shown in operation in Fig. 1. A close-up of the pin heads which represent the Braille symbols is shown in Fig. 2. This second model was designed so as to maintain close tolerances in the paper-tape to pin array, with more attention directed toward smooth synchronization of paper motion to pin motion and with better provision to strip the tape from the pins without damage at the end of the reading surface. Provision was also included to facilitate the reversal of the drive and allow therefore the back-up of the punched tape for re-reading purposes.

The redesigned unit operated quite satisfactorily over a considerable period of use, however, two difficulties developed. The brass segments carrying the pins were soldered to the beryllium copper ribbon as in the previous model. In time, the soldered connections proved inadequate to withstand the fatigue induced by the flexure of the ribbon when traversing over the pulleys. An attempt to re-solder the individual segments failed due to difficulty in positioning the segments on the ribbon. Also, the loss of ribbon temper due to excessive localized heating rendered it easily deformable causing noticeable transverse wrinkles.

Concurrent with the metallurgical difficulties it was found that the accumulated longitudinal variations of the punched tape holes over the display length of the belt caused occasional malfunctioning due to lack of concentricity between holes and pins. Such difficulty did not occur often, but since there does not appear to be sufficient hole spacing control in the present punching machines (possibly because

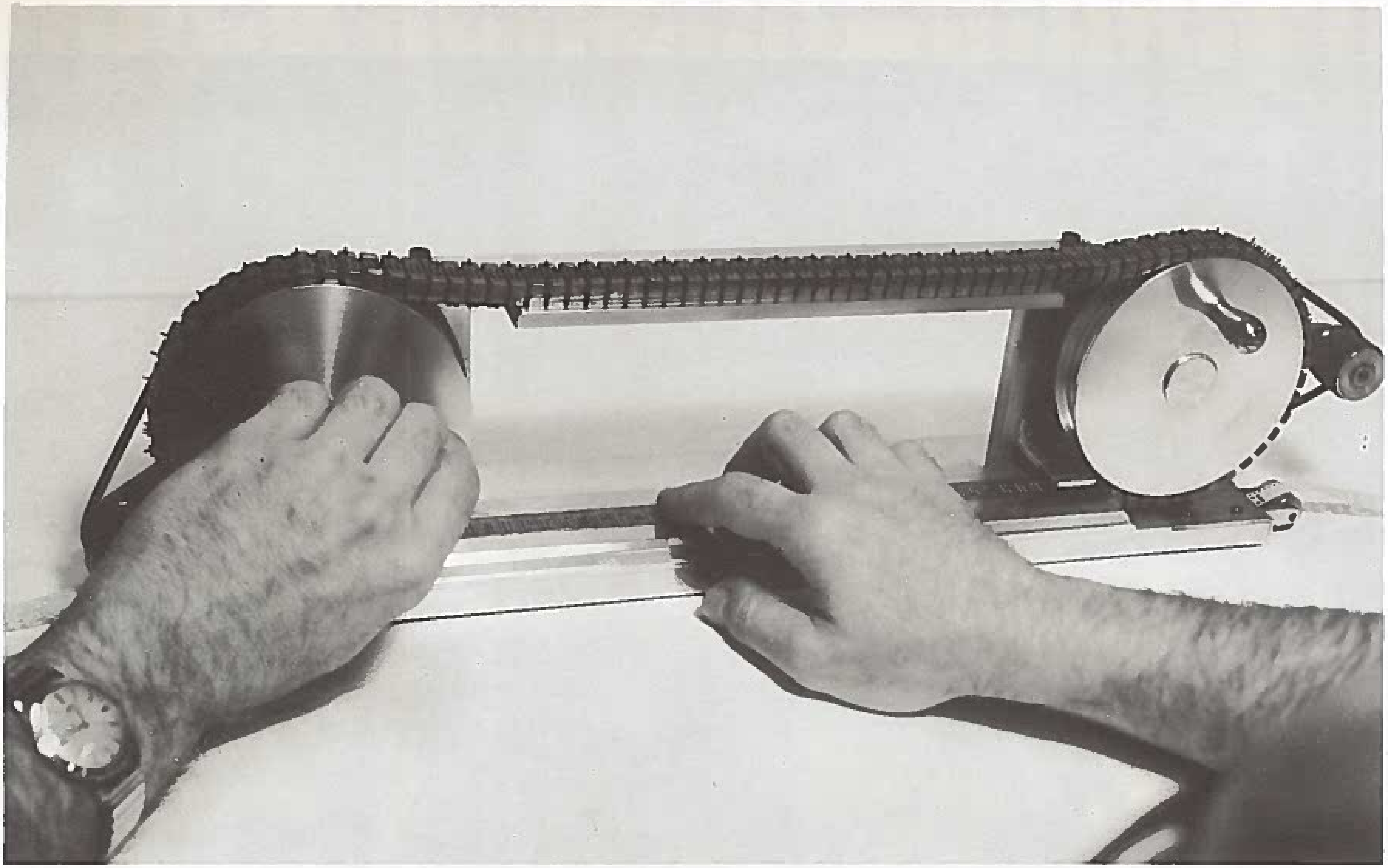


Fig. 1. Punched paper tape to Braille Transducer using a continuous belt carrying pin elements. Device is shown in reading position.

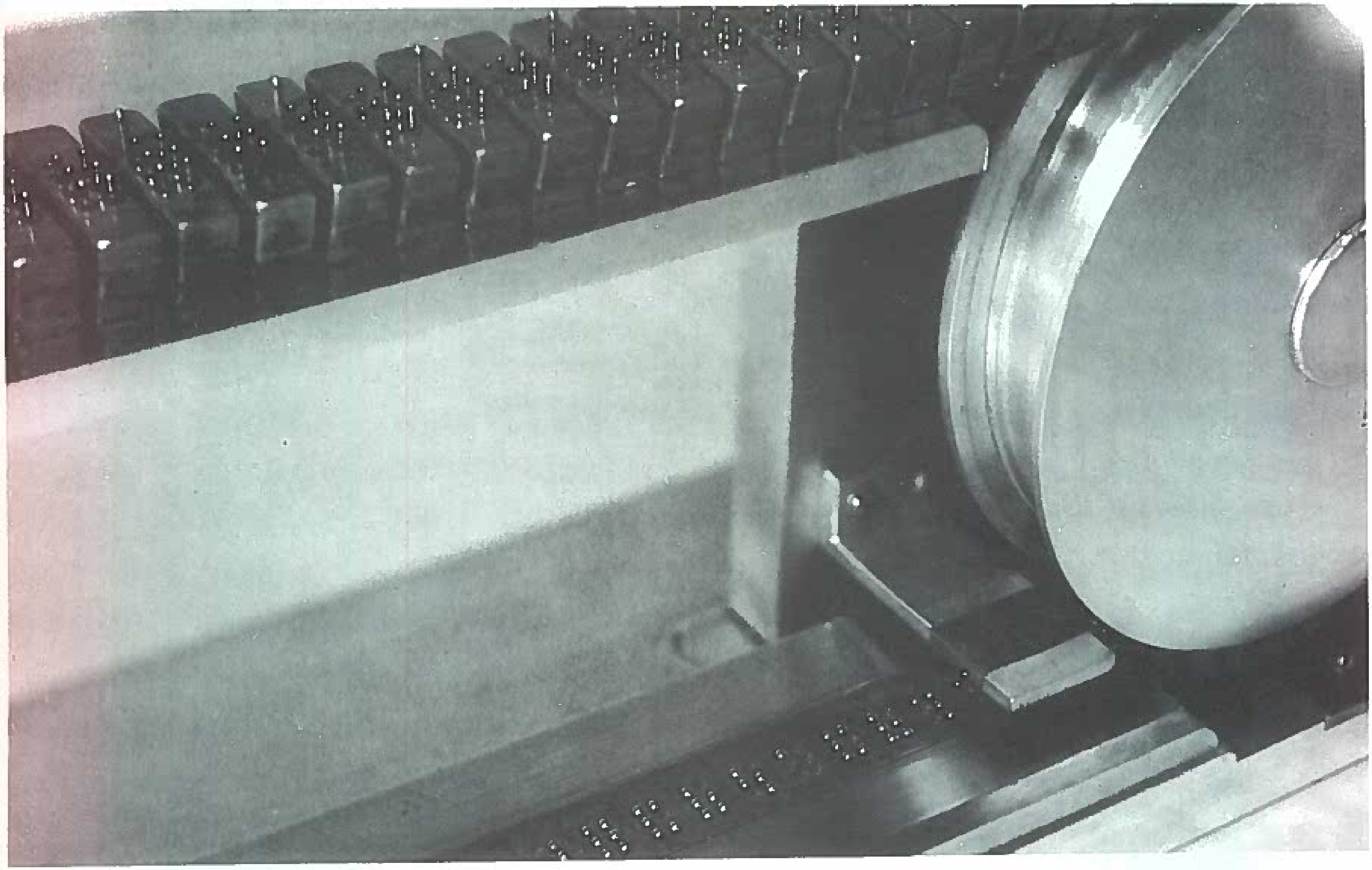


Fig. 2. Reading surface of the "Braille-out" showing pin heads characterizing the Braille embossings.

most tape readers are not affected by accumulated lengthwise errors), and since paper is also subject to physical changes with environmental conditions, an alternative arrangement was sought.

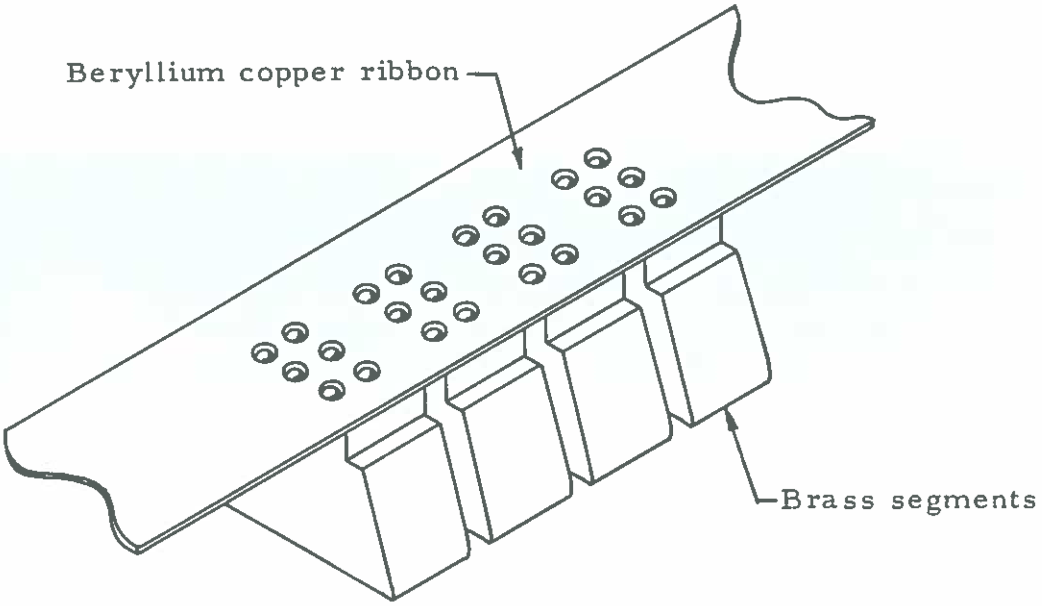
Both the bonding and tolerance problems were solved by threading the original brass segments by means of two fine steel wires. The segments are spaced with sheet rubber which provides some lengthwise compliance to accommodate tape variations. In the latest modification the wires have been replaced by two fine steel cables which increase the fatigue life of the assembly and simplify the problem of providing a durable belt joint. Figure 3 shows the belt construction. The gaps between segments which show in Fig. 4 (the rubber upper surface is recessed below the reading surface) has posed no "background" problem for the blind subjects who have tried the device.

A variable speed electric motor driving unit is in the process of being installed to free the user's non-reading hand and in order to record starts, stops, rates of motion, and reversals of typical users during evaluation. A plan for the evaluation of the device by blind subjects has been developed and some evaluation materials have been prepared.[6]

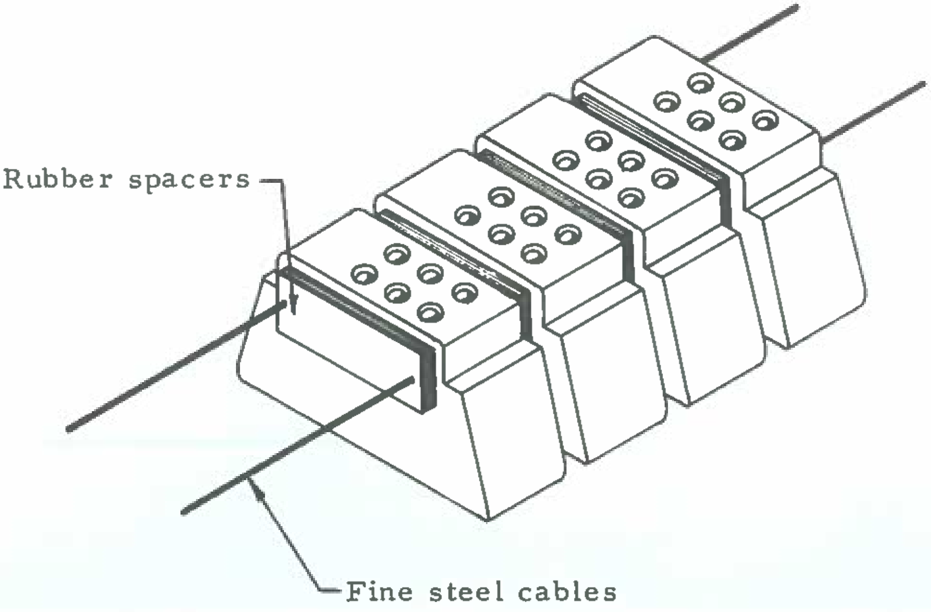
Last year's report also included a description of a transducer in which the tape, punched with holes where the Braille dots were to appear, stripped small ball bearings from a hopper. The spherical surface of the balls extended through the paper tape holes and provided the reading surface. The simple and crude model shown in last year's report (built by a Freshman as part of a seminar on Braille) proved promising enough when tested by several blind that a more sophisticated version was undertaken.

For this model it was proposed to use the punched tape as a valve to retain or release small bearing balls to drop into a special Braille display belt. This arrangement would not subject the paper tape to the abuse it would experience if it were actually carrying the balls during reading. Furthermore, the Braille code punched into the tape could be the standard 6 channel tape with one row per Braille symbol according to the Standard Braille Communication Code Format[3] arrangement rather than the non-standard two-by-three matrix plus

Fig. 2. Reading surface of the "Braille-out" showing pin heads characterizing the Braille embossings.



Original Belt Construction



Present Belt Construction

Fig. 3.

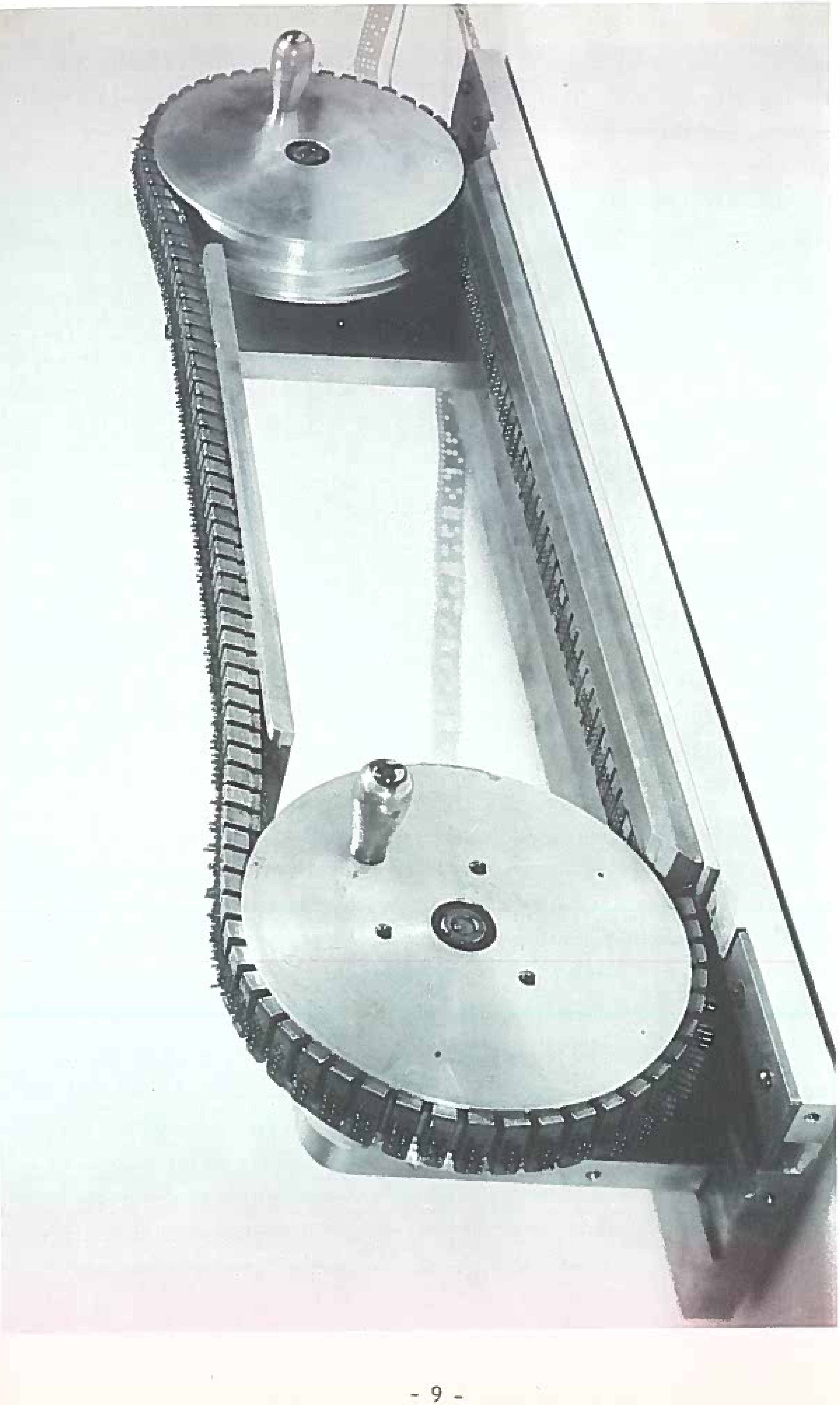


Fig. 4. The pin-type "Braille-out" with wire cable support and spacers between Braille cell blocks.

space required for the pin approach to direct reading. The balls falling through the holes punched in the one-by-six code would be rearranged into the Braille two-by-three matrix by appropriate chutes. This scheme could also employ a display belt conforming exactly to the standard Braille dimensions rather than the slightly different paper tape dimensions, a requirement imposed on the pin transducer.

A hand-operated prototype model has been designed and built and is illustrated in Fig. 5. The punched paper tape enters the transducer from the left and passes through a distributor, shown with front removed in Fig. 6. A drum rotates under a hopper filled with 1/16 in. diameter bearing balls. These balls fill cells drilled in the periphery of the drum -- one ball to each cell. The paper tape follows the drum through about one-fourth of its rotation. The tape is positioned on the drum with sprocket teeth so that where a hole is punched, a ball drops out of the matching cell, through the tape, and down a chute to the display belt located about 3/4 in. below the tape. The tape and the belt are driven at corresponding speeds.

The display belt is a laminate of thin sheet steel and a strip of cork. Holes punched in the steel allow a segment of the respective balls to extend through the steel, thus resembling a raised Braille dot. Larger matching holes in the cork locate the balls over the proper holes in the steel.

The balls drop into the belt at the bottom of the machine where the belt is upside down. The belt carrying the balls then travels around a pulley at the right hand end and then across the top of the machine from right to left. Here the belt entrapping the balls resembles a single line of Braille.

The blind person reads the Braille as it moves from right to left under his fingers as shown in Fig. 7. A ten-inch line allows him some freedom to vary his reading speed by superimposing his hand motion on the machine belt motion. As the display belt disappears at the left end, the balls drop out of the belt and return to the hopper in the distributor. The empty belt travels around another pulley and then passes under the distributor to receive another Braille message.

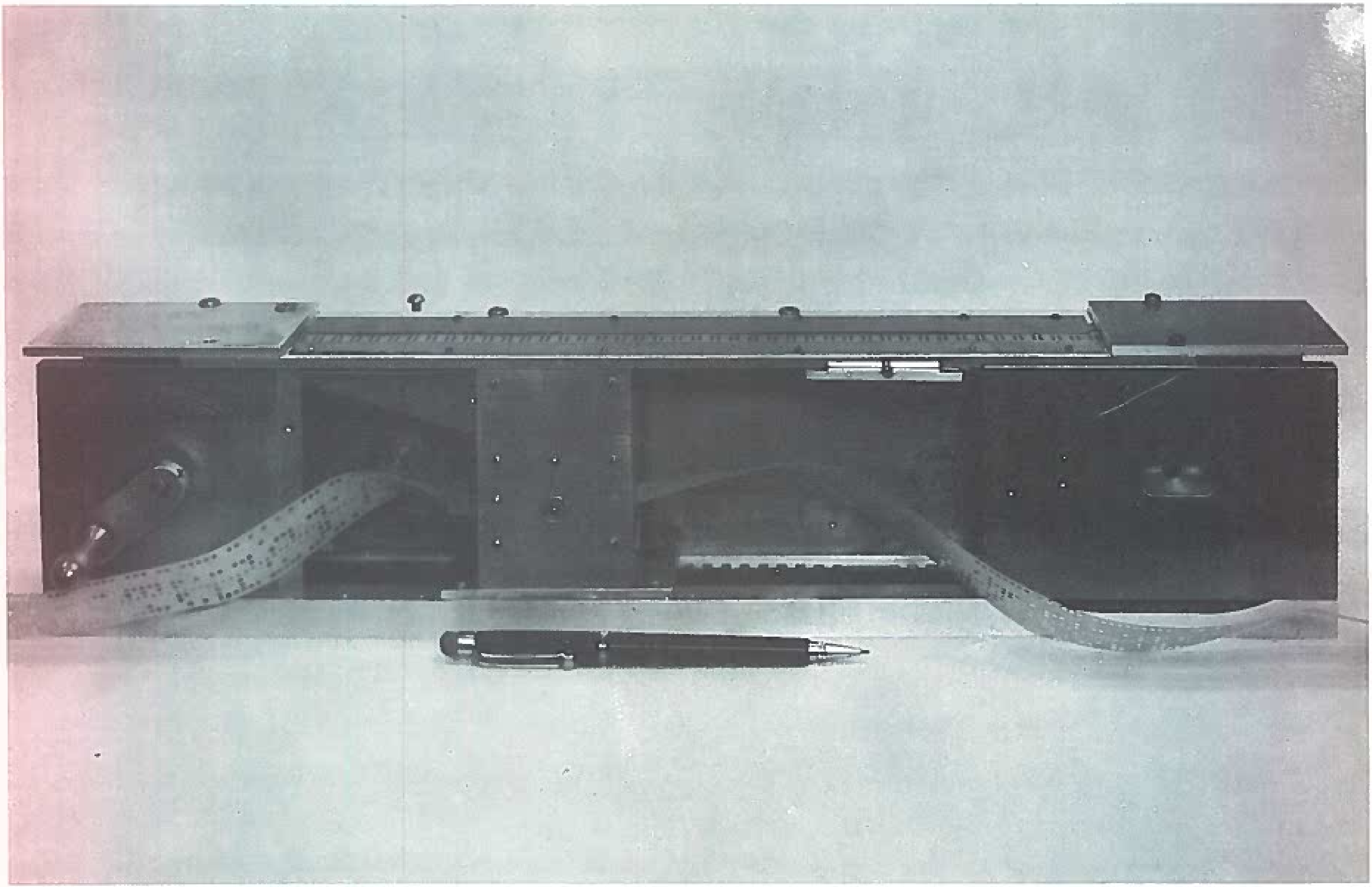


Fig. 5. Spherical ball "Braille-out" using standard format punched paper tape as input.

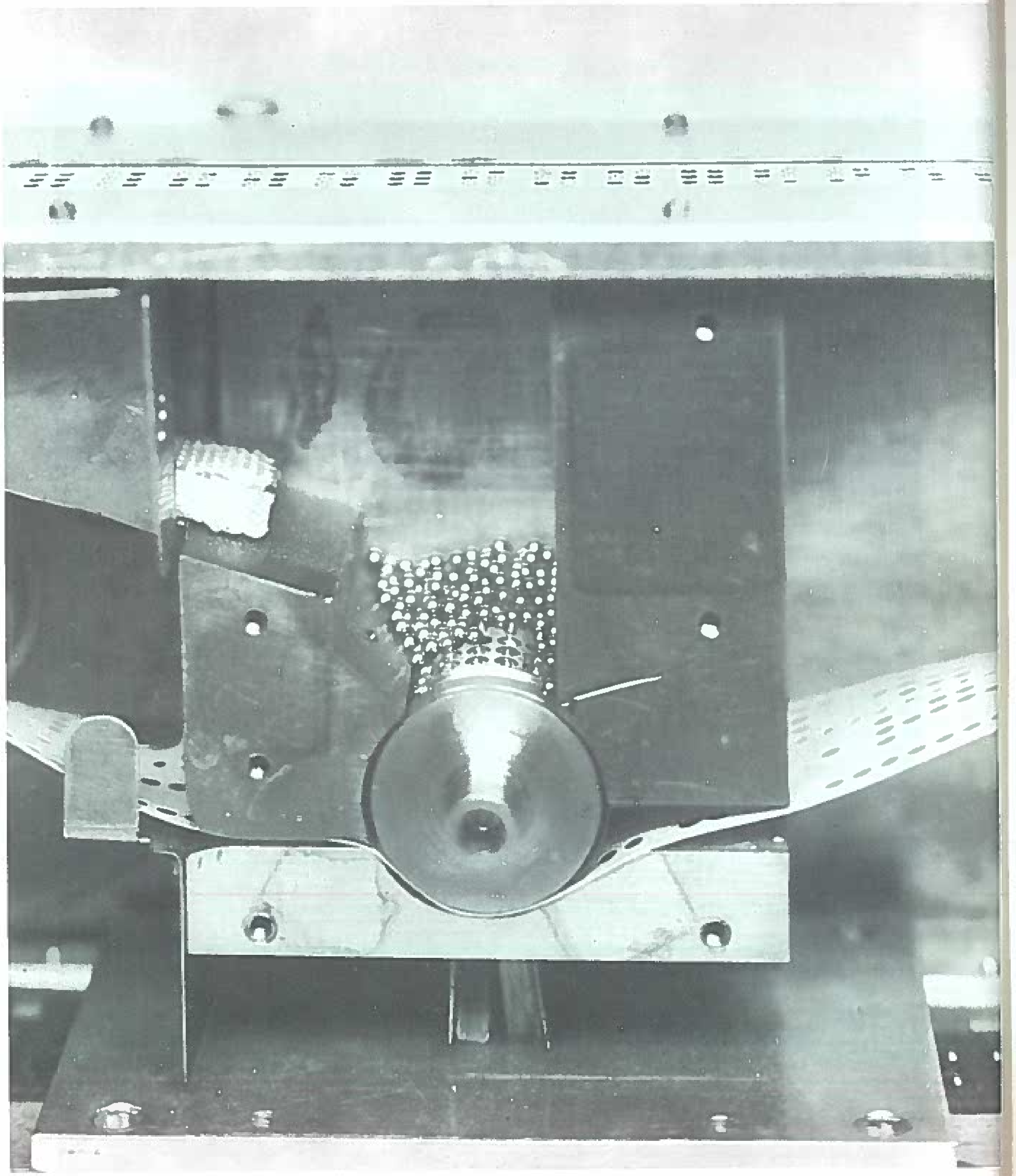


Fig. 6. Distribution of spherical ball "Braille-out" showing punched paper tape "valve".

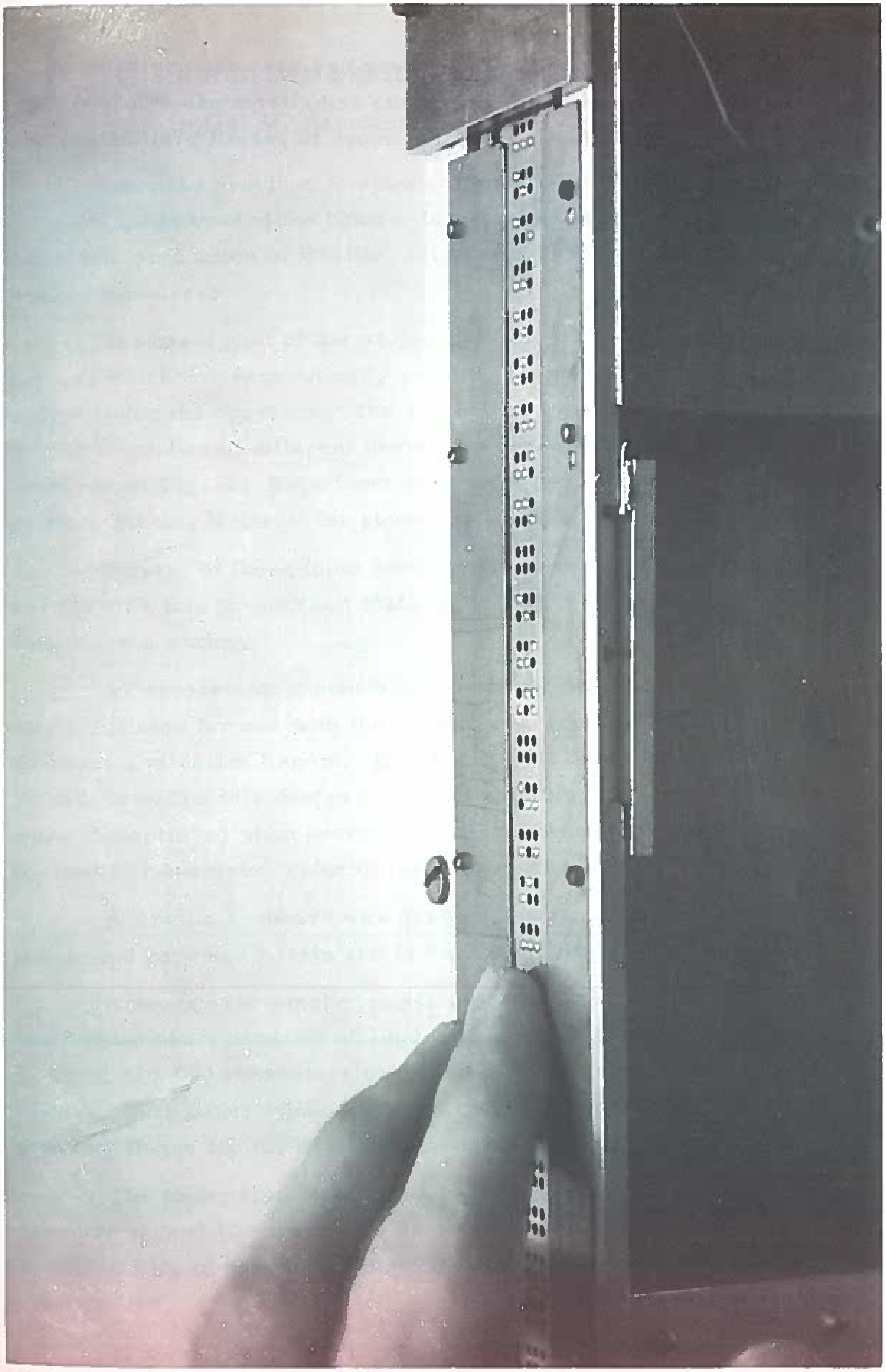


Fig. 7. Reading surface of the spherical ball "Braille-out".

As of this writing, the transducer has been demonstrated to operate. However, some improvements and alterations will have to be made before operation is reliable enough to permit preliminary testing with blind subjects.

3. HIGH-SPEED BRAILLE EMBOSSING SYSTEM

Dwight M. Baumann, Daniel W. Kennedy

Since the previous Evaluation Report,[1] substantial progress has been made toward the completion of a high-speed system for the automatic production of Braille, all arrayed around the High Speed Braille Embosser.

The basic goal of the project has not changed: a system is desired which can economically produce embossed Braille with minimum difficulty for the operator. The system must also be very flexible and permit a number of different devices to generate inputs to the embosser as shown in Fig. 8. Each input device, of course, has its own peculiarities, making it useful for some applications and not for others.

Several of these input devices have been investigated in connection with this project and their applicability to Braille in particular was under scrutiny.

An encoder for a standard typewriter was designed by Mr. David Eglinton for use with the system and was described in the previous Evaluation Report. It is more fully described in his thesis.[7] Efforts to refine this design to a level suitable for limited production were discontinued when several commercial devices appeared on the market (for example, refer to Invac Corporation, Natick, Mass.).

A Braille keyboard was designed by Mr. Robert Maskrey[8] during the period reported herein and is discussed later in this report.

A reader for punched paper tape, see Fig. 9, was designed and built which has a capacity of 1000 feet of paper tape. This corresponds to about 120,000 characters or 100 double-spaced typewritten pages of text. Such paper tapes are now available through the American Printing House for the Blind in Lexington, Kentucky.

The paper tape reader can read tape at rates up to 16 characters per second (the maximum speed of the Braille embosser) and is provided with an external control facility to permit synchronization with the Brailler.

In some instances, paper tapes are available which have not been punched with the Standard Braille Communication Code Format.[3] To

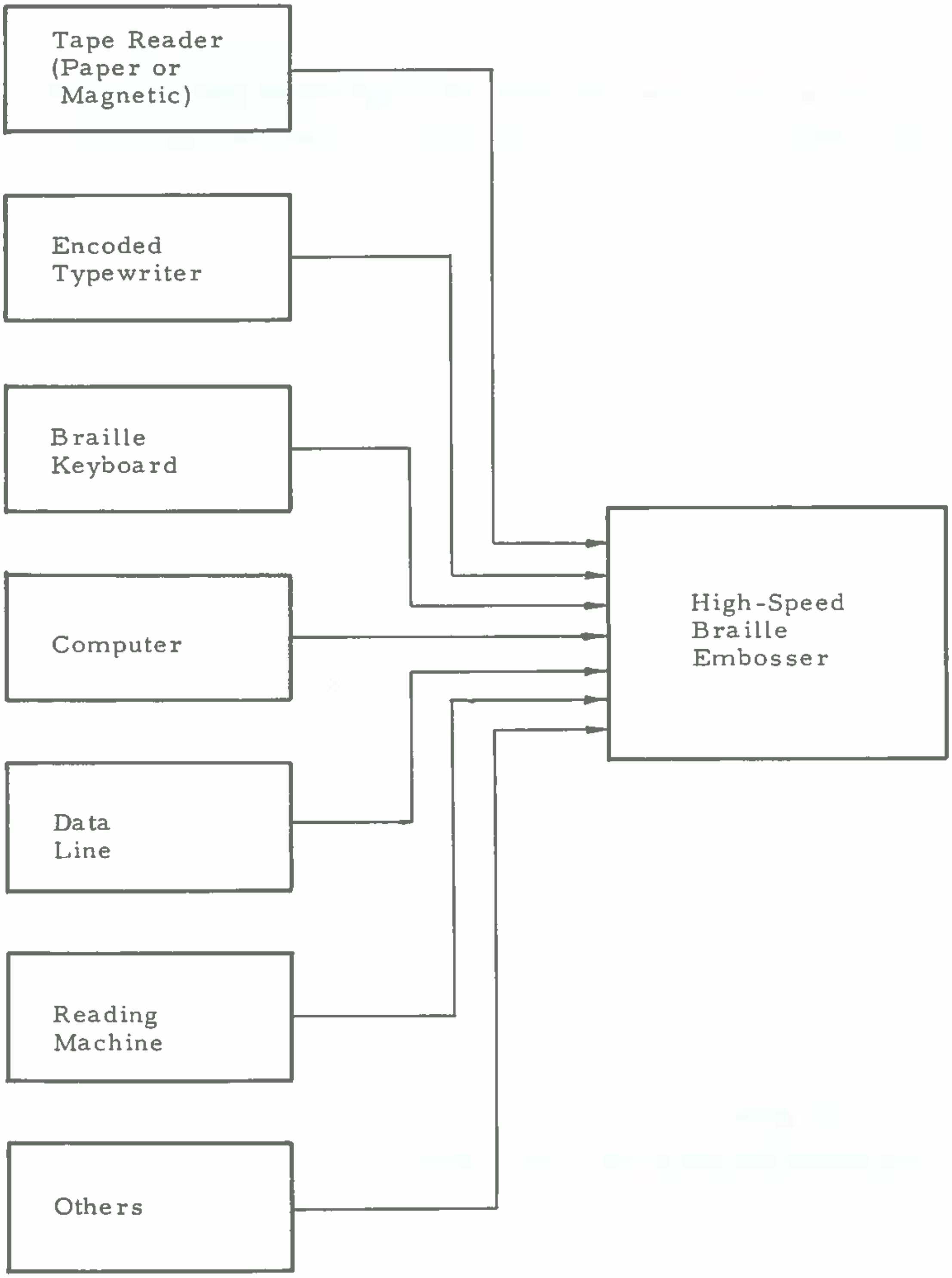


Fig. 8. Automated Braille System

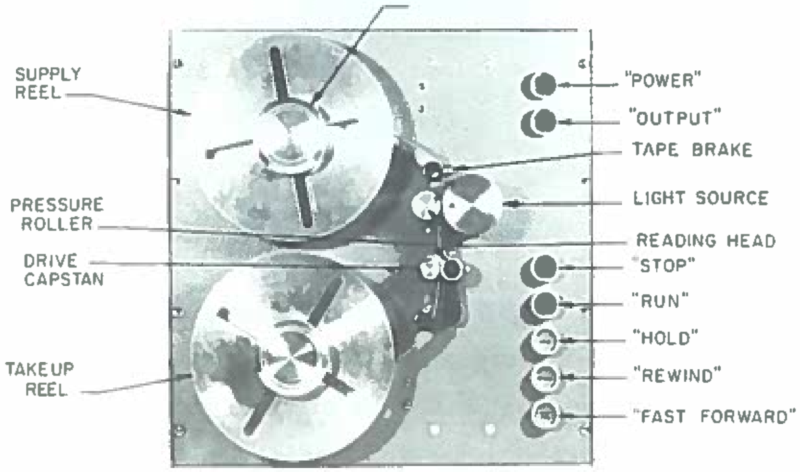


Fig. 9. Front of tape reader.

permit use of these tapes with the system, a digital code converter was designed by Mr. Robert Oaklund.[9] This converter effects a character-by-character translation of any eight-bit code into any other eight-bit code such as the Braille Communication Code. Obviously, with character-by-character translation, straight English text can be translated into only an approximate Grade 1.0 Braille form. This device is covered more thoroughly elsewhere in this report.

3.1 High Speed Braille Embosser

The High-Speed Brailler itself has advanced to the stage of a working prototype and is described in detail in Mr. Daniel Kennedy's thesis.[10] In all cases, parts were designed with the vision of limited production in the near future. Sheet metal parts were designed so that they could be easily stamped and the more massive parts were designed for ease of casting. Standard machine parts were used wherever possible to reduce the cost of small quantity production. Electronic components perform the functions of timing and holding since they can be acquired and assembled at a lower cost than the equivalent mechanical counterparts for the projected low production envisaged for the Brailler.

Fig. 10 gives an over-all version of the Brailler mechanism while Fig. 11 is a close-up of one of the embossing heads, now made of Delrin plastic.

Considerable effort went into the development of suitable mechanisms for driving the trio of embossing heads in their merry-go-round path. A small gearmotor is coupled to the driving sprocket through a helical spring arranged so as to provide fairly low torsional rigidity. The gear-motor winds up the spring until the torque is just sufficient to stall the motor. The motor is of such design that it can be stalled indefinitely without overheating. The embossing heads are held in position by an escapement rack which engages a tooth protruding from the bottom of each head. To make the heads index forward, the escapement rack is removed from contact with the heads for a few milliseconds whereby the heads quickly move forward under the influence of the energy stored in the coupling spring. The escapement rack is immediately brought back toward the heads before they reach the next tooth position in the rack whereupon they are again brought to rest.

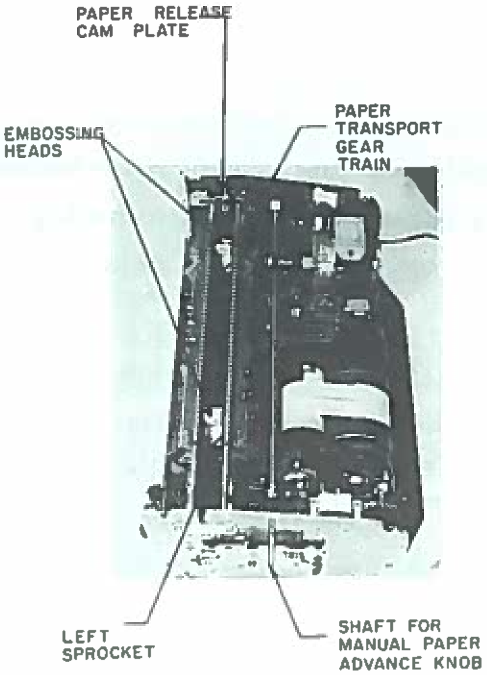


Fig. 10. Top view with platen removed.

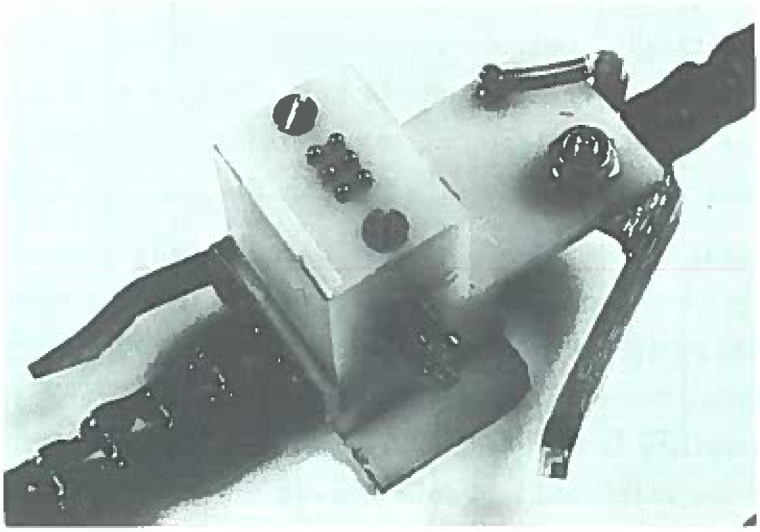


Fig. 11. The embossing head.

The entire process of moving the embossing heads from one embossing position to the next requires about 20 milliseconds. During this interval, the embossing heads experience high accelerations and decelerations, but this motion is effectively isolated from the gear-motor by the coupling spring. Thus, the embossing heads move (intentionally) in a very jerky fashion while the high inertia motor supplies power to the system in a smooth relatively continuous manner.

The solenoids which convert the electrical control signals into mechanical power were studied in some detail. As it turned out, the commercial solenoids which were originally used became very hot after about 20 minutes of machine operation and as a result, their performance (speed of response) deteriorated to an unacceptable level (8 to 10 characters per second). A new solenoid was designed with lower power input and a larger heat dissipation surface which operates at lower temperatures. The room temperature response of these solenoids is about 30 characters per second and after sufficient warmup time the performance drops off to about 20 characters per second which is safely above the required maximum operating speed of 16 characters per second.

The electronic controls were constructed and refined during this period. Essentially, the control unit consists of five sections: the input buffer storage, decoding logic, solenoid drivers, timing controls and the power supply as shown in Fig. 12.

The input buffer "remembers" the incoming signal until the Brailler has had time to operate on it and perform the required function. This is necessary so that no specifications are placed on the duration of an input signal thereby lessening the flexibility of the system. A parity check facility is built in to the memory so that each incoming character can be validated and thus lessen the possibility of malfunctions due to inoperative input elements, etc. The input signal is then decoded to determine which solenoids must be operated to perform the requested function. These "solenoid operate" signals are then amplified by the solenoid drivers to provide adequate power for the mechanical conversion.

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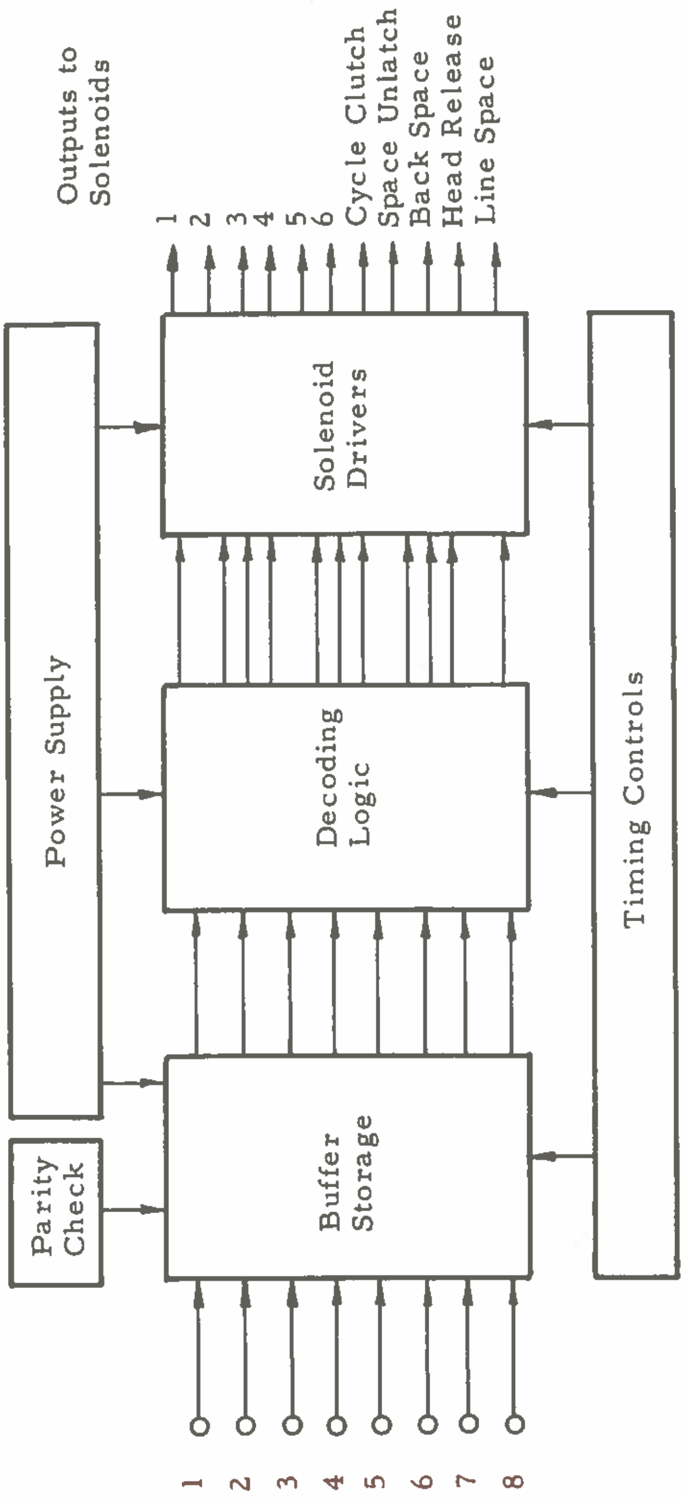


Fig. 12. Control Unit Block Diagram of Braille Embosser.

The timing control section acts as the "traffic cop" for all other operations. Under the influence of the timing control, the signal is sequentially brought from the input terminals to the solenoid terminals. Finally, the memory is "erased" in preparation for the next input command.

All in all, the electronic control unit accounts for about 500 of the Brailler's 1500 parts and shares a substantial portion of the total effort involved in fabricating a Brailler. As mentioned previously, much of the timing is performed by the control unit. However, there are several precision timing jobs which are handled by cams in the mechanical operational control unit. When accurate timing of a power operation is required, good old-fashioned cams are hard to beat. Five are used in the Brailler.

3.2 Braille Keyboard (Dwight M. Baumann, Robert H. Maskrey)

As a part of the high speed Braille producing system developed in the EPL at M.I.T., the design and development of a Braille Keyboard was undertaken. The purpose of this keyboard is to produce an output suitable for use by the High Speed Brailler, from an input of the depression of any or all of six keys corresponding to these used on the Perkins Brailler and other Braille producing devices.

The function of the keyboard is to convert a mechanical input into an electrical output. In doing so, the machine must accept any combination of six keys and machine functions, provide a coded output that is correlated in time, and it must provide visual and/or tactile feedback to the operator. These aims must be accomplished while maintaining compatibility with the Brailler in terms of input requirements, high speed, flexibility in the sense that it must be operable either one handed or two handed and should be adaptable to other uses than Braille, inexpensive, easy to construct and reliable.

To meet these requirements the keyboard utilizes a series of bails which are depressed by coded tabs on the keys which in turn energize a series of switches. The switches in turn produce an acceptable output for the Brailler. To correlate the output in time in spite of time lags in the input, a mechanical memory locks the keys in place until the last key has been depressed. When this happens the signal is released to the Brailler. For an operational diagram of this system see Fig. 13.

The feedback to the operator is provided through a keyboard lockout that prevents the operator from producing an output when the Brailler is executing an operation.

The keyboard itself consists of 13 separate keys of which 5 are essentially machine functions. Of the remaining eight, two are duplicated. Figure 14a indicates the present configurations of these keys. As now designed the keyboard can be operated either one handed by ignoring the keys 6 and 1 or in the conventional two handed mode by ignoring keys number $6'$ and $1'$.

Figure 14b proposes a key configuration which optimizes prospects for one and two handed operation.

The first use of the keyboard should be to evaluate the key spacing. When the optimum key spacing is determined, the most efficient keybar design can be considered to facilitate one handed operation. Then the keyboard should be used to evaluate the relative merits of Braille preparation with a conventional typewriter keyboard versus the six key keyboard.

3.3 Digital Code Converter (Dwight M. Baumann, Robert E. Oaklund)

Since the High Speed Braille Embosser accepts only the Standard Braille code,[3] means must be provided to translate otherwise readily obtainable coded information into the Braille code. For example, output, either direct or on paper tapes, prepared on standard Flexowriters and other encoding typewriters, information on certain of the typesetter tapes, etc., could form a useful input for the Brailler provided the individual character codes common to the source material can be translated into the Standard Braille code.

Of course a computer can be interposed between source material and Braille to achieve translation as described in the first section of this Evaluation Report, and only in this way can the contractions and special rules of Grade 2.0 Braille translation be achieved.

But many practical cases exist where transliteration character-by-character into the code acceptable to the Brailler will be satisfactory, although even here the Braille rules on capitals and numerals

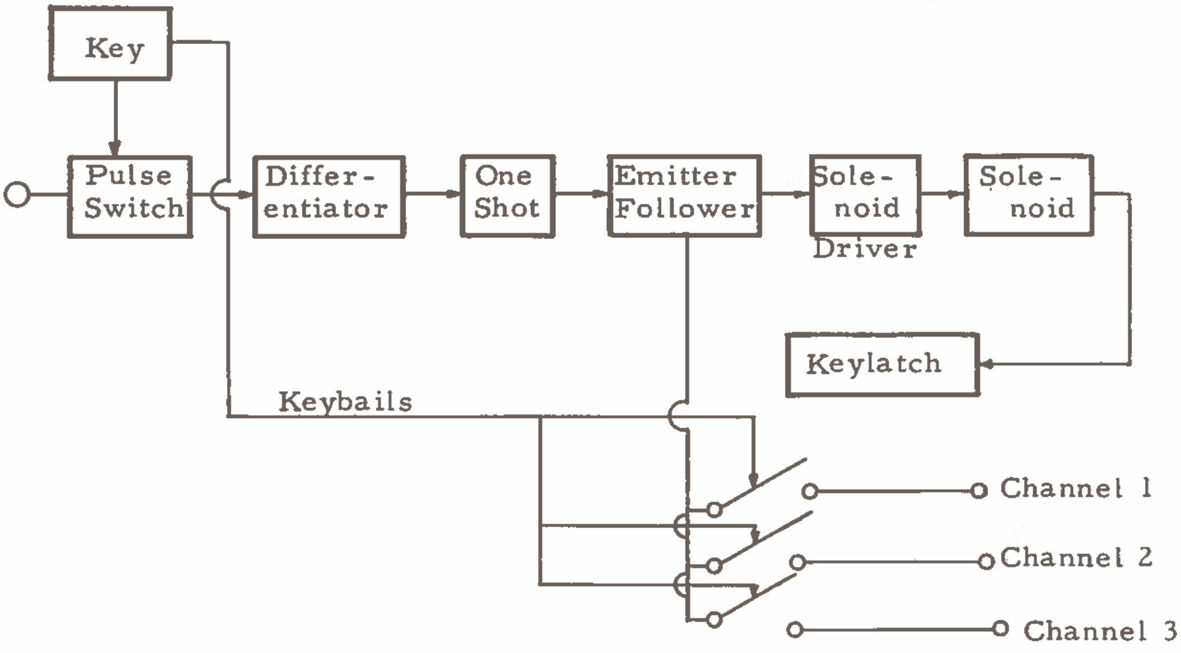


Fig. 13. Operational Diagram of Brailler Keyboard.

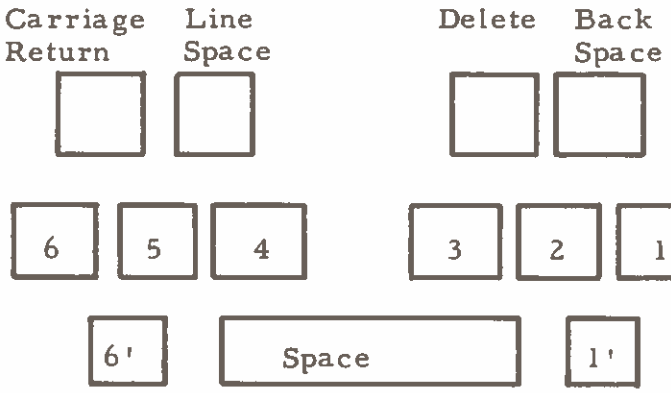


Fig. 14a. Key Configuration.

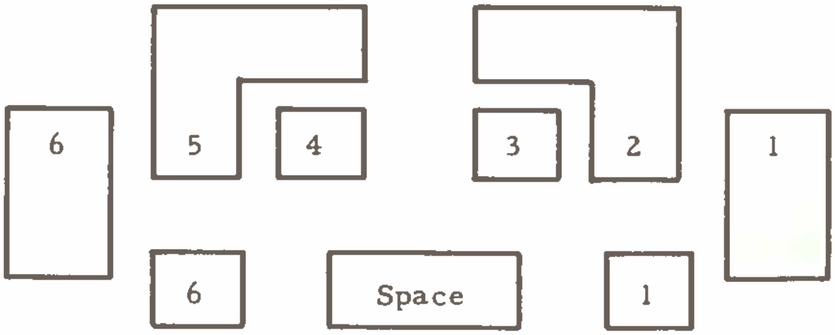


Fig. 14b. Proposed Key Configuration.

will not permit an exact Grade 1.0 translation unless the input is augmented appropriately or several minor Braille rule changes are assumed.

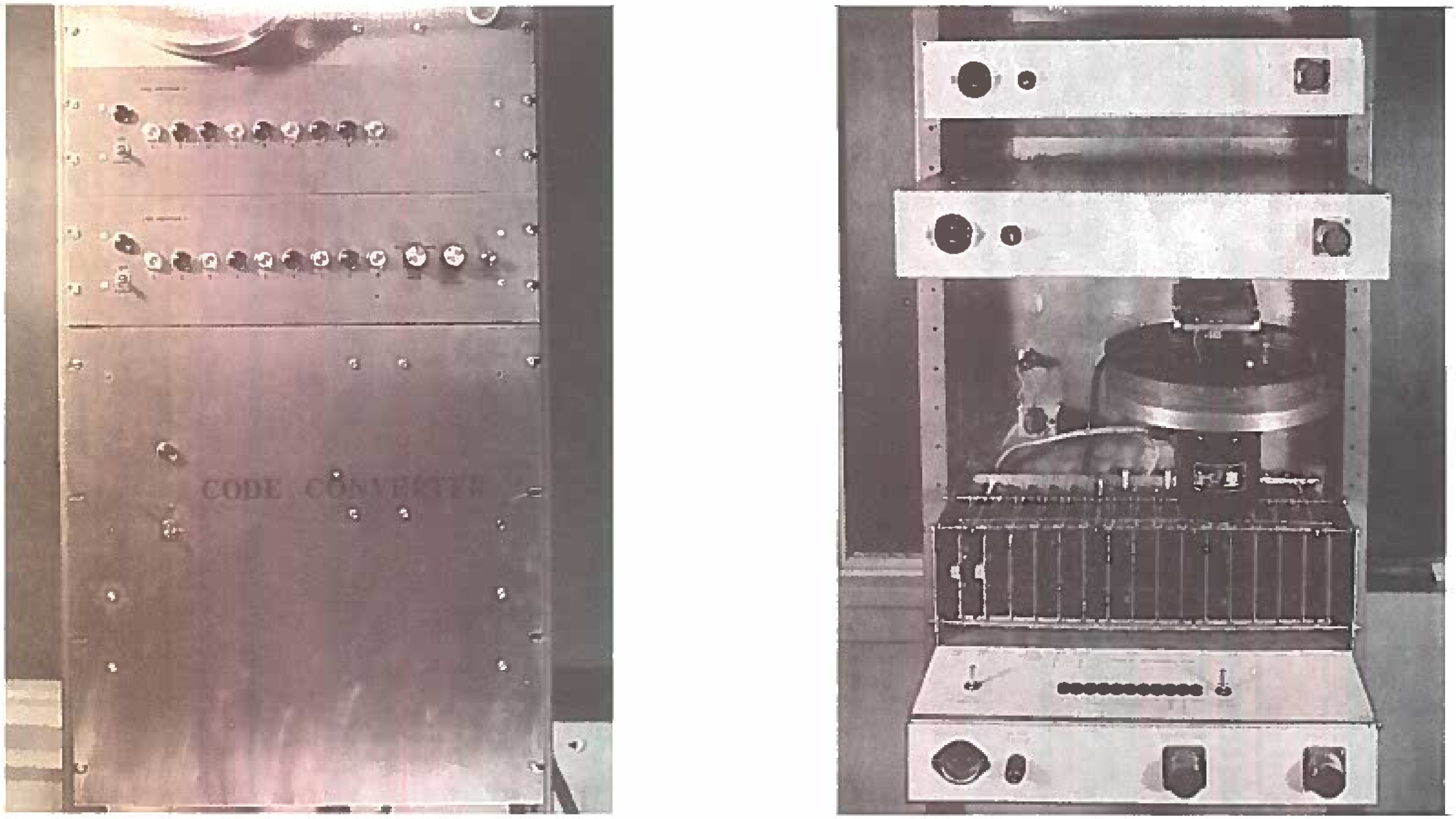
In order to satisfy this transliteration requirement for situations which would not warrant the expensive interposition of a computer, the design of a Digital Code Converter capable of translating <u>any</u> code of up to 8 bits into <u>any</u> other code of up to 8 bits at a rate of 30 characters per second was undertaken. The converter is especially intended to translate coded information between various input devices and the Brailler, but the particular design is adaptable, as will be shown, whenever direct translation is necessary, whatever the respective input and output codes.

The entire assembled structure of the code converter is shown in Fig. 15 from a front and rear view.

The code converter can be structurally separated into two parts, the drum assembly and the electrical assembly. Both are shown in Fig. 16. The drum assembly consists of a drum mounted on an A.C. motor which is attached to a supporting framework which also mounts the lamp and reading head. The reading head is shown in Fig. 17.

The drum is an aluminum disk with a clear plexiglas cylinder mounted to it, around which the coded output tape is wrapped. The code tape is standard one inch wide, eight channel punched paper tape. The tape is held in alignment between the aluminum disk and a thin strip of opaque plexiglas mounted on the plexiglas cylinder.

The lamp is mounted to the framework inside the drum opposite the reading head, which is mounted outside the drum. Contained in the reading head are ten light sensors, Texas Instruments H-38 Photo Duo Diodes. Eight of the light sensors track the eight channels on the tape. One light sensor is used in conjunction with the sprocket holes in the tape which is used as a counting track. The tenth light sensor can detect a small gap in the opaque plexiglas strip and is used as a reset for the counting track. The light from the lamp shines through the holes in the code tape and the reset gap to activate the light sensors.

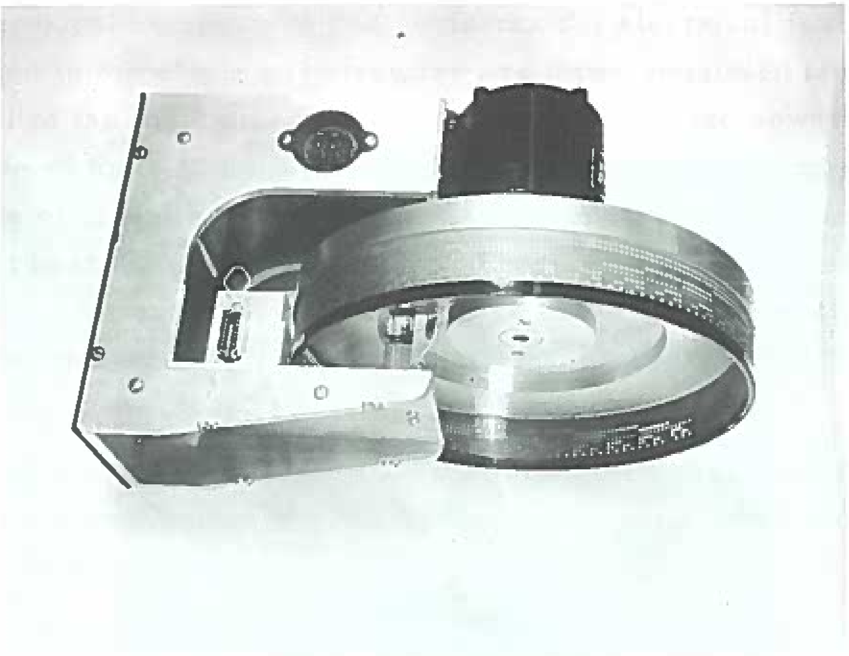


Front

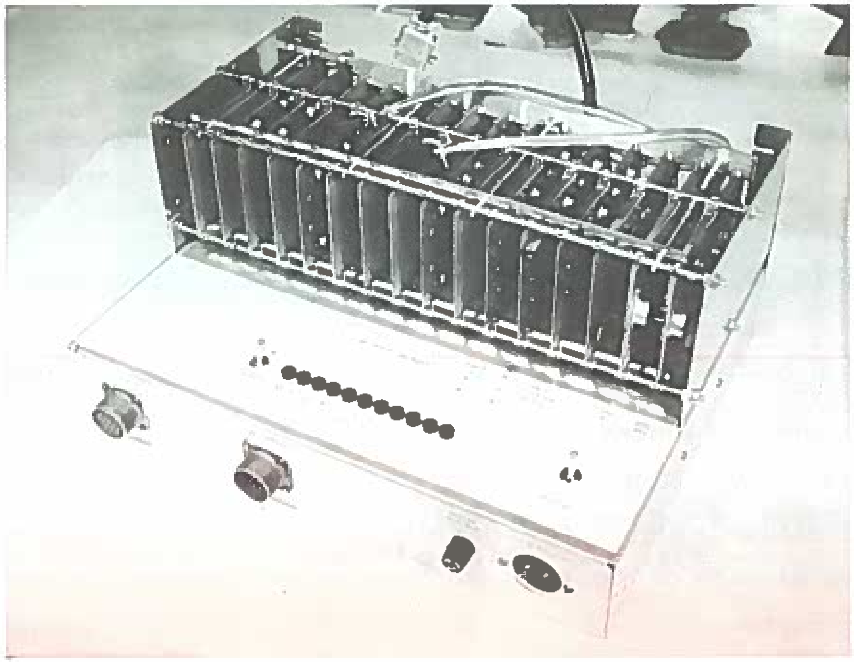
Rear

Fig. 15. Code Converter and Line Monitor Test Units.

Fig. 15. Code Converter and Line Monitor Test Units.



Drum Assembly



Electronics Assembly

Fig. 16.

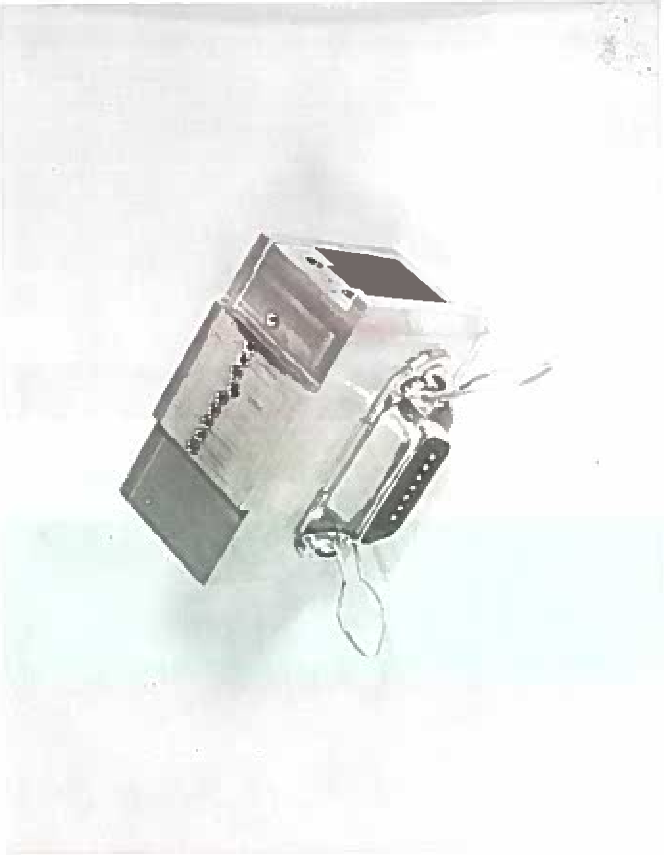


Fig. 17. Reading Head.

The electrical assembly of the code converter contains all of its electrical components and performs the electrical functions. Included in the electrical circuitry are three regulated power supplies and all of the logic circuitry. Two of the regulated power supplies provide +5 and -30 volts for the logic circuitry; the third provides a voltage of 22 volts for the lamp. All logic circuitry is on printed circuit boards contained in the card rack which is mounted on the chassis. All external connections are made to the chassis, which contains the power supply transformers and rectifiers.

Both the drum assembly and electrical assembly are mounted to a single front panel. The rear of the entire assembly is enclosed in an aluminum cover to prevent light and nosy fingers from entering. This cover is not shown in Fig. 15.

The fundamental operation of the code converter is shown in the diagram of Fig. 18. The operation can be fundamentally described by the following scheme:

$$X \longrightarrow \boxed{\Psi} \longrightarrow Y$$

where X = input = any combination of $x_1, x_2, \ldots, x_8$
and Y = output = any combination of $y_1, y_2, \ldots, y_8$
and Ψ = a nonlinear active delay function where the delay is less than 0.033 seconds

The function Ψ depends directly upon the coded output tape.

For purposes of describing the operation for one cycle, assume that the system is running and awaiting an input. When an input is received at the input gate it yields a "gate" pulse, which immediately produces an "enable" pulse to allow the input to pass to the storage flip-flops. There it can be considered a stored binary number. The drum rotates constantly, yielding count pulses which pass to the binary counter and are seen in the counter as binary numbers. When a binary number in the counter is the same as that in the storage flip-flops, all the comparators will have the proper combination of input signals and each will yield a output. A "Read" pulse is then generated by the "On"

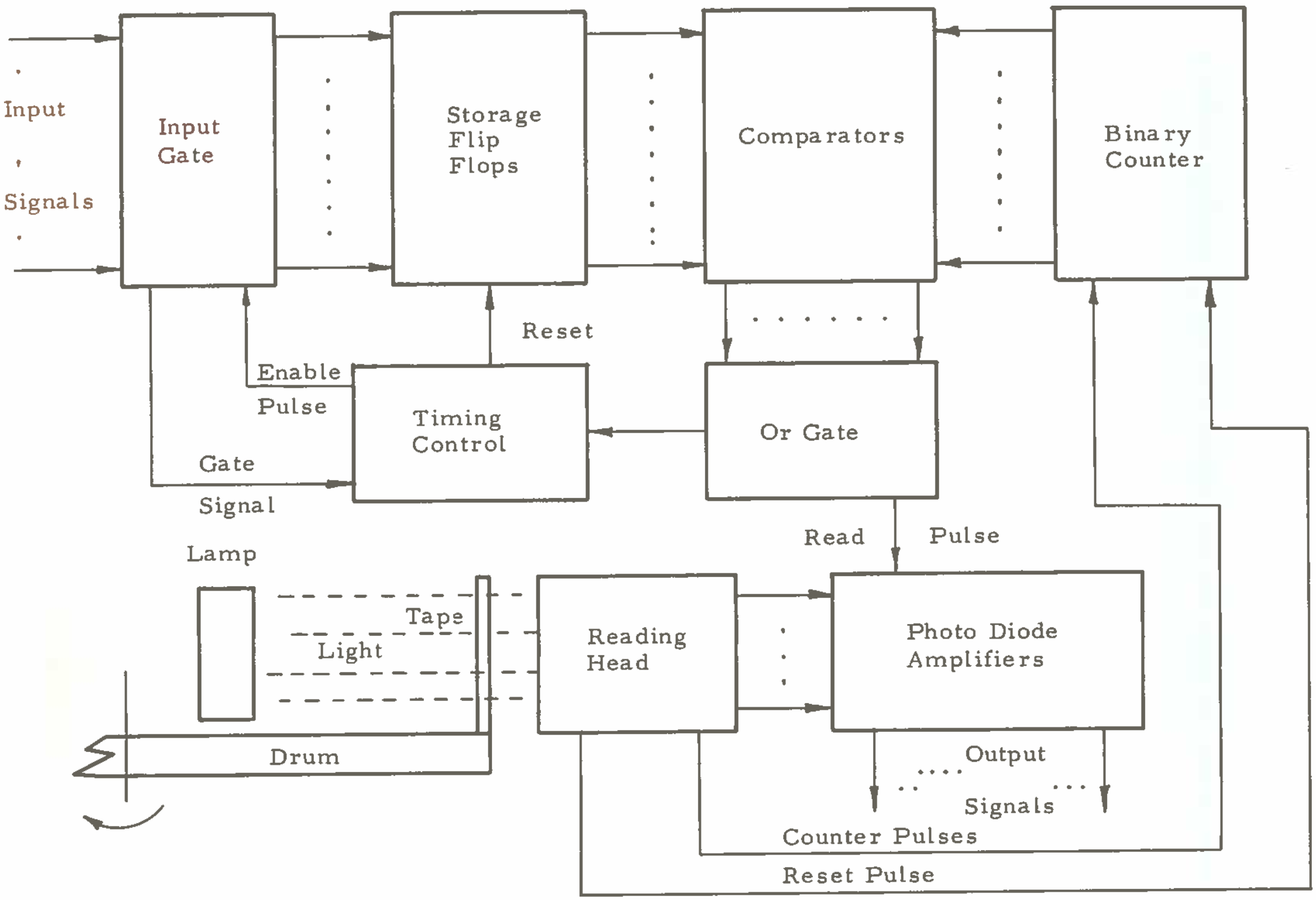


Fig. 18. Operational Block Diagram.

gate. This pulse allows the photo diode amplifiers to pass the output code found on the tape adjacent to the last count (sprocket) hole. The pulse also causes the timing control to reset the storage flip-flops. After these are reset the system is ready to receive another input. Many secondary operations are omitted in this description.

The distinguishing characteristic of this code converter is that the codes can be changed inexpensively and in a matter of minutes, simply by changing the code tape on the drum. The code tape can be prepared on any 8 bit tape punch.

The code converter has been subjected to various tests, all proving successful.

Fig. 18. Operational Block Diagram.

4. DIRECTIONAL PHOTOELECTRIC PROBE WITH TACTILE OUTPUT

Dwight M. Baumann, Azriel S. Genachowski

The object of this study is the design of a small, portable, light-weight probe which would make it possible for the blind person to read by tracing a printed line.[12] It continues the work of Alan Krigman[13] and the late Dr. C. Witcher, who wished to enable the blind operator to "see", by distinguishing variations in light intensity, the position of printing or writing on paper and to follow a line. A probe that would allow the blind person to trace a line in this way must give him information as to the changes in direction the line takes.

The basic parts of the probe are: 1) the input device, 2) the output device, and 3) the amplifier and power supply.

The input consists of a four-channel information-gathering capability. Illumination is obtained through placement of a single bulb on the top of a cylinder to direct the light. Photocells make a small angle with the center line of the cylinder. A double convex lens is used to focus the appropriate area which the cells should scan. Four H-11 duo-diodes are used as photosensitive components, and four Mite-T-Lite Lamps cast into a lamp assembly are used as the light source. The four diodes and lamps are focused to points on four corners of a square 1/8 in. apart. This dimension was dictated by the relative sizes of the lamps and diodes.

Since the goal is the transmission of visual information to the blind, a choice has to be made as to the sensory modality to employ. A vibration signal was selected as the output for the probe. The output consists of two parts: 1) the transducers, and 2) the housing for the transducers. The tactile vibratory signal is low-powered because 1) little pressure is needed to stimulate the skin, and 2) it is hoped that the probe will ultimately be operated on battery power.

When no commercially available units proved suitable, a vibrator using a coil of some form had to be designed to meet the requirements. A solenoid was modified, its air gap decreased to reduce the energy required to activate it by substituting a "T" shaped unit for its regular plunger. The magnetic flux passes through the branches of the "T" to the outer cylinder surrounding the coil. The force generated by the magnetic flux has to overcome the inertia of the system to make it vibrate and exert enough energy to stimulate the skin. The energy required for the latter is 6 gram/mm[13]. Transmitting this pressure through the 1/32 in. cross-sectional area of the stynulus required 0.03 Newton.

The schematic of the power supplies and amplifiers is shown in Fig. 19. Each of the four information channels has its own independent circuit, fed from a common power supply. The AC voltage converts the signal picked up by the photo diode into an AC signal. The output device will vibrate when the probe is scanning a black background, and be quiescent over a white background.

After three stages of amplification the signal goes through a Schmitt trigger, including a variable resistor which sets the level of the triggering reference point. It then enters a monostable flip-flop which switches from a -20 volt output to a zero output when it gets a signal. The next stage is a continuously-oscillating 30 cps astable flip-flop. The output of the astable and the monostable flip-flops are fed into an "and gate"; if both signals are "on" the gate will pass a signal activating the vibrator. If only one signal is "on" (as when the probe is on a white background), the output of the monostable flip-flop is 0 and the vibrator will not vibrate.

The probe itself is comprised of 1) the input device, 2) the first stage amplification, and 3) the vibrators housing and vibrators. The most compact arrangement is in the form of a vertical block. The structural members of the probe are two columns extending from a terminal board on top of the input device to the vibrator housing. The terminal board is the end point for the wires from the photodiodes, the first stage amplifiers, and the lamp assembly, and it is a platform for the two columns going to the vibrator housing. A magnetic shield is mounted on the columns to protect the amplifiers and photo-diodes from the magnetic field. The final dimensions of the probe are 3-11/16 in. long, 1-57/64 in. wide, and 1-11/32 in. deep.

The cable between the probe and the auxiliary circuitry is about four feet long, allowing coverage of a large area without moving the frame with the auxiliary printed circuit boards. When the probe

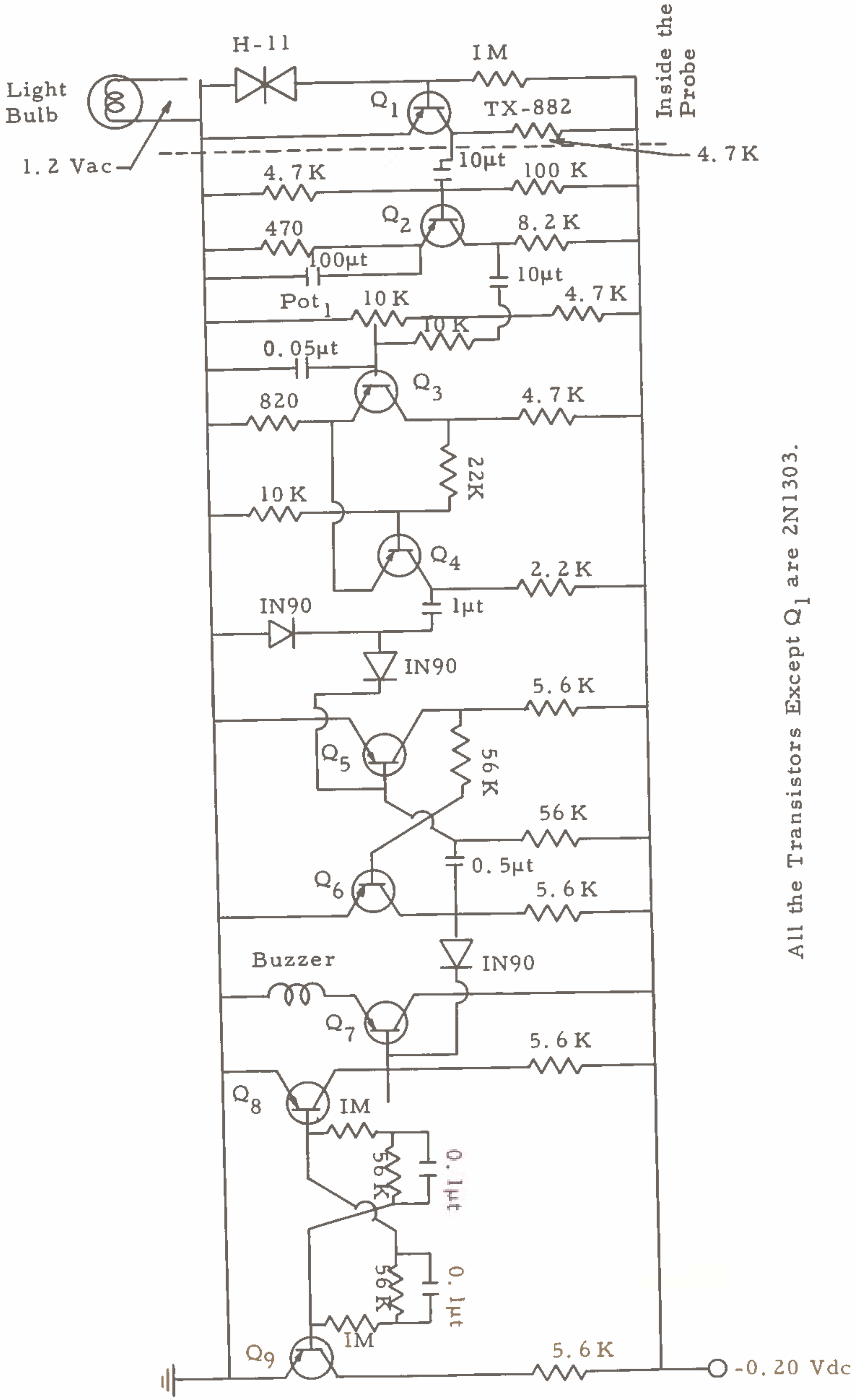


Fig. 19. Schematic of Electronic Circuitry for One Channel.

was turned on and pushed slowly across the paper, the photodiodes scanning the area beneath them, it was found that the minimum width of line that the probe could detect was 0.022 in. with the circuitry adjusted to its most sensitive point. Also, the probe must rest absolutely flush to the paper. If slightly lifted or tilted, it "sees" black, and all the vibrators start vibrating.

It is easier to detect an 0.022 in. line than to actually follow it. Due to hand motion and jerk, it is easy to lose too narrow a line after a short period of travel.

The outputs of the vibrators are slightly non-uniform. It takes a considerable period of time to learn to interpret the signal. As the vibration is very weak, it causes no discomfort, but requires some concentration to know exactly when a vibrator starts and stops.

Tests show that wider lines are easier to track. The best way to follow a line is to "catch" it with two photodiodes, detecting a change in direction with the other two photodiodes. The probability is 50%, however, that the line will change in the opposite direction of the two unused diodes, so a small search must be made to establish whether a line terminates or takes another direction.

The first tests were run on white bond paper, the lines drawn in black India ink. Whenever the background was changed, i.e. different paper or the intensity of the lines changed, it was necessary to readjust the variable resistor.

The resulting probe is small, portable, and light-weight. It enables the user to trace printed lines and gives him information as to the impending changes of direction of a line.

No sighted person can possibly give a fair test of the probe because his skin is not as sensitive to delicate simuli as that of a blind person, nor is he as interested in learning to use the probe.

5. COLLAPSIBLE BLIND TRAVELLER'S CANE

The previous Evaluation Report[1] described the development of three possible designs for a blind traveller's cane which, extended, would be a faithful replica of the duraluminum long cane in weight, balance, rigidity and vibration transmission characteristics, but which could be easily and rapidly collapsed to a carrying length of about one foot. Thus the cane could be unobtrusively carried in pocket or purse when not needed, as while sitting in an auto, theatre, etc. The joints in the cane must also be capable of repeated extension and collapse with no deterioration in the connections which would decrease rigidity, vibration transmission, etc., and the cane should be as simple and inexpensive as is commensurate with the other requirements.

During this report period some very limited evaluations were conducted on the three cane designs which were originally conceived by juniors in their Mechanical Engineering laboratory course. The "spiral" cane was provided with a carrying case and extension collapse clamp and saw some limited use. However, none of the designs were deemed to warrant further development.

Subsequent to the annual period of this report the cane project has been reactivated and some very promising results have been achieved which will be reported in detail in the 1963-1964 Evaluation Report.

6. INERTIAL GUIDANCE DEVICE FOR BLIND TRAVELLERS

Robert W. Mann, David R. Sawyer

One of the most difficult travel situations encountered by the blind person is the navigation of large open areas such as fields, spacious lobbies, halls, terminals, and smooth-surfaced streets. This difficulty stems from an almost complete lack of the normal and necessary cane-guidance cues such as walls, curbs, sidewalk cracks, etc., as well as the absence of sound reflecting surfaces such as building fronts which provide audio cues. Consequently, the blind man travelling in such areas exhibits a strong tendency to veer considerably from his intended straight-line course. Thus, it is necessary that in his traning for cane travel the blind man be made cognizant of this veering tendency, so that he can compensate for it and can develop a keener sense of straight-line navigation.

A useful training device, therefore, would be one enabling a blind traveller to maintain a straight course by informing him of any deviation from his course. After a sufficient period of use, the blind trainee would possess a better sense of on-course navigation and would no longer need to rely on the device. Indeed, even if the device could be used as a permanent navigating aid, rather than only a training aid, more significant and permanent progress would result if the blind man is made to develop and rely on his own senses and personal confidence, rather than depending on a less-reliable, fragile, mechanical instrument. A possible exception may be that individual whose navigational sense is so poor that he would be unable to travel about at all without the mechanical aid.

The guidance device should be compact, light, hand-held or worn on the body, and should neither hamper nor monopolize any of the senses used in travelling. It must be of sufficient accuracy to produce reliable course indication, yet not so sophisticated as to require expensive or complex components. Fortunately, since the unit would be operating for just a short period in any one instance, extreme accuracy is not required. That the unit be inexpensive is of prime importance, since the units will not be mass-produced on a large scale. The units must be within the financial means of the training centers for blind travellers, which operate on limited budgets.

Investigations were made into the uses of magnetic compasses and modified portable transistor radios to provide heading references. The compass scheme was found impractical because of the deviating effects of nearby magnetic objects; the radio scheme was rejected because it required auditory senses and relied on an external signal easily affected by the proximity of radio stations, the interference of tall buildings, etc.

The system finally decided upon utilizes a self-contained, battery-operated, inertial-guidance, rate-integrating gyroscope with a tactile output.[14] The course is set and a readout pin aligned with a reference. From there on, any deviation from the straight course results in a displacement of the readout pin. Subsequent corrections in course direction will, in turn, act to return the readout pin to the initial reference position.

The principle of operation of the device is as follows. If a wheel of moment of inertia, J, is rotated with angular speed ω about axis x-x, its angular momentum vector, M, points along the axis as shown in Fig. 20a. If the gyroscope is twisted about axis z-z, the momentum vector will change by an amount dM. Since torque, $\vec{T}$, equals $d\vec{M}/dt$, a torque will be produced whose vector is in the same direction as $d\vec{M}$, namely, along the y-y axis as shown. This will cause the gyro to turn about the y-y axis.

If a damper is connected to the y-y axis as shown in Fig. 20b, the gyro becomes a rate-integrating gyroscope by the following relations:

For the gyro: $$T_{yy} \alpha \frac{dM}{dt} \alpha \frac{d\Theta_z}{dt} \qquad (1)$$

For the damper: $$T_{yy} \alpha \frac{d\Theta_y}{dt} \qquad (2)$$ (Damping torque is proportional to angular speed.)

Therefore, for the damped gyro: $$\frac{d\Theta_z}{dt} \alpha \frac{d\Theta_y}{dt} \qquad (3)$$

And, integrating: $$\Theta_y \alpha \Theta_z + c \qquad (4)$$

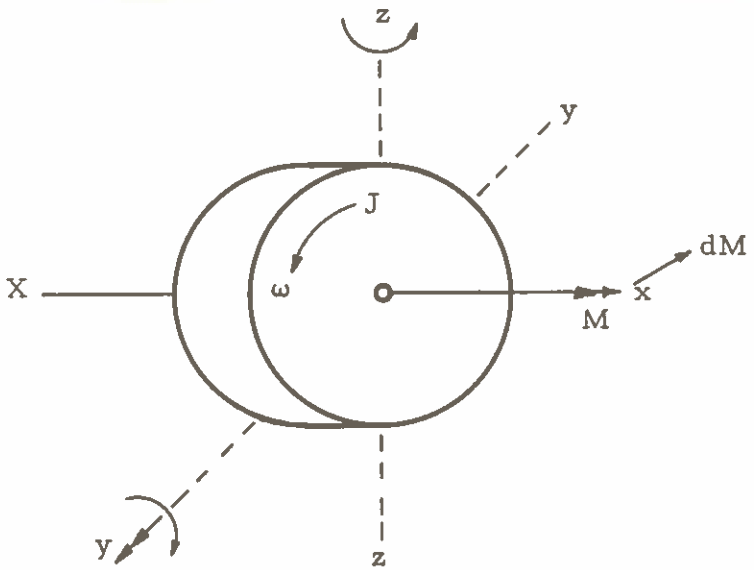


Fig. 20a. Gyroscopic Axes.

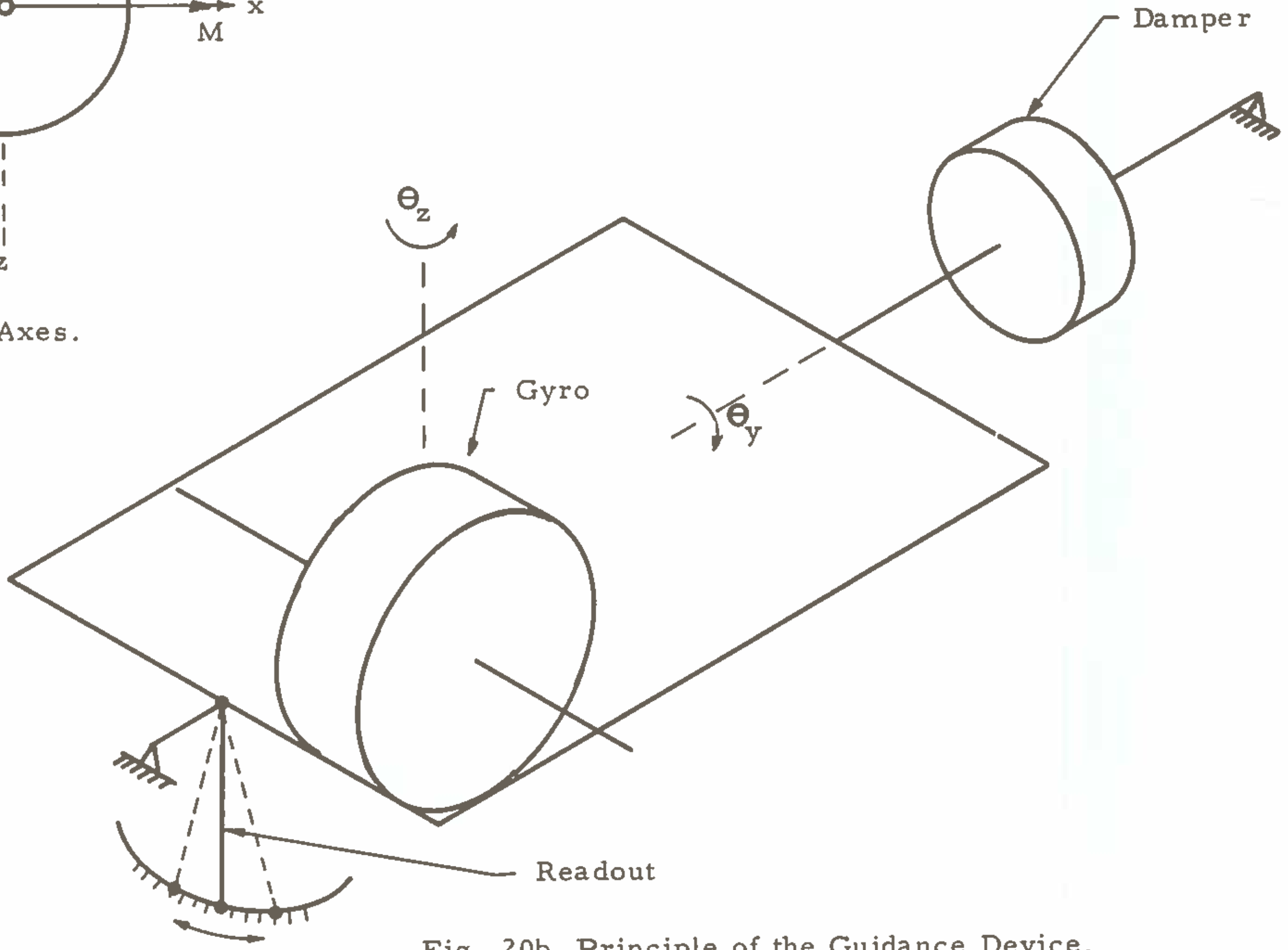


Fig. 20b. Principle of the Guidance Device.

For a centered course: $\Theta_y , \Theta_z = 0$ (5)

For the guidance system: $\boxed{\Theta_y \sim \Theta_z}$ (6)

The above relations state, therefore, that the damped gyro will deflect about the y-y axis proportional to the amount by which it is turned about the z-z axis. If a readout is connected to the gyro assembly as shown in Fig. 20b, it will give a direct indication of the amount of off-course deviation since any deviation from a straight course would necessitate a rotation about the z-z axis.

The design of the guidance unit entailed the development of an inexpensive battery-powered, damped gyro which could be enclosed in a small, light, hand-held case to make the readout easily accessible. The first successful attempt at an integrating-rate-gyro guidance device utilized a small, very inexpensive, toy motor with a brass gear as the gyro wheel. After some experimentation with different damping schemes, the piston of a hypodermic syringe rotating within the cylinder and containing a film of oil between them was found to make a highly satisfactory rotary dashpot. From this first model evolved the present unit, the interior of which is shown in Fig. 21.

The motor is a 3-volt instrument motor whose case has been shortened somewhat, powered by two D-cells. This drives a brass gyro wheel which partially encloses the motor. The assembly is statically balanced about a central axis. The gimbal bearings are self-aligning, and oil-retaining. On the same shaft is a rotary damper with silicone oil contained between a brass rotor and cylinder. Also connected to the shaft is the readout pin. The support for this assembly is isolated from the rest of the case by rubber shock mounts in order to reduce noise and vibration transmission to the case and thence to the hand of the user.

The case for the unit, shown in Fig. 22, is made of brass sheet hammered over forming dies, silver soldered, and nickel plated. The bottom cover of the unit is easily removed for replacing batteries.

Fig. 21. Interior of guidance device

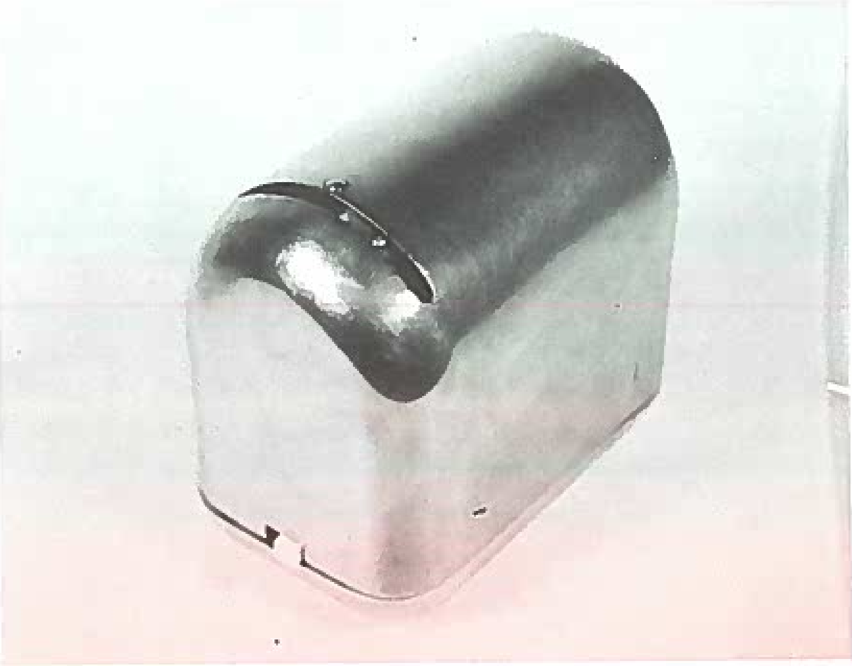


Fig. 22. Complete guidance unit.

The readout pin, shown in Fig. 22 , moves back and forth along the slot in the front of the case, and course deflection is determined by comparing pin position with the reference bump. Fig. 23 shows the unit in use. The leather case and belt strap protect the unit from falling, and allow the hand to be free when not using the device.

The unit is held so that pin position can be felt along the finger. At the beginning of a course the unit is switched on, oriented along the body, and the readout pin is centered by the user. The unit will then indicate major course deflections, while, with a well balanced gyro, body motion will be self-cancelling.

The guidance device has been used at St. Paul's Rehabilitation Center in Newton, Massachusetts and has proved very effective for aiding trainees in maintaining a straight course. The primary modification which these tests have suggested is that some readout system be developed which would not restrict gyro motion when touched.

Investigation into this and other improvements in the device are presently underway.

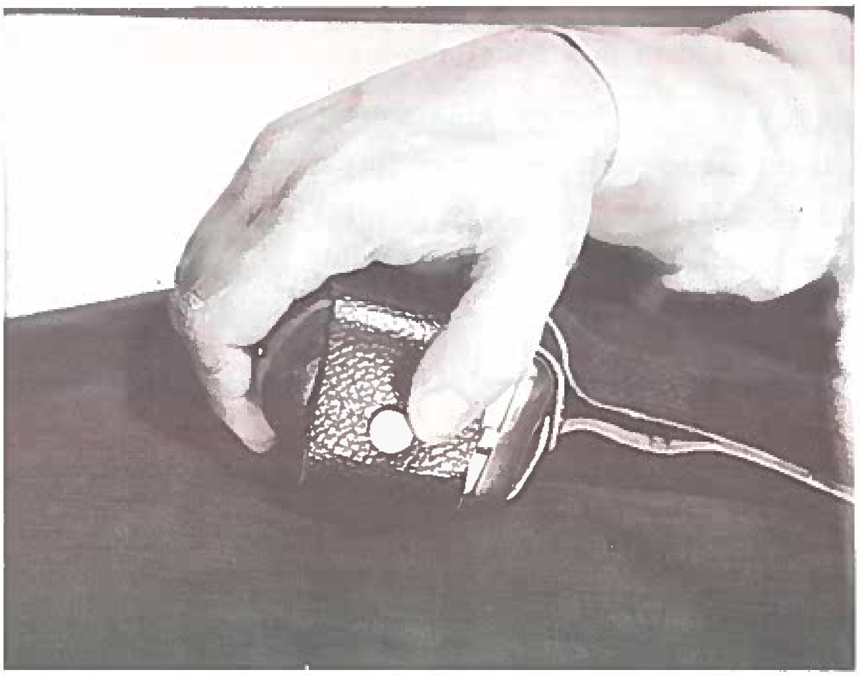


Fig. 23. Guidance unit in use.

7. SOUND-SOURCE BALL

Robert W. Mann, Ronald C. Rothchild

The range of activities open to most blind children is very restricted; their lack of physical exercise, bad in itself, also inhibits development of muscular coordination. Ball-oriented games comprise a valuable aid to this development in sighted children.

A request was made by Perkins School for the Blind that a basketball be developed which would produce a loud, continuous, non-directional sound, which would be physically soft enough not to hurt the children when it hit them, which could be bounced, thrown, kicked, and batted without damage, and which would have the feel and balance of an ordinary basketball.

These requirements have been somewhat compromised by a ball designed by Mr. Ronald C. Rothchild as a bachelor's thesis.[15] The sound is slightly directional; the ball should not be batted; it does not feel exactly like a basketball; and dynamic balance is not perfect. However, the ball is a great improvement over anything previously available. When completed, it is expected to perform satisfactorily and should withstand rugged treatment.

The first prototype weighed one pound, three and one-half ounces; the second is expected to weigh roughly the same and perhaps less. Its sound equipment generates just under a watt, most of which reaches the outside of the ball reasonably non-directionally, when the skin is pressurized and taut.

A design suitable for limited production was kept in mind throughout the project; an attempt was therefore made to keep production costs low. A tetrahedral arrangement of speakers would have been ideal for acoustic considerations, but the complex structure required would have been very expensive to produce. Therefore, a relatively simple triangular arrangement was used. The inherent directionality of the speakers is reduced by transmission through the taut spherical skin.

Three types of electric-to-acoustic transducers were considered: crystal, electrostatic, and electromagnetic. Due to the high impedance and low power output of an individual crystal, a large number of these would have had to be mounted in parallel. The cost of a sufficient number of these units would be prohibitive.

Electro-static speakers are restricted by their high impedance. Only about 12 square in. are available for speaker area. To achieve the desired acoustic power level the clearance between plates at zero signal must be about 0.010 in. The impedance of this capacitor would be several megohms; for the required power level at least 2,000 volts are necessary. A battery power supply provides three to six volts; a light-weight impedance matching transformer with a turn of ratio several hundred to one would be needed. Arcing would present a severe problem. For these several reasons electrostatic speakers are not practical for this application.

Although dynamic speakers are undesirable from a weight point of view, they have many advantages. They are available with the required low impedances which need no transformer. Using three such speakers, each must be rated at 1/4 watt peak and 1/8 watt continuous. Suitable speakers may be bought as stock items for about $1.00 each. In the event that the ball is produced in quantity, a lightweight speaker with a narrow bandwidth resonating at the desired frequency could be specified at little or no additional cost. Dynamic speakers are therefore chosen for the ball; in the first prototype they are 2-3/4 in. in diameter and in the second prototype 1-1/2 in. Both weigh approximately the same --- three ounces.

High accelerations resulting from ball motion, of the order of 1,000 g's, necessitate a strong, rigid package for the sound system and an equally strong but resilient suspension; flexible enough to reduce the jerk on the package, but rigid enough to keep the package reasonably centered was to maintain the dynamic balance of the ball.

At no time must the package and skin be in contact, which means that when the ball bounces from any surface, it must stop and reverse direction within the 2-1/2 to 3-1/2 in. clearance (depending upon speaker size) so that the package will not hit the surface. A strong, high-pressurized skin is therefore needed. Also, this feature eliminates the original possibility of batting the ball as the area of contact between bat and ball could be too small. The skin must also be thin enough to allow transmission of the sound. These requirements were met by using rubberized nylon cloth in the first prototype, and in the second the rubber was replaced by a special neoprene compound for abrasion resistance.

The sound generated is six to seven pulses per second of a 700 cps square wave. Actually a pure tone of 700 cps was to be preferred, but the square wave generator is lighter and more compact and most of the higher harmonics, which are smaller in amplitude anyhow, are absorbed by the skin.

In trying to locate a sound source, there are possible situations which would cause a non-directional sound to seem directional and thus lead to errors of the order of several yards in locating the ball.

The most obvious and also the most severe source of confusion would be a sound reflecting surface near and parallel to the line between the ball and the listener. If the surface is very close, the echo off the surface, or error signal, is very strong. However, since the error signal and source signal are originating from approximately the same place, the error made by the listener is slight.

If the surface is at some large distance from both the ball and the listener, the error signal comes from someplace far from the actual source but is very weak, so the apparent source will be approximately the same as the actual source.

At some distance between very far and very close, depending upon the surface, the combination of decreased error signal strength and increased discrepance between the locations of the error and source signals will produce a maximum discrepancy between the locations of the imagined and actual sources, or a maximum error on the part of the listener trying to locate the ball.

Under these "worst" conditions a perfectly directional source would seem to the listener to be at the sound-reflecting surface. A perfectly non-directional source would seem to be somewhere between the surface and the actual source. These situations are illustrated in Fig. 24 a and b.

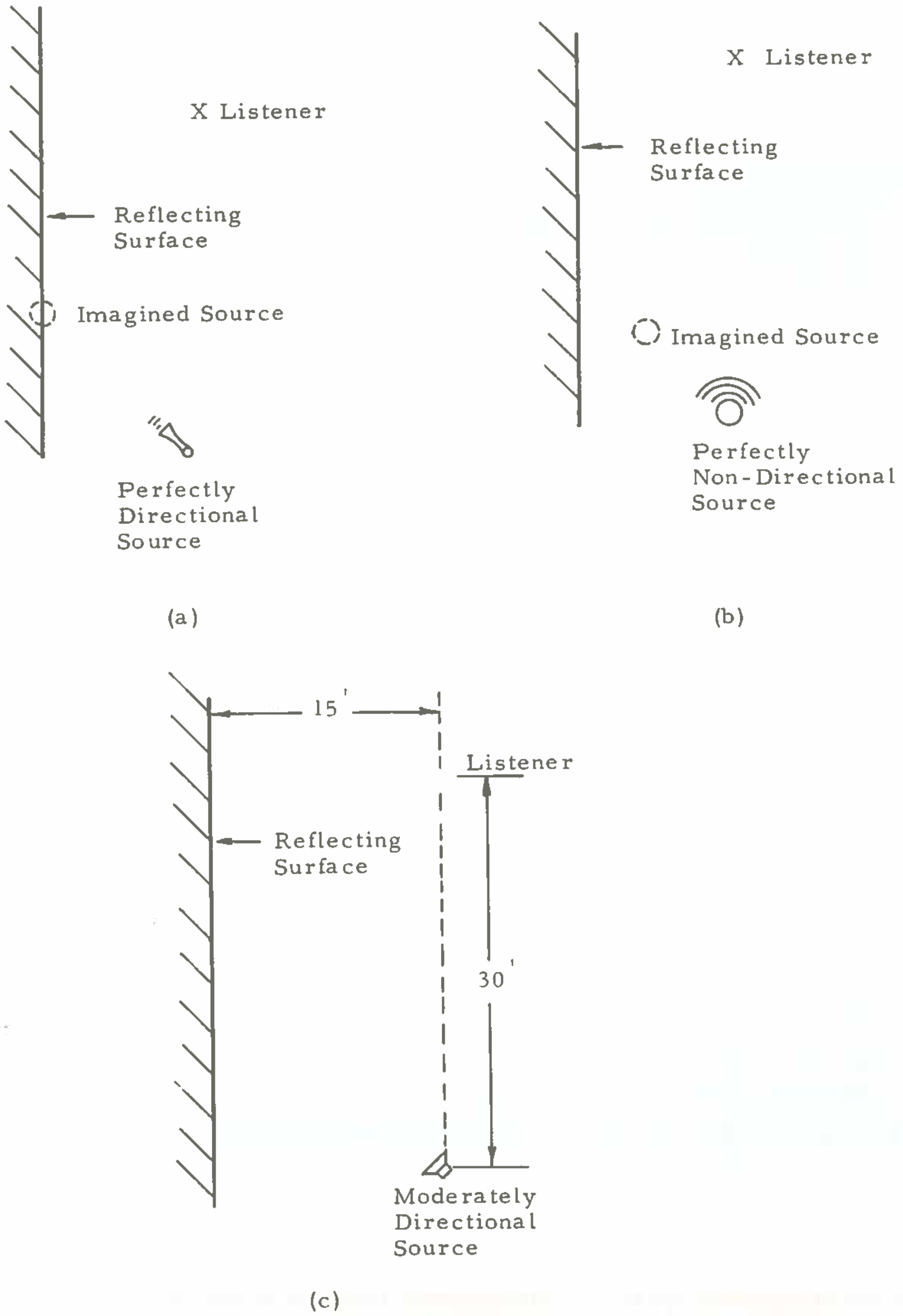


Fig. 24. Acoustic Geometry for Sound-Source Ball.

This effect, which increases with the frequency generated by the source, might be eliminated by a sufficiently low frequency.

Another conflicting effect to consider is background noise. Higher frequency signals are more easily distinguished in the presence of noise.

Because a person's ability to locate a signal is more easily measured (with reproducible accuracy) than his ability to distinguish the signal from background noise, it was decided to generate in the ball the highest frequency at which most children can accurately locate a ball. The following test was made to determine this frequency.

The test setup shown in Fig. 24c was used in the gynmasium of Perkins School for the Blind. The actual sound source is an ordinary speaker connected to a variable frequency audio generator. The children tested were instructed to point to the apparent sound source as the frequency was slowly lowered from 3000 cps to 50 cps. They were not told that the actual source was stationary nor were they given any information as to its location. Before the sound began they were placed with their backs to the source. When the sound was turned on at 3000 cps, all of them pointed toward the wall. As the frequency was lowered, their imagined source moved closer to the actual source, and the frequency at which their imagined source first coincided with the actual source was considered the highest frequency at which a source could be accurately located.

The results are tabulated graphically in Fig. 25, each dot representing one of 70 children tested and the highest frequency at which he or she located the actual source. The frequency chosen to incorporate in the ball is 700 cps, at which 48 children could locate the source and 22 could not. The author was advised by the staff at Perkins that many of those who could not locate the source at the time of the test would be able to with some training.

Referring again to the problem of distinguishing the signal from background noise, an intermittent sound is better than a steady sound. The sound decided upon was six to seven pulses per second of 700 cps.

Each dot represents one child and gives the highest frequency at which he could accurately locate the actual sound source.

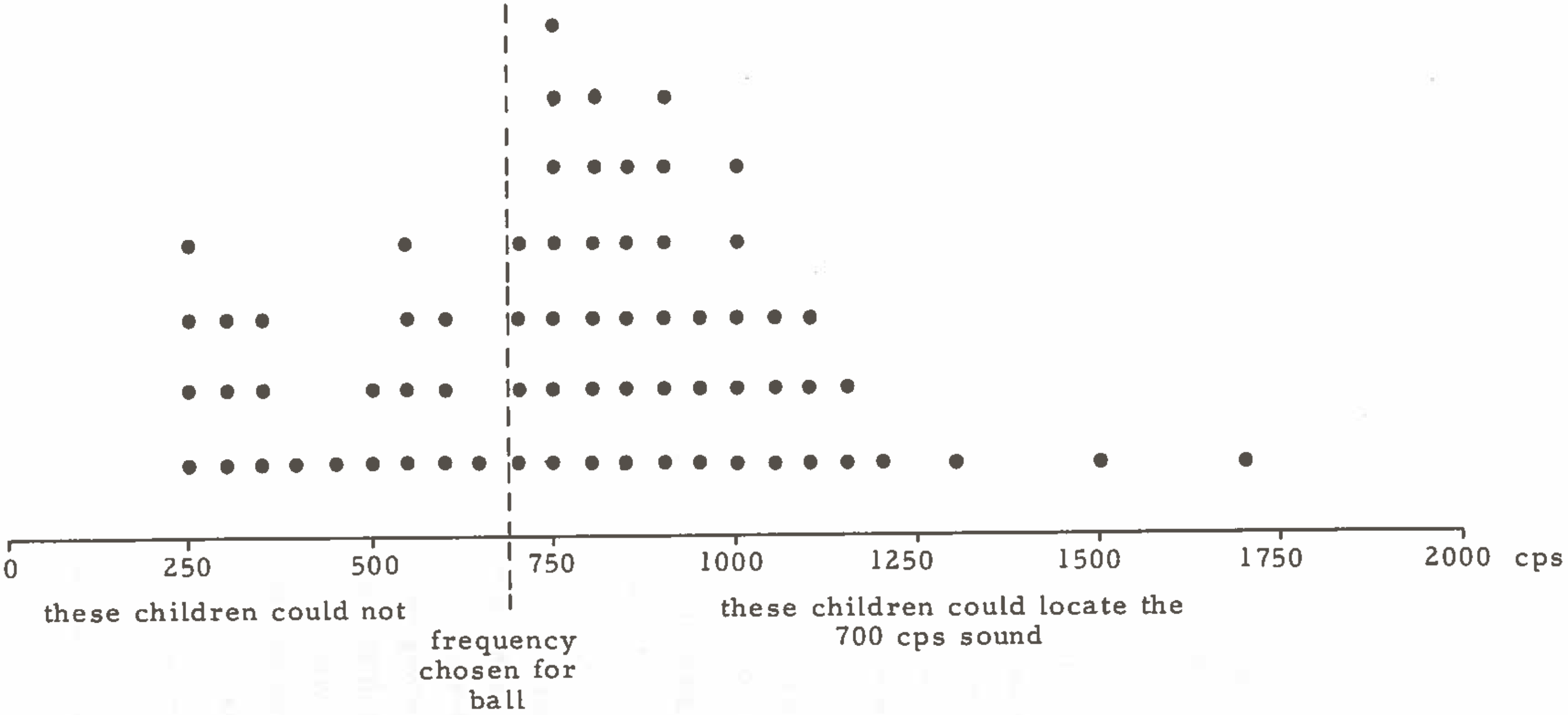


Fig. 25. Experimental Data on Acoustical Test for Sound-Source Ball.

The signal generator used in the ball is comprised of two astable multivibrators at 700 and 6 cps, the slower one acting as a switch for the faster one. The power supply consists of five nickel-cadmium cells, rated at 1.25 V each. The speakers are permanent magnet, transistor radio, replacement speakers, rated at about eight ohms impedance and 1/4 watt each, connected in series.

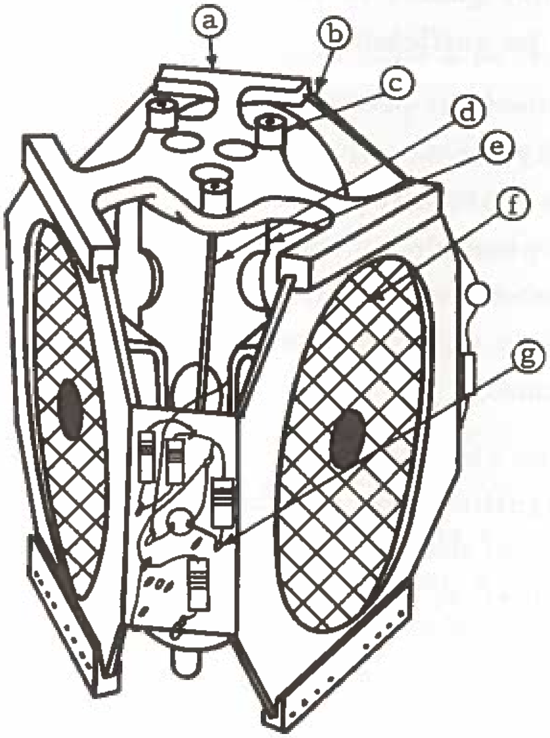
The three speakers are mounted radially about a central hub. Extending axially through the center of the package is an aluminum alloy tube 1-1/16 in. outside diameter and 1 in. inside diameter, coated on its inside surface with a thin layer of epoxy long in the second; five nickel-cadmium cells are mounted in its center. These five cells together are approximately 1-3/4 in. long and are supported by a steel compression spring at either end of the column which double as terminals. Lead wires are soldered directly to the springs. Holding the springs in compression against the cells are two hubs of 7075 aluminum, compressed together by three steel struts parallel to the tube. Between the base of each compression spring and the end hub is an insulating disk of fiberglass-epoxy.

Extending from each hub are three arms with slotted crossmembers at their ends; fitting into the slots and between the crossmembers of the two hubs are three panels of fiberglass-epoxy laminate, with a large hole in each, to hold the speakers against the battery tube. Between the rear of each speaker and the tube is a pad of nylon-epoxy, molded in place, and the speakers are kept from sliding along the fiber-glass panels by the aluminum crossmembers on top and bottom, and by fiberglass supports along the sides. The construction of the package in the first prototype is illustrated in Figs. 26a and 26b. Basic construction of the second prototype is the same.

The completed package of the first prototype weighs 15 ounces: 3-1/2 ounces of structure and 11-1/2 ounces of sound equipment. The package in the second prototype will be an ounce or two lighter.

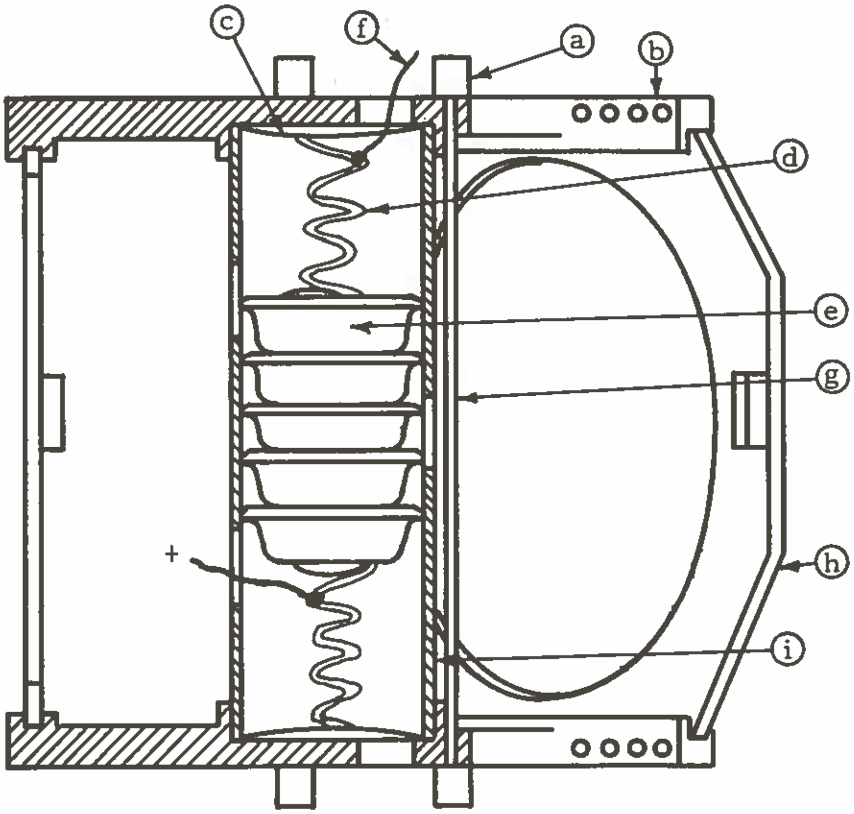
The suspension is a critical part of the design and failed in the first prototype. The package is suspended at six points by two 1/8 in. nylon ropes at each point. Suspension failure was caused at

The Complete Package



ⓐ hub
ⓑ speaker panel
ⓒ strut nut
ⓓ strut
ⓔ battery tube
ⓕ speaker
ⓖ circuit board

Fig. 26a. The Sound-Source Package.



ⓐ strut nut
ⓑ hub
ⓒ fiberglass insulating disc
ⓓ battery support spring
ⓔ battery
ⓕ lead wire
ⓖ strut
ⓗ speaker panel
ⓘ battery tube

Fig. 26b. Cutaway of Battery Tube (Speakers the fabric loop which connected the rope to the skin. These have been redesigned with semicircular rubber rope guides to relieve stress concentrations which, it is hoped, will be sufficient.

The most annoying problem in the first prototype was leakage. The design in the second model is nearly the same; however, changes have been made in the order of steps in fabrication. Leakage is not expected to be a problem in the second prototype. The first prototype had been bounced from a height of about six feet, corresponding to 20 ft/sec, or a maximum of about 400 g's. The ball bounced nicely, but the suspension failed on the fifth bounce.

When the ball is caught or shaken abruptly, it is obvious to the catcher or shaker that there is a significant mass attached to the ball with motion slightly different from that of the skin. This effect, though noticeable, should not interfere with normal use of the ball.

8. SPEECH RECEPTION BY THE DEAF-BLIND

Ernesto E. Blanco, Robert J. Hansen

At the present time a person who is both deaf and blind may be "spoken to" in one of two ways. The normal subject can spell out each letter of each word by using the finger alphabet or by tracing the individual letters on the palm of the deaf-blind person's hand. Alternatively, the Tadoma (Vibration) Method may be employed. This second means of communication involves the deaf-blind subject placing his hand over the face of the person who is speaking. The position of the lips and chin, the pressure of the breath flow from the mouth, and other cues present on the exterior of the face enable the deaf-blind person to perceive what the speaker is saying. The first of these means of communication is unsatisfactory because it is slow compared to normal speech rates. The second, while representing a great increase in speed over the first, is also limited in usefulness because it necessitates physical contact between the speaker and the deaf-blind person. In many situations, such as in the classroom or when the normal subject is driving a car, this limitation prevents the use of the second method.

In part because of the limitations of these two methods of communication, attempts have been made to build apparatus which would translate human speech into a form intelligible to a deaf-blind person. The first attempt was made by R. H. Gault in the late 1920's and early 1930's. He used the amplifier signal from a microphone to drive a vibrating plate. The second and third attempts, conducted respectively at M. I. T. as the Felix Project and at University of Capetown by R. W. Guelke and R. S. Huyssen, were based upon the knowledge gained from the Visible Speech Project at Bell Laboratories during World War II. In both cases devices were built which separated speech sounds into frequency bands and then translated the presence or absence of speech energy in each band into a tactile display. Unfortunately, none of these three devices satisfactorily performed the function for which it was designed. Even the apparatus built by Huyssen and Guelke, though very sophisticated from electronic and psychophysical points of view, allowed the "listener" to discriminate readily only among vowel sounds. Differentiation among consonants was not easily made on the whole. The Felix device and Gault's apparatus were less sophisticated and less successful than that of Huyssen and Guelke.

The fact that all three of the above devices translated acoustical properties of speech into a tactile display, along with the observation that the Tadoma Method Provides an excellent means of communication compared to any of these devices, led us to approach the problem in a somewhat different manner. When the deaf-blind subject places his hand over the face of a speaker, i.e. uses the Tadoma Method, he moniters some of the changes in the articulatory mechanism which are manifested on the outside of the face. Hence, we postulated, a more successful device for translating speech into a tactile display would moniter some of the same cues apparently made use of in the Tadoma Method rather than performing an acoustical analysis of the resulting speech.

To test this postulate apparatus to moniter lip position, pressure of breath flow from the mouth, and amplitudes of vibration over the bridge of the nose and over the larynx were designed.

Figures 27 and 28 illustrate the displacement, pressure and audio frequency transduction used, which are mounted on a military helmet liner in order to expedite the fitting of the transducers to the subjects involved in the study. Fig.29 gives an overall view of the experimental set-up showing the transducer amplifiers and multi-channel oscillographic recorder used to synchronously record the multiple data channels.

Construction of the apparatus began in June, 1963 and was completed in mid-July. Since that time we have monitered the speech of five persons speaking designated one syllable words. In these tests the output has been traced on a visual recorder rather than a tactile display. The visual display was used so that we might determine readily 1) whether or not the variables being monitered provide sufficient information to differentiate between words spoken by a single speaker, 2) to what extent the variables are the same for the same word spoken by different speakers, 3) which variables being monitered are or are not important to distinguishing between words.

Though analysis of the data thus obtained is not complete, we may tentatively conclude that the variables monitered do provide sufficient information to allow differentiation among initial consonant sounds for a single speaker. On the basis of these variables the vowel sounds can only

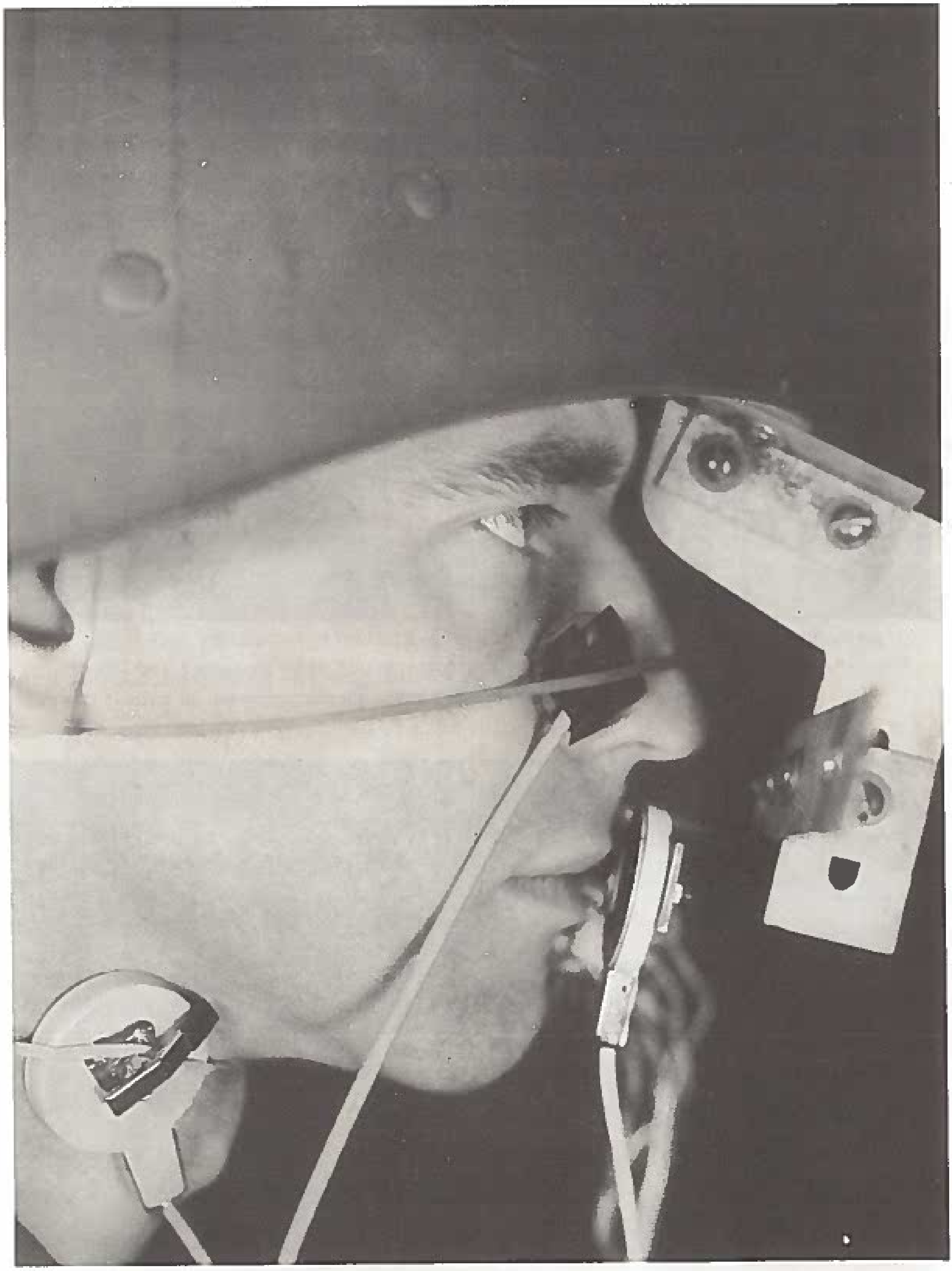


Fig. 27. Instrumentation for Deaf-Blind Speech Reception research showing larynx and bridge-of-nose microphones and breath pressure flow transducer.

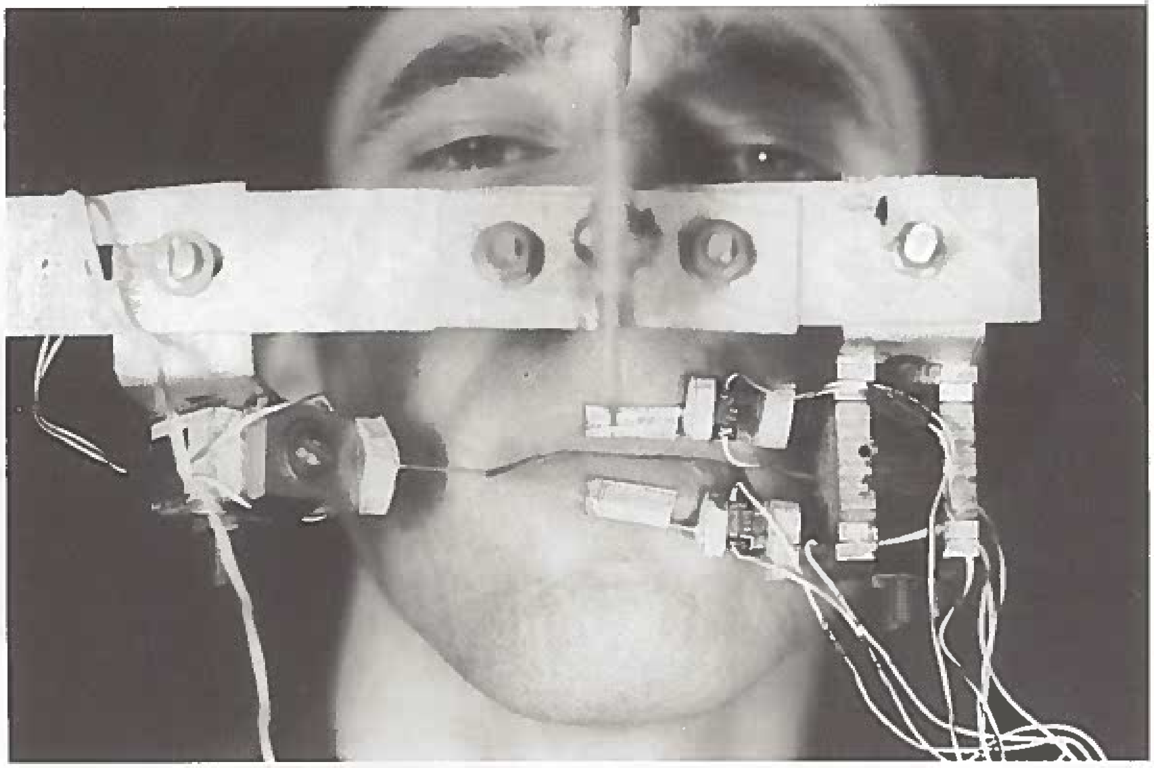


Fig. 28. Deaf-Blind Speech Reception Instrumentation showing upper and lower lip, and mouth corner displacement transducers mounted in helmit liner.

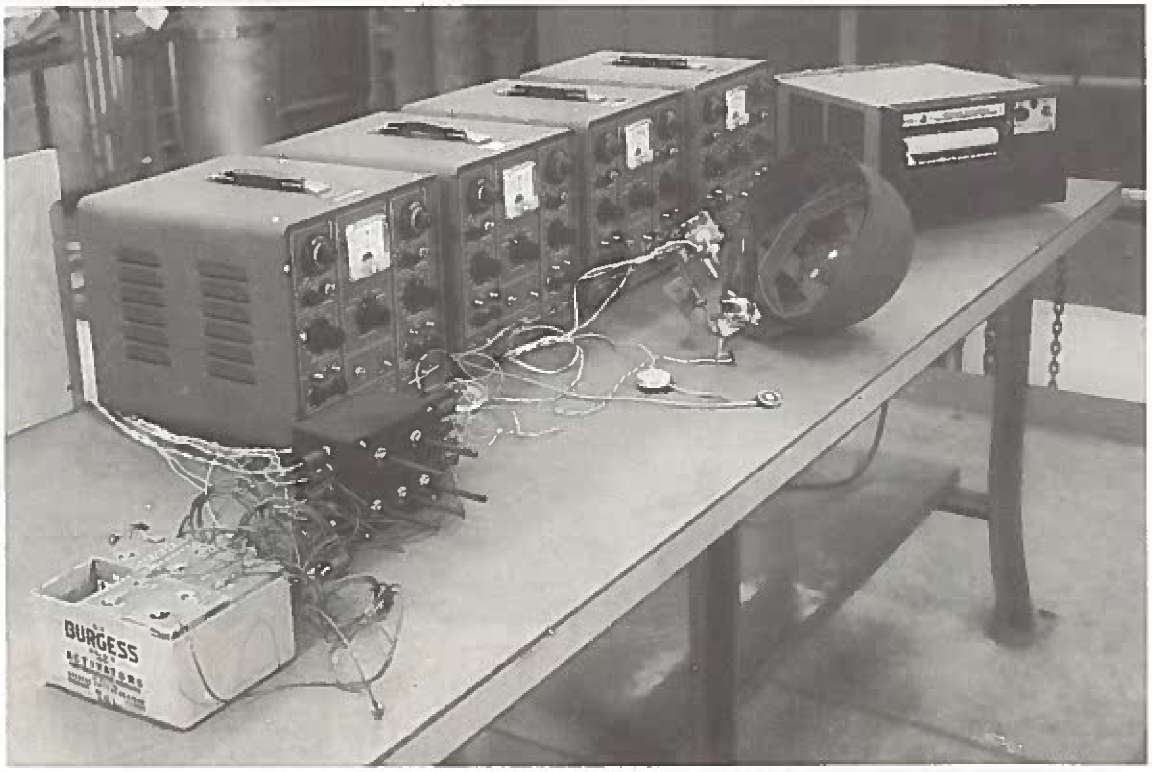


Fig. 29. Overall view of Deaf-Blind Speech Reception Apparatus showing instrumented helmit and amplifiers and multi-channel recorder.

be divided into two groups, however, those in which the lips move outward (as in the long o sound) and those in which they do not (as in the short i sound). Variability from speaker to speaker is considerable, but not so great as to prohibit matching of the same word spoken by two speakers. Relative importance of the variables being monitered has not yet been considered. Hence, by monitering characteristics of the articulatory system we obtain a result complementary to that of devices based upon acoustical analysis. We obtain good consonant discrimination, and they provide good vowel discrimination.

Because of the complementary nature of articulatory and acoustical analyses, it has been suggested that the two be combined in a single device. While such a step might later be taken, our immediate plans are to complete the analysis of the data which we now possess. We are particularly interested in trying to normalize the data for given words such that the variability between speakers for these words will be minimized. Having normalized the data, we shall then consider the relative importance for word identification of the variables being monitered.

As presently scheduled the results will be published in a thesis submitted in June 1964.

9. INFORMATION ANALYSIS FOR DISCRETE TRANSDUCER ARRAY

Thomas B. Sheridan, Thomas L. DeFazio

Of major concern in artificially sensing devices for the blind is the economic trading relation between a) processing large amounts of data in a computer, and transmitting to the blind person only key decisions, and b) processing in a computer only to the extent of properly coding the sensed information and transmitting large quantities of data to the blind person. The area of tactile sensing lacks an analytical basis for planning; some quantification based upon hypothetical transducer configurations and task requirements appears is warranted. The discussion[16] which follows represents one approach: conceiving of a general form of transducer, a general class of objects, and computation implications of discriminating among the given objects with the given transducer.

Consider individual transducers assembled such as to be independent in their output, that is, if any single transducer were directly stimulated, it would be the only one to produce an output. The advantages behind this approach include ease of transducer analysis, ease of providing processing, suitability for direct display of raw data, possibility of expansion or contraction of transducer (intentionally or accidentally) without necessity of changing processing routines.

If the extent of the class of objects in question (to be discriminated by this transducer) is known, it is simple to calculate the capabilities of the transducer to specify location and orientation of the object "touched". Capabilities for recognition or differentiation, however, depend upon the class of objects in question. Generally applicable means of classifying or dimensioning differences in characteristics of objects in question are lacking, though recognition capabilities can be evaluated for a particular class of objects.

A transducer of this kind is considered as a model in quantitative considerations. It consists of a two-dimensional Cartesian array of n^2 plungers, the coordinates of rows and column separated by distance L as seen in Fig. 30. Each plunger indicates $n/2$ levels of depression, with space L between levels. The mechanism involved is outside of present considerations.

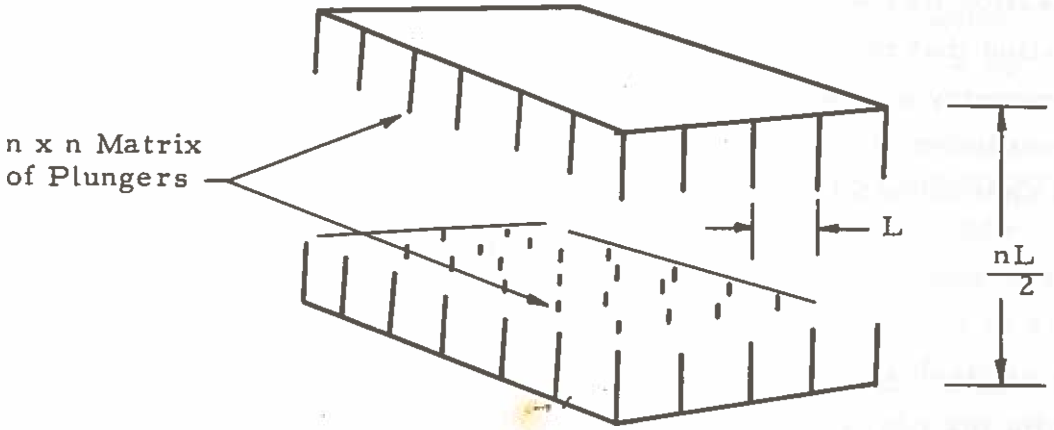


Fig. 30. Transducer Model.

The plunger transducer in cubic array is used to locate and orient bodies to the accuracy limit of the transducer. The plunger transducer is also used to identify among many similar bodies. The information (uncertainty reduction) produced by the transducer is of quantity:

$$\log \text{ (number of possible state-combinations)} = \log \left(\frac{n}{2}\right)^{n^2}$$

Suppose the desired information is location and orientation of an object with a characteristic length nL/2 and suppose the object in question lies within the bounds of the transducer. Assume for illustration that the objects in which we are interested have rotational symmetry as does a cube. The number of possible states that the transducer can assume with an object of such class can be shown to be approximately:

$$\left(\frac{n}{2}\right)^3 \left(\frac{\pi n}{4}\right)^3$$

The $(n/2)^3$ factor comes from the three translational degrees of freedom while the $(\pi n/4)^3$ term comes from the three rotational degrees of freedom, less symmetry. This represents an information content of:

$$\log \left(\frac{\pi n^2}{8}\right)^3 = 3 \log \frac{\pi n^2}{8}$$

A quotient can now be formed and named (R) which indicates the efficiency of information or data reduction as the transducer parameter n varies:

$$R\ (n) = \frac{\text{actual uncertainty}}{\text{maximum uncertainty}} = \frac{3}{n^2} \; \frac{\log \left(\frac{\pi n^2}{8}\right)}{\log \left(\frac{n}{2}\right)}$$

This is a kind of practical utility factor for the transducer. Such a calculation gives a quantitative estimate of channel requirements. Note that the numerator of R(n) is a function of task specification rather than of transducer characteristics.

Once the designer has task specifications and a design for the transducer, the next step would be to program or assemble a computer to accomplish the data processing. These steps should yield enough information concerning component requirements to make estimates of power and weight requirements for data processing and /or transmission equipment.

If the system is to perform a recognition task, and if the objects are known in advance, the system can classify objects according to a group of properties it is aware of in advance. The minimum amount of information needed by the observer in performing such tasks is log N where N is the number of objects or properties. This information, if transmitted, is added to any other information transmitted such as location and orientation information.

Some characteristics of objects to be differentiated among are especially easy to determine and may well serve as bases for differentiation if the objects do vary in these characteristics. Volume and maximum extent are examples. If the orientation of the objects is assured, length along transducer coordinates and cross-section areas across transducer planes are examples. If the differences in these characteristics are slight, use can be made of the following relation.

$$\frac{\sigma_{L}'}{D}, \quad \frac{\sigma_{A}'}{D^2}, \quad \frac{\sigma_{V}'}{D^3} \sim \frac{1}{n\sqrt{N}}$$

where: σ is the rms deviation of measurement of:

L' = length
A' = area
V' = volume

D is characteristic dimension of the class of objects
n is transducer parameter
N is number of independent trials

Implicit assumption:

$D \sim \frac{nL}{2}$ where L is the spacing between plungers and levels of the transducer.

If the above routines are insufficient for differentiation and n cannot be varied, more complex routines considering shapes of the object in question are available.

Other work in the thesis has dealt with specific data reduction schemes for discriminating among two- and three-dimensional objects with many regular facets of characteristic dimension d, $d < D$. Criteria for choosing L as a function of d and D are given.

Finally, some empirical experiments were performed to test how fine a grid is necessary to discriminate two dimensional polygons. As a criterion, a transducer was chosen with dimension $n \sim 2K^2/\pi$, for a k-sided polygon. Empirical tests of this criterion were made by randomly placing polygons of 3, 4, 5, 6, 7 sides on a rectangular grid and evaluating a single interior angle. Results (percent correct recognition) showed that a better criterion might have been a linear relationship between n and k.

These experiments were primarily to demonstrate an approach and were not sufficient to draw definitive conclusions.

10. EXTERNAL PELVIC FRAME ORTHESIS

Robert W. Mann, William H. Pettus III

This study investigates the design of an external orthotic device that would maintain a geometrically fixed relationship to the pelvic girdle and would bear weight. The work was done in the context of a bachelor's thesis [17] and was carried out in cooperation with the staff at the Children's Hospital, Boston, Massachusetts.

Such an orthesis might be applied in the case of, for instance, Leg-Perthes disease, in which the head of the femur in the hip joint deteriorates. All pressure must be relieved from the joint in order that the femur head have a chance to regenerate.

The skeletal unit called the pelvic girdle, structurally an arch connecting the two femurs (thigh-bones) and supporting the spinal column is actually a fusion of three bones -- the ilium, the ischium, and the pubis. A device fitted to this structure should provide good support because the pelvis serves as the center and reference point for bodily motivation and stability. About this center of gravity the iliac crest describes an almost perfect arc.

An initial design purported to concentrate weight support at the iliac crests. Two semi-circular rings of 5/16 in. steel bar stock were constructed to be forced in from the sides under the crests to support the body. However, this did not prove feasible because of 1) difficulties in contouring the rings to a comfortable shape, 2) the variability in pelvis orientation and varying degrees of tilt, and 3) the extreme pressures on the flesh at the iliac crests over an extended period of time.

A second design approach, therefore, required the inclusion of an ischial seat. The latter would support the weight of the entire body, with assistance from the available weight-carrying potential of the flare of the iliac crests. Stability would be provided by capturing the prominences of the anterior and posterior superior spines and the iliac crests, with some assistance from the ischial seat. Support for upper body weight would result from a pulling-in over the iliac crests. This design would therefore afford 1) weight support, 2) stability from below, 3) torso support, and 4) stability from above.

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COURSE PROJECTS

Junior Laboratory

Investigation and Development of Typewriter to Brailler Converter.
Information Transmittal Via the Blind Man's Cane.
Design of Collapsible Blind Man's Cane.

Junior Design

Externally-Powered Prosthetic Limb.
Mobility Devices for the Incapacitated.

Freshman Seminar

Type Compositors Tape-to-Braille System.