The Burroughs Electrographic Printer-Plotter for Ordnance Computing

H. Epstein

P. Kintner

Synopsis: This paper will be in four parts, the first section will cover a system concept involving an automatic digital data-handling system feeding a high-speed output directly rather than through a buffer device as a tape storage system. Some representative programming details are indicated for this type of system involving the Ordvad computer. The next part covers the design approach, and details of the particular mechanization which was chosen to satisfy the requirement based upon electrographic recording. The electrographic recording technique is reviewed and the various relevant parts of the plotter and its capability are discussed. The third part covers the details of the computer programing required to achieve the direct output described in the first section. Part four covers some of the results obtained on the feasibility model of the printer-plotter in actual use.

The Ballistic Research Laboratories have for some time been concerned with the development of a digital plotter capable of absorbing the output of present and future high-speed digital computers used in processing of missile ballistic data. The desired characteristics of the

Epstein, Kintner—The Bepoc
A number of recording methods have been investigated for possible use in the proposed plotter. Among these have been systems using electro-chemical, magnetic, and electrostatic techniques. Of those investigated, the electrostatic recording method appeared to offer the best possibility of meeting the desired performance characteristics from the standpoint of speed, appearance, and adaptability to digital plotting. A contract was let to the Burroughs Corporation to develop a preliminary model of plotter based on their electrostatic recording technique, known as the electrographic process. This model was delivered during June, 1956, and has been under test and evaluation operating in conjunction with the Ordvac Computer at the Ballistic Research Laboratories. The unit has been named the Bepoc (Burroughs Electrographic Printer-Plotter for Ordnance Computing).

The Burroughs Electrographic Printer-Plotter is, as finally developed, actually a general purpose data-recording device, and represents one specific embodiment of the electrographic recording technique. The printer-plotter has capabilities for recording data consistent with the needs of the greatest digital computer capacity presently available.

The original specification of 100 points per second minimum plotting speed has been accomplished at a 300 points per second rate. The Bepoc imposes no practical limit on the recording resolution. Legends and graph lines are automatically incorporated. Reproducibility of the original record has been obtained by use of translucent paper and normal blueprint reproducing machines. Although not originally required, the machine functions as a high-speed page printer.

System Approach

An early consideration in the formulation of a system for the Bepoc was the development of a method of translating computer words into plotting positions and alphameric information. Two basic approaches were considered: (1) a decoding system external to the computer, and (2) internal computer translation. Suitable external decoding systems are readily available based on conventional digital computer components. Methods of internal translation are somewhat less familiar and understood.

The most prevalent use of internal translation is in the systems of card input-output in use on several computers. In such systems, card input is accomplished by placing an "image" of the card into the computer memory with a one-to-one correspondence between bit positions and card hole positions. A simple computer program suffices to translate the image into computer words representing the information originally punched onto the card. Conversely, card output is accomplished by a program which constructs a card image within the computer memory from the computer words desired to be punched as card numbers, and "dumps" that image onto the card, again with a one-to-one correspondence between memory bit positions and card hole positions.

Internal translation obviously saves a great deal of electronic equipment, since extensive decoding apparatus can be replaced by the computer itself. A less obvious advantage is that the flexibility of an internal translation system is limited only by the capabilities of the computer and the ingenuity of the programmers devising the translation programs. The one disadvantage is, of course, that both computer time and memory must be committed to the translation process. For the intended application, it was finally decided that the economy and flexibility of internal translation outweighed the disadvantage of requiring computer time and memory.

More than anything else, the requirement for numbering and titling of the plot along with the plotting action forced the choice of the internal system, for it soon became evident that an unreasonable amount of external apparatus would be required to accomplish plotting and printing simultaneously through external translation.

Design Approach

Characteristics

The device is designed to record in page-form the output of a high-speed computer in either alphameric (printer) or graphical (plotter) form, or both. The record is made on a continuous roll of 11-inch wide paper with 1/4-inch margins on either side giving 10¾-inch line-length. The record is made by printing data in dot form. Each dot is 0.010 to 0.012 inch in diameter in a matrix 50 by 50 per inch. The paper is scanned transversely by a wheel carrying a row of 30 printing pins spaced 0.020 inch apart printing a section of the paper 0.6 inch by 10¾ inches, 30 by 500 dots, on each scan. The paper is advanced 0.6 inch between scans, the recording being done while the paper is stationary.

The alphameric information, three complete lines, can be recorded during each scan, each character printed in a 5 by 7 matrix, 0.08 by 0.12 inch, 5 lines per inch, 7.14 characters per inch, or 72 characters per line. If graphical infor-
mation is recorded, the normal format allows a 1/2 inch of the 10\(^{1/2}\) inch wide record for legend with a plot area 10 inches wide and as long as desired. Provision is made for recording faint graph lines at 5 lines per inch in each of the two co-ordinates.

As stated previously, format control in the present design rests entirely with the data handling system or computer which provides the source information. As was discussed in detail in the first section, the entire organization of the plot or printing patterns can be accomplished by internal programming within the computer. The printer can essentially be regarded in this instance as a high-speed means of recording a memory "dump"; that is, the printer at each of the 500 printing stations in a scan records a 30-bit word from the computer output register, resulting in 500 recorded words in each scan. At the normal speed of 10 scans per second, a scan occupies 20 milliseconds, during which 15,000 bits of information are fed from the computer; during the remaining 80 milliseconds of the cycle no information is fed to the printer. The word rate during the 20 milliseconds recording interval is 25 kc, 30-bit words recorded per second. The presence of each individual word in the computer output register is not indicated to the printer; it is assumed that the computer can provide information at the 25-kc rate. The recording of a word is made visible by inking with a single suitable powder and made permanent by thermal fixing. In applications in which the images are to be erased and the medium reused, the thermal fixing stage is eliminated. During the recording stage the electrical discharge from the point electrode to a grounded metal plate is used as the source of charge to form the electrostatic latent image on the high-resistivity paper surface. The size and shape of the image depend mainly upon the polarity, the electric field strength, and the surface coating used on the paper. A relatively low negative voltage applied to the point electrode gives small round dots suitable, for instance, for high-speed matrix printing. The recording medium is a relatively low-cost, uniformly and smoothly coated paper. The coating is a colorless, high-resistivity, thermoplastic coating. The thermoplastic feature of the coating in combination with a suitable ink, and appropriate heat processing makes it possible to make the development electrographic image completely permanent. The electrographic ink consists of a single powder consisting of material colored as desired. To ink the latent image the paper is passed through an inker containing the powder to give a visible image with virtually no background discoloration. The image is made permanently visible by passing the inked paper over a temperature-controlled hot plate. The three steps in the recording process are necessarily consecutive, and are performed as the paper moves continuously at the appropriate speed for the particular recording application.

**The Electrographic Recording Technique**

The printer-plotter is based upon the electrographic recording technique. Fig. 1 shows the rudiments of the technique. The electrographic recording technique produces controlled, visible dots by electrical pulse means directly. In its essentials, the process utilizes a controlled source of charge to form small charged areas on a high-resistivity surface such as a coated paper. The electrostatic latent image formed by the charged areas is made visible by inking with a single suitable powder and made permanent by thermal fixing. In applications in which the images are to be erased and the medium reused, the thermal fixing stage is eliminated. During the recording stage the electrical discharge from the point electrode to a grounded metal plate is used as the source of charge to form the electrostatic latent image on the high-resistivity paper surface. The size and shape of the image depend mainly upon the polarity, the electric field strength, and the surface coating used on the paper. A relatively low negative voltage applied to the point electrode gives small round dots suitable, for instance, for high-speed matrix printing. The recording medium is a relatively low-cost, uniformly and smoothly coated paper. The coating is a colorless, high-resistivity, thermoplastic coating. The thermoplastic feature of the coating in combination with a suitable ink, and appropriate heat processing makes it possible to make the development electrographic image completely permanent. The electrographic ink consists of a single powder consisting of material colored as desired. To ink the latent image the paper is passed through an inker containing the powder to give a visible image with virtually no background discoloration. The image is made permanently visible by passing the inked paper over a temperature-controlled hot plate. The three steps in the recording process are necessarily consecutive, and are performed as the paper moves continuously at the appropriate speed for the particular recording application.

**Scanning**

No known computer will transmit in one operation a 30 by 500 matrix to an external device. It is evident that the computer's output order must 'scan' the matrix as it exists in the computer's memory, and that the Bepoc must follow suit, scanning its recording medium in a one-to-one correspondence.

Two types of scanning for the recording device come to mind: (1) electronic and (2) mechanical. A possible electronic scheme could be based on a single row of recording stylii, whose number is equal to the number of plotting levels, and a means of gating successive computer words into successive groups of stylii (successive computer words representing the scan action of the recording...
matrix). Such a scheme was not adopted because of the large number of styli and gates required (500). The mechanical scanning system adopted consists of a group of 30 stylii mounted on a rotating wheel which is moved transversely across the recording medium with 500 plotting levels defined by a “clock” wheel attached to the recording wheel. Successive computer words are fed in parallel fashion to the stylii as they move and coincide with positions defined by the clock. The stylii are thereby time-shared and it is possible to record a comparatively large matrix with a small number of stylii. In this system of scanning, the computer words are oriented in the short or abscissa direction of the matrix and the matrix is scanned along its long or ordinate direction. Plotting levels have a one-to-one correspondence with the memory addresses of the matrix, and abscissa positions are determined by the relative bit positions within the computer words. It might be mentioned in passing that the electrographic process facilitates mechanical scanning since the stylii do not have to be in contact with the recording medium.

**Details of the Bepoc**

A block diagram of the electronic control circuitry associated with the printer-plotter designed to operate on-line with a high-speed digital computer is shown in Fig. 2. The computer is assumed to be able to provide a 30-bit output in parallel, 1 bit for each of the recording pins. Four signals are needed in order to allow a printing scan to take place: the machine “start” button has to be depressed, the computer ready signal indicating that the computer has available the information to be printed, the “start print” pulse from the timing wheel associated with the plotter, and the output indicating that the paper has advanced to the next print position must be present concurrently to set the print flip-flop. This allows for each of the synchronizing or clock print pulses derived from a notched timing wheel to set the column pulser, and read-out the 30-bit word from the computer into the 30 pulse generators. The pulses from the pulse generators are fed through slip-rings, and to the print head and recording pins. This is accomplished for each of the print positions across the paper, namely 500, after which a “stop print” pulse derived for the timing wheels on the printer resets the print flip-flop, and causes the paper to be advanced and excites the interposing flip-flop. Whenever graph lines in the transverse direction are desired pins 1, 11, and 21, or every tenth pin, are excited to print faint graph lines. If a computer ready signal is not derived from the computer and the paper remains stationary the scanning wheel, as discussed in a later section, goes through the scan but no printing takes place. It should be noted that the computer must have available the information to be printed in one scan. This is indicated to the printer-plotter by means of the computer ready signal. The printer-plotter then provides its own clock signals to derive this information from the computer and print the information at the proper positions in the scan cycle.

The printer input circuitry for each of the 30 channels is quite simple. As each of the 30-bit words is read out serially, each of the 30 bits is fed into a printer pulser and fed into each of the 30 pins in parallel as indicated in Fig. 3. The printer pulse generator with the associated input gates shown in Fig. 4. The printer pulse generator in this case is a blocking oscillator with a step-up output winding on the pulse transformer coupled to the pin. The circuitry involves conventional miniature tubes and standard supply voltages.

The 30 pins in the printing head are mounted on the periphery of a cylindrical disc which rotates at 10 times a second.

**Fig. 3. Printer input circuitry for each of 30 channels**

**Fig. 4. Printer pulse generator with associated input gate**

**Fig. 5.** Schematically shows the recording wheel, Fig. 6 shows the recording head mounted in the wheel. The paper is curved in a trough to conform with a trough of a vacuum anvil with the coated side of the paper facing the printing pins. As the print head scans across the paper it prints out the 30-bit word in the 500 printing positions as synchronized by the printer timing wheel and associated circuitry. The paper path through the machine is indicated in Fig. 7. The paper is taken from a supply reel and fed through a friction drive. The metering mechanism allows 0.6 inch of paper to be advanced as the printing for each scan is completed. The mechanism basically operates by clamping one side of the paper and unclamping the other side allowing a roller to pull through 0.6 inch of paper from the supply reel. The clamps cycle to the opposite phase allowing the paper to be fed through to the printing station. There is a drive at either end, one supplying the paper to the metering mechanism, and the other to pull the paper through the remainder of the machine. The paper travels through the metering mechanism, through a neutralizing device in order to electrically clean the surface of the paper, thence to the printing station. The paper is then taken through the inker and fixer and onto the take-up reels. A single scan is pictured in Fig. 8. The 30-bit word takes up 0.6 inch of paper, since the printing pins, packed at a 50 per inch density, scan across the paper through the 500 positions so that for each scan a band 0.6 inch by 10½ inches wide is printed, comprising the roughly 15,000 possible dot locations. This printing is done while the paper is stationary in 20 milliseconds. The 80 milliseconds remaining part of the cycle is taken in moving the paper and allowing the source device to accumulate the data to be printed in the subsequent 20 milliseconds. A schematic representative output is

*Epstein, Kintner—The Bepoc*
shown in Fig. 9. Faint graph lines 5 per inch each way or one for every pin can be provided; legends in either coordinate axis can be printed along with plots built up by a succession of points. Any number of plots can be multiplexed into the output record, and the alphameric printing can be accomplished and are entirely dependent upon the computer programming and capability as will be discussed in the next section.

Computer Programming

Plotting

As stated previously, the recording matrix for the Bepoc has a one-to-one correspondence between plotting levels, and memory addresses of words within the matrix. A translation program for the translation of plot values into a plotting pattern within the recording matrix is accomplished simply by "planting" binary one's in the matrix, and at addresses fixed by the plot values. The position of a binary one within a word at a given address is based on the abscissa value of the point being plotted.

The exact nature of a translation program depends, of course, upon the particular order structure of the computer. One possible scheme is to have 30 "plant" orders as follows:

1 Transmit from \( A_1 \) to \( B_1 \)
2 Transmit from \( A_2 \) to \( B_2 \)
3 Transmit from \( A_3 \) to \( B_3 \)

The \( A \) addresses contain the binary one's to be planted and the \( B \) addresses are those of the recording matrix.

The Bepoc is intended to be primarily applied to missile data processing, and such data is almost plotted in respect to sequentially increasing time values as the abscissa of plots. In this case, the contents of the \( A \) address would be as follows:

\[
\begin{align*}
A_1 & = 00000 \ldots 0001 \\
A_2 & = 00000 \ldots 0010 \\
A_3 & = 00000 \ldots 0100 \\
& \vdots \\
A_{30} & = 10000 \ldots 0000
\end{align*}
\]

The values to be plotted must be normalized to fit the number of plotting levels (500) and then placed in turn into the \( B \) address portions of the plant orders. Before the plant orders are executed, the entire recording matrix must be cleared to binary zero's.

The nature of the plant orders needs further discussion. A simple transmit from address \( A \) to address \( B \) will not suffice, since when plotting a constant value, a given \( B \)-address in the matrix will receive a series of one's. It is evident that the transmit into \( B \) must be of such a nature as not to destroy previously transmitted binary one's. A transmit add order, where \( A \) is added to \( B \) and the result stored in \( B \), will take care of the situation for single-valued data plots. However, for multiple-value plots a binary one may not only be transmitted to the same word in succession but also to the same bit position. An \textit{add} action in this case would produce a zero together with a carry to the next position. To prevent such an action, the transmit action should be of a type where the bit-by-bit logical sum of the contents of \( A \) and \( B \) is formed, and the result stored in \( B \). A logical summing action as is well known, is given by the following:

\[
\begin{align*}
0+0 & = 0 \\
1+0 & = 1 \\
0+1 & = 1 \\
1+1 & = 1
\end{align*}
\]

No carries, of course, are permitted to take place.

Recording

Recording is based on a series of submatrices which represent alphameric information in dot form. A prevalent system of dot-matrix representation of alphameric information is based on 5 by 7 matrices as shown in Fig. 10.

It is assumed that a complete set of patterns as shown in Fig. 10 is stored within the computer memory, at a place other than the recording matrix. Placing alphameric information into the matrix is accomplished simply by transferring submatrices from the stored pattern or "bank" portion of the memory into the recording matrix portion of the memory. The basic order is

Transmit from address \( A \) to address \( B \).

Address \( A \) is set in accordance with the location in the bank of desired alphameric character to be recorded, and address \( B \) is set according to the position on the plot.
where the alphameric information is desired to be placed. The action is seen to parallel that of a hand typesetter. The basic order states that a type is to be picked from the type bank and placed in a type stick. Address A determines the type to be picked and address B determines the place where the type is placed by the compositor. It should be added that the basic order must be repeated 5 to 7 times, depending upon orientation of the sub-matrix, with both addresses increasing by one on each action, until the entire submatrix has been transferred.

Actually, address B in the above described basic order only allows placement along the long dimension of the matrix. Placement along the short dimension could be accomplished by shifting the pattern between picking it from the bank and storing in the matrix. However, this would be time consuming. A better method is to store the pattern in multiple within the bank, repeating it say three times for three possible positions in the short or abscissa dimension of the matrix, and then to "extract" into the recording matrix against a control "mask" which effectively chooses one of the sets of patterns corresponding to the abscissa position desired. This would give sufficient placement discrimination for normal plottiling, and would fit in directly with a system for straight printing. It is to be noted that repeating the pattern in the bank in the manner described does not require additional memory space over a single listing of the pattern.

PROGRAM TIMES

The time required to carry out a translation program is dependent, of course, upon the computer being used. The Bepoc was originally designed to be used with a Univac Scientific (Engineering Research Associates 1103) computer, and typical times will be given from this machine.

Plotting. It is assumed that any plotting scheme will require a normalizing action and that normalizing therefore should not be charged to the translation process. Also, as data is generated in a normalized fashion, it can be stored in the "plant" orders. This leaves only the time to clear the recording matrix and the time to perform 30 plant orders chargeable to the translation program. Typical times on the Univac scientific computer for these are: clear matrix in 12 milliseconds; perform plant orders in 1.5 milliseconds, or a total of 13.5 milliseconds. It has been shown that the mechanical design of the Bepoc requires 20 milliseconds for recording the matrix,
and that 80 milliseconds is available for a translation program or other action between recordings. It is evident that there is more than enough time available for the translation program in this instance.

**Recording.** The Univac Scientific has within its order structure an order, the so-called repeat order, which greatly facilitates the transmitting of alphameric submatrices into the recording matrix. Utilizing this order, the time for the transmission of a single character is approximately 0.5 millisecond. Allowing time for the clearing of the matrix and the recording process results in an over-all printing rate of approximately 1,000 characters per second, of the same order of magnitude as parallel wide-line high-speed mechanical printers.

**Computer Design to Facilitate Internal Programming**

The above program times could be considerably shortened if some consideration could be given in the design of the computer for this particular internal programming. One simple addition would be an output order which cleared the memory position from which it took information, so that the matrix clear action would not have to be performed by the translation program. This could be accomplished by simply inhibiting the "restore" action which regenerates a memory position after the usual destructive readout. The result would be that not only the need for a clear action eliminated, but also the output order is speeded up.

The second possibility is to store the alphameric patterns in a separate section of the memory, with non-destructive readout. Such a system might transmit ten times faster than the conventional transmit, where restoring action, etc. must be performed. It should be possible then to obtain translation rates of around 20,000 characters per second.

As has been indicated previously, the order structure of the computer can greatly facilitate the internal translation required for the Bepoc. Desirable orders are the logical sum, or bit-by-bit OR, and the logical product, or bit-by-bit AND, sometimes termed an EXTRACT order. A means of repeating an n times, with the order addresses automatically advanced by one for each action is extremely valuable for manipulating alphameric submatrices.

**Results**

Patterns fed to the Bepoc during the developmental phase have been from a "simulator" consisting of a group of shift registers arranged to give a 30 by 10 matrix. Patterns placed in shift registers are repeated 60 times on a scan action. Fig. 11 shows a printing pattern obtained from the simulator. Fig. 12 shows graph lines as recorded by the Bepoc. Fig. 13 indicated a plot of a function along with the numerical value of the function given periodically. This plot was made with the Bepoc coupled on line to the Ordvac.
Conclusion

A device for high-speed plotting, printing or both has been described. The device is intended specifically for the high-speed recording of the output of computers used for the processing of missile ballistic data, but is actually a general purpose data recording device, and has capabilities for recording data consistent with the greatest digital computer capacity presently available. Results obtained from the feasibility model indicate that this device is capable of substantially advancing the art of high-speed recording of digital computer outputs.

Reference


Discussion

J. L. Hill (Remington Rand Univac Corporation): Are the blocking oscillator trans

A Transistorized Transcribing Card Punch


The RCA (Radio Corporation of America) BIZMAC Transistorized Transcribing Card Punch described in this paper provides a means for converting large volumes of data stored on magnetic tape in the Bizmac code into characters punched on electronic accounting machine cards using the IBM (International Business Machines Corporation) code. This output device will transcribe information at the rate of 150 cards per minute, and provides accuracy control features to assure correct data punching. The functional operation of the transcribing card punch is compatible with the Bizmac system and with general punched-card system requirements as well.

The device consists of two packages. The electronic circuits are housed in racks which permit rapid access to vertical mounting panels for servicing. Plug-ins are used throughout, and a simple transistor circuit element which performs all the logical functions is employed. The results of a review of punching methods, coupled with a requirement for easy replacement of parts, guided the mechanical design of the card transport and punch mechanisms. These are placed in a separate cabinet with removable covers. Input and output hoppers are at a convenient height. Design emphasis was primarily directed toward obtaining a high degree of accuracy control in a device with maximum functional flexibility.

Functional Description

Input messages to the Transcribing Card Punch are received from a BIZMAC magnetic tape station through seven channels. Character rates of 10 to 30 kc are acceptable. The Transcribing Card Punch requires that messages from magnetic tape be of fixed field format. BIZMAC alphanumeric characters and the eight punctuation marks which have IBM 407 punch equivalents are translated and punched on cards. The six BIZMAC punctuation marks which do not have IBM equivalents are translated as blank columns on the cards. All BIZMAC control symbols such as start message, item separator, and end message, are eliminated during translation and do not create blank columns.

A plugboard is incorporated to permit data rearrangement and character insertion. Specifically, the plugboard provides the following functions: (1) The formation from magnetic tape can be rearranged in any sequence on the cards. (2) Control symbols can be overpunched into the same card column with numeric punches. (3) Fixed data may be

C. T. Cole, Jr., K. L. Chrien, and C. H. Propster, Jr. are with the Radio Corporation of America, Camden, New Jersey. The authors wish to acknowledge the contributions of J. E. Palmer, R. F. Bov, H. H. Cramer, and J. O'Donnell on this project.