Hard-copy computer output and its future

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ABSTRACT

Descriptions provided for classes of products available for hard-copy output of computers include: impact and non-impact printer technologies; serial character and parallel line printers; shaped character and dot matrix character images; and plotters which use movable pens or dot matrix imaging with non-impact printing technologies. The significance of factors such as print quality, speed, flexibility, reliability and cost, which determine the selection for a given application, will be discussed.

The future of these products depends on the utilization and enhancement of microelectronics, new materials and new manufacturing processes, as well as the needs of users in the marketplace. New products will have even higher price/performance ratios, better reliability and increased output flexibility and graphic capabilities.

INTRODUCTION

The principal hard-copy output of computer systems is alpha-numeric data produced on computer output printers which range in speed from 10 cps (characters per second) to 18,000 lpm (lines per minute), and the prices range from $1,000 to $300,000. The two basic methods of printing are impact and non-impact. Impact printers utilize mechanical pressure to transfer the character image from an inked ribbon to the paper. Non-impact printers utilize other technologies such as thermal printing where the character image is formed by using heating elements with the shape of the character to heat a sensitized thermal paper which changes color with applied heat. Printing is performed either a character at a time in a serial format by a character printer, or a line at a time in a parallel format by a line printer. Character images are printed either as shaped characters, which is the familiar form of book printing, or as a set of dots representing the character out of a dot matrix pattern. Thus, a printer is classified by three characteristics: impact or non-impact, character or line printer, shaped or dot matrix characters. Table I lists printer speed classes with the associated types of printers and typical U.S. end user price ranges when interfaced to a computer.

The three general types of plotters in use are the drum, the flat-bed and the electrostatic printer/plotter. It is also possible to use certain types of computer output printers for plotting if the printed symbol spacing can match the plotting requirements. The ink-based plotters contain means of moving the pen in two dimensions across the paper. The flat-bed plotter uses a pen which is moved in two dimensions. The drum plotter utilizes paper motion for one dimension and moves the pen for the other. Electrostatic plotters move the paper for one dimension and use a set of styli across the paper which is selected to cause printing on dielectric-coated paper. Plotters are utilized for hard-copy whenever graphical data is the prime output of the computer.

The applications for different speed classes of output printers have been dependent on the volume of output required and the price of the printers. The most widely used printers are the low cost 10 cps (characters per second) character printers used primarily in terminals. Higher speed character printers, with speeds up to 200 cps, are also used with microcomputers and small business systems. Medium to high-speed printers in the 300 to 2000 lpm class represent the major output devices for small, medium and large computers. Very high-speed printers in the 4000 to 18,000 lpm class are utilized by very large computer systems with volumes of printout greater than 1 million forms per month.

The particular choice of a hard-copy output device for a given system depends on the application, the print quality and/or graphic output requirements, the volume of the output, the speed of data availability and output speed capabilities, the flexibility and availability of output character sets and symbols, system costs, expendable costs and, finally, the maintainability and reliability. The significance of these factors as they affect the choices will be discussed.

IMPACT PRINTING

Printer units consist of a printing mechanism which produces the printed characters and a paper moving mechanism which moves the paper past the printing mechanism. Impact printer mechanisms consist of some means of scanning the characters past the printing positions, some means
TABLE I.—Typical U.S. End User Printer Equipment Prices and Speeds

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Speed/Price (Characters/sec./$(OOO))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Character (Shaped Character)</td>
<td>Speed-Lines/min. Price-$(OOO)</td>
</tr>
<tr>
<td>IMPACT CHARACTER (DOT MATRIX CHARACTER)</td>
<td>90-250 300-700</td>
</tr>
<tr>
<td>IMPACT LINE (SHAPED CHARACTER)</td>
<td>3-17 3-51</td>
</tr>
<tr>
<td>IMPACT LINE (DOT MATRIX CHARACTER)</td>
<td>300-600 1000-3500</td>
</tr>
<tr>
<td>NON-IMPACT CHARACTER (DOT MATRIX CHARACTER)</td>
<td>300-100</td>
</tr>
<tr>
<td>NON-IMPACT LINE (DOT MATRIX CHARACTER)</td>
<td>5-10 10-300</td>
</tr>
</tbody>
</table>

of impacting the character to transfer the character image through the inked ribbon to the paper and a ribbon moving mechanism. There are many techniques of scanning the characters past the print station, and these will be discussed with individual printer types.

There are two basic methods of impacting the character. One method is to impact the ribbon and paper with the character to be printed, as is done with an ordinary typewriter. This is known as a front-striking character impact mechanism. The other technique is to place the character to be printed behind the ribbon with the paper in front of the ribbon. The character image is formed when the hammer impacts the paper causing pressure on the ribbon and the character. The characters are scanned past the hammers and are moving when impact occurs as shown in Figure 1. The latter hammer-impact technique is the one employed in all drum, chain, and train printers and this represents the majority of the installed impact medium and high-speed printers.

The ribbon mechanism uses either a wide towel-like ribbon which passes the print station in the vertical direction, or a narrow ribbon like a typewriter which passes the station horizontally. One form of the paper moving mechanism consists of utilizing paper with sprocketed edges so that a sprocket-feed mechanism moves the paper. The friction feed rollers are normally used in low-speed printers or in very high-speed printers which do not intermittently stop for printing. Printing of forms is normally accomplished by means of sprocketed paper since the form must be aligned with the printer mechanism to print properly on the form. The two basic sizes of printers permit 80 column or 132 column print widths at 10 columns per inch. Higher print densities are available on some printers which permit 132-column printing on 11-in. wide forms.

Printer units also contain control electronics and power supplies. There is an interface to the computer or to the control unit which is used to transfer data to be printed and format control information. The control electronics contain timing control, electromechanical control, power circuits such as hammer drivers and, if required, code translators. Character printers generally accept a character at a time, and the printer mechanism prints the character and moves to the next column to print the next character accepted. Line printers contain print line buffers. All the characters for a print line are sent to the printer and they are stored in the buffer. The printer control electronics scan the buffer and actuate the hammers, at the correct time, to print the line. The power supplies provide power to operate the control electronics and to operate the electromechanical portions of the printer.

**Impact serial character printers (shaped characters)**

The printing mechanism of a serial character printer moves serially across the printing area, usually from left to right, as the characters are printed a column at a time. Both the character impact and hammer impact methods are employed. The majority of serial printers, over 700,000, are...
the character impact printers produced by Teletype Corporation. Teletype printers use a cylinder with characters on the cylindrical surface to print at 10 cps. IBM uses a replaceable sphere with characters on the spherical surface on their Selectric printers to print at 15 cps. Univac uses the hammer impact method with a one-character-wide drum to print at 30 cps. The Xerox-Diablo and Qume printers use a daisy wheel with characters mounted on flexible arms at the outer perimeter and print at speeds up to 55 cps. These printers can also be used for plotting, since incremental motions of 1/24 in. are possible.

General Electric Termitet printers use a belt on which the characters are mounted. Hammers behind the belt impact the characters and then, in turn, impact the ribbon and paper. It is not really a character printer since the print mechanism does not move across the print line. Some versions are character printers since the hammers fire in groups from left to right, while other versions are line printers up to speeds of 340 lpm.

Impact serial character printers have been utilized in two different types of applications. The difference in the application depends on the print quality obtainable with the printer. Printers in the teletype class, such as the Teletype Model 33, have been primarily used in communication situations where print quality is not very important and low cost is a desirable feature. On the other hand, the IBM Selectric and the daisy wheel printers are utilized for printout where good print quality is a requirement, such as the output of word processing equipment for business letters.

**Impact dot matrix printers**

Most of the printers in the field using impact dot matrix printing are character printers, but there are some which are line printers. Most character dot matrix printers use a 7-wire matrix to produce matrix characters ranging from $5 \times 7$ to $9 \times 7$ dots. The use of an 8-wire or a 9-wire matrix permits character generation for characters which extend below the print line. Many different character sets can be generated with the same print head using different dot matrix character generating ROM’s (read-only-memories). Character sets with different shapes than English, such as the Japanese Katakana, may be generated by merely changing the ROM.

Recently, Centronics and others have introduced printers with ROM’s to generate high density character sets of up to 15 cpi (characters per inch), instead of 10 cpi normally used for computer printout. In this way, a 132-column printout can be produced on an 11-in. width sheet. Plotting may also be performed by dot matrix printers using the dot grid available from the print mechanism. The plotting capability requires additional electronic control and software, and is available on very few matrix printers.

Several line printers in relatively low production volume are available which use dot matrix printing. There are two basic approaches used for printing. The first approach, used by Tally, Okidata and Printronics, uses a matrix comb of wire actuators across the page which moves back and forth to print dots for one row of dots across the sheet. The sheet is moved to print the 7 or 9 dots vertically to generate characters. Potter manufactures several models with speeds up to 500 lpm which utilize a rotating print drum consisting of a cylinder with helical ridges on its periphery. The impact hammer, which is several columns wide with the height of a dot, is used to print all the dots for the columns it covers. The impact of the hammer on the paper and ribbon at the time that the ridge is at an appropriate position, causes the dot to appear.

The use of character dot matrix printers has greatly increased in the past few years. They permit printing at lower prices for applications between the 30 cps shaped character printers and the 100-300 lpm low-speed line printers. A whole new series of products is just emerging in the 30 cps to 100 cps speed range with generally higher prices than the Teletype Model 33, but with speeds at least tripled and with reliability greatly increased over the Teletype printer. Higher speed models use multiple heads to increase speeds. The prices for these printers in the 60-120 lpm speed range have been priced lower than line printers in the 100-300 lpm range. Although the dot matrix printers are lower priced than line printers, they generally suffer from lower reliability and require more maintenance.

**Impact line printers**

The hammer impact class of line printers constitutes the major population of medium and high-speed printers. Technology improvements have increased the speed from 600 lpm in 1960, to 2000 lpm in 1972. In addition to increasing speeds, the prices for equipment have been reduced and the reliability increased. Although printing appears to occur a line at a time, it actually occurs by sets of characters being printed simultaneously on a line and eventually all the sets of characters get printed to form a line. The print mechanism contains one hammer per column of print position. The printable character set is scanned past the hammers. When a character reaches the column to be printed with that character, the printer control causes the hammer to impact the character at that column.

The two basic methods for moving character sets past the hammers are the horizontal moving techniques and the vertical moving drum. IBM pioneered the chain- and train-drive printers with its 1403N1 at 1100 lpm. While the majority of non-IBM printers use drums. Chains and trains use slugs constrained by tracks which need lubrication to keep friction down and to minimize wear due to sliding friction. Drums are more reliable since they are rotated on bearings and have no friction in moving the character set. Chains and trains are more flexible since character sets can be larger and can be changed by the operator. Drums, on the other hand, last longer because 35 times as many of the same characters are used for printing.

The other approaches to horizontal scanning use belts which move in one of two planes. The first moves like the
tread of a tractor and is used by the Teletype Model 40 and the Dataproducts Charaband. The second moves like a belt that wraps around one's waist and is used in the G.E. Terminet and the IBM and Univac steel belt printers. These belt mechanisms vary in the amount of friction encountered due to the basic design approach. The Dataproducts Charaband uses print slugs attached to a band riding on a ball-bearing mechanism which minimizes friction and wear and, thus, eliminates complex lubrication systems and increases life. Printers using belts have speeds which range from 30 cps to 2250 lpm.

Printer performance is measured by print quality, flexibility, speed, reliability and maintainability. The principal factors which determine print quality are horizontal and vertical character registration, character smear, character tilt, character clipping, ghosting, character voids, and variations in character density. These print quality factors are determined by the design of the print mechanism, the type of ribbon used and the ability of the print mechanism to stay adjusted. Designs such as Dataproducts printers use components, such as the Mark IV friction-free hammer mechanisms, which retain their adjustment for over 150 million printed lines.

The speed of line printers is a function of the character scan speed, the size of the character set, the characters printed on the line and the time it takes to move the paper to the next line. The speeds of line printers vary from 75 to 2000 lpm with increments generally of 300 lpm. The most widely used speeds are 75, 150, 300, 600, 900, 1200, 1500 and 2000 lpm.

The last factors of reliability and maintainability are influenced by the general technology used and the mechanization of the principal subsystems consisting of the character scanning mechanism, the paper feed mechanism and, most important of all, the hammer impact mechanism. Most manufacturers use an electromagnet and push rod which impacts a pivoted or flex-pivoted hammer slug. Parts of the electromagnet mechanism are subject to wear as well as the push rod-slug interface.

The Dataproducts friction-free Mark IV hammer actuator consists of the hammer impact slug which is mounted on a flat coil and suspended by two flex-pivot springs which also carry current to energize the coil. The coil is placed between permanent magnets and, hence, an electromagnetic field is produced which causes the hammer to impact the paper, ribbon and the character to be printed. Field experience indicates that the mean number of strokes between failures for the hammer actuator is approximately 2,000 million, and flight time adjustments are required at about 150 million strokes. It is a more reliable hammer mechanism and requires less maintenance than other designs.

Impact line printers—somewhat serial

This class of printer is used for medium to low-speed line printing in the range of 100 to 700 lpm. Lower product cost is achieved than is possible with a line printer by sharing some of the components in the printer, hence, fewer parts are used.

Dataproducts pioneered this approach in 1969, and produced its 80-column Model 2310 printer by sharing 20 electrical hammer drivers for 80 hammer actuators. This same sharing technique is used in the Dataproducts 2910 military line printer with speeds ranging between 356 and 1110 lpm depending on the number of columns printed. IBM uses a double width hammer in its new steel band printer for the 3770 terminals and the System/32 at speeds between 50 and 150 lpm. One hammer is used for two columns, hence, only one-half the hammer mechanisms are required. Another version of IBM's steel band printer is available with one hammer per column which prints at 400 lpm.

Dataproducts offers the 2230 printer which uses one-half the number of hammer actuators to achieve a print speed of 300 lpm. The hammer bank with the Mark IV friction-free hammer, is flex-mounted and servo-driven to two positions by means of a voice-coil positioner. An optical transducer is used for position sensing and a magnetic transducer is used for velocity sensing.

NON-IMPACT PRINTERS

A variety of technologies exists for printing with non-impact printers. Some utilize special papers such as electrostatic, electrolytic, photographic or thermal, and others utilize ordinary paper. Printing speeds range from 10 cps to 45,000 lpm. All impact printers have the property that they can produce multiple copies at the time of printing, since the impact pressure through the carbons is transmitted to the copies. Non-impact printers produce only one original copy.

The two technologies of non-impact printing which utilize normal paper are the ink-jet and xerographic printers. Low speed ink-jet printers are used in word processing applications. High-speed xerographic printers are used for high volume printing. These printers are just emerging in the marketplace.

The other techniques of non-impact printing employ special papers which have properties for producing print without impact. The most widely used is thermal paper which is printed upon by heating dot elements which form dot matrix characters on the paper. Thermal printers utilizing this technique are employed as interactive keyboard terminals. Next in use is electrostatic printing which is performed by using a paper which is dielectric coated and used in applications which require printing and plotting.

Each of the technologies will be discussed with the printers' speed range, advantages and disadvantages, price range and significance for use as hard-copy output devices.

Thermal matrix printers

Most of the thermal printers in the field utilize an array of 5x7 individual elements within one head. Each element in
the array can be switched on and off to impart heat. The head stops at each printing position as it is stepped across the paper. Dark marks are produced on the thermally sensitive paper at those points of the array which have been heated. Speeds of up to 120 cps are available using this technology, but most of the printers operate at 30 cps.

The prime suppliers of thermal printers are Texas Instruments and NCR, with TI being the dominant supplier. Until recently, impact dot matrix printers have been considerably more expensive than thermal printers. The new 30 cps impact printers of Digital Equipment Corporation and GE are still more expensive than the thermals, but they are closer in price than they were. Thermal printers are also being utilized for calculators and small personal computers. They are quiet and have a lower initial cost than comparable impact printers. If the volume of printing is not high, then the cost of the paper is not a deterrent for its use. Paper costs can be two to four times the cost of normal paper.

**Electrolytic and electrographic printers**

Both processes use specially coated papers which change in color with the application of a voltage on the writing element. The electrolytic process is a wet process where moist paper is drawn between electrodes. The electrographic process is a dry process which uses electrosensitive paper which has a metallic sheen and retains finger mark impressions when handled. Applying a voltage to the paper causes a light surface layer to burn away and leave a dark layer underneath. Both processes have been used in facsimile systems, military communication equipment and commercial terminal equipment.

The printing mechanism in commercial terminal equipment, such as the UNIVAC printer, uses a dot matrix print head containing 9 styli that etch 7 columns of dots per character as the print head moves across the page.

The technology provides fairly low printer prices with fairly high serial printer speeds, up to 300 cps. The principal problem with utilizing the technology is the appearance of the paper and its expense. The approach could be used for output plotting at the plot densities available from the head configuration. Further developments in the paper technology could make this approach more viable in the marketplace.

**Electrostatic printers**

Electrostatic printers utilize specially coated paper and are line printers, since a row of conductive styli are used with a density of between 100 and 200 styli per inch. Each stylus is selectively charged according to the required output, so that each character is formed out of a mosaic of charged spots on the paper. The data for successive rows are produced as the paper moves. The paper is subsequently passed through the toner bath where the charged areas attract ink particles. The appeal of the technology stems from its ability to both print and provide relatively rapid plotting. Printing speeds vary between 300 to 3600 lpm for most printers, except for Honeywell which has a speed of 18,000 lpm. The prices are quite competitive with the fastest impact printers and often are significantly lower. Very fine resolutions are possible, which makes a variety of good quality character styles available.

Three vendors are supplying printer/plotters: Versatec, Varian and Gould.

Versatec is the dominant supplier. A new printer has emerged which is low cost for printing only and is manufactured by Houston Instruments. Honeywell has a high-speed version of this technology printing up to 18,000 lpm. The prices range between $5,000 to $13,000 for lower speeds, and up to $165,000 for the high-speed Honeywell printer.

The principal disadvantage of this technology is the cost of paper. If very high printing volumes are expected, then the cost of paper could be prohibitive to its use. Honeywell sells their paper at a fairly low price, but charge for use of the printer on a per copy fee. When these printers are used as printer/plotters, then the cost of paper is not a significant factor since the convenience of the output is the prime driving force for its use. Plotters are available with widths up to 72 inches using this technology.

**Magnetic printers**

One currently available printer, manufactured by Inforex, uses a technology that can be described as indirect magnetic. In this printer, a tape coated with magnetic material is passed over a recording head, which creates a magnetic latent image of a complete character mosaic. This tape is then toned with a magnetic ink powder. When a full line of text is ready, the tape is placed in contact with the paper and the ink particles are transferred. The ink powder is fused into place as the tape is wound on past an erasing head. Speeds of 200 lpm can be achieved in this way. It is being manufactured in fairly low volume, and has poor printing quality. It is not too cost effective and is not a significant technology in the marketplace today. Future developments could make this technology more viable.

**Ink-jet printers**

Ink-jet printers produce a jet of ink droplets which are directed against plain paper. The droplets first pass through an electric field which places an electrostatic charge on the droplet. They next pass through a deflection plate which deflects the droplets in proportion to their charge. At points where no ink mark is required, the ink droplet is deflected into a gutter, leaving the paper clear. There are two ink-jet printers in the marketplace today at opposite ends of the speed spectrum. Ink-jet printing technology is also used in a variety of applications outside of the data processing industry, such as the printing of containers.

The IBM 6640 document printer produces output at 92 cps with print quality that is very close to that produced by
the IBM Selectric typewriter, and is used in word processing applications. This print quality is achieved by utilizing a dot matrix structure of dots at 240 per inch both horizontally and vertically. A single ink jet is used which is directed vertically and moves horizontally in a serial manner. Although the 6640 does not currently have a graphics plotting capability, it certainly would be possible to provide very good quality graphical output provided the control were designed into the printing mechanism. This certainly could happen in the future.

The Mead Dijit printer system produces printout at 45,000 lpm, or 600 feet per minute, in terms of press speeds. The print head utilizes 100 jets per inch and a single jet for each droplet position. It is an expensive printer, and is currently being used in specialized applications such as very large volume direct mail letters. Its utilization is closer to that of a high-speed printing press with variable information being printed as controlled from a computer output.

More ink-jet printers will be appearing in the marketplace in the future. Higher speed serial printers will be available with lower print quality than the IBM 6640. The success will ultimately depend on how reliable and maintainable the printers are, and how cost effective they are in relation to comparable impact printers. Specialized applications will be found for the very high-speed printer, but it will not be used widely for high-speed computer printout, since other methods which are somewhat slower are available and are cost effective in the marketplace.

Xerographic printers

Xerographic printers utilize a printing process identical to that utilized by xerographic copiers. The difference between a xerographic copier and a xerographic printer is the method of imaging. The Xerox 1200, first delivered in 1974, utilizes a photographic drum with character images similar to a line printer drum, but uses flashes of light to image the characters on the xerographic printing drum. The IBM Model 3800, first delivered in 1976, uses a laser beam character generator to generate a dot matrix character on the surface of the photoconductor. In both cases, after the images are formed, the toner is applied to the photoconductor surface and the image is created by the toner on the surface. The image is then transferred to output paper and fused into place. Both systems contain a forms overlay feature which allows a form created as a photographic image to be reproduced on the printed output. This eliminates the need for utilizing forms which are pre-printed and saves the costs of purchasing forms printed by a printing press.

The Xerox 1200 uses 8½ x 11 in. sheets, prints at 13.3 characters/inch and 8 lines/inch, at a speed of 60 sheets/minute, or 4000 lpm. It prints 95 ASCII symbols including upper and lower case alphabets, numerics and special characters. The cost is $145,000 and a usage charge, based on the number of copies, is added to take care of maintenance.

The IBM 3800 utilizes continuous sprocketed forms and a dot matrix structure for its output characters, with 180 dots/inch in the horizontal direction and 144 dots/inch in the vertical direction. The dot structure is fine enough to produce output characters which appear to be shaped character images. The dot matrix structure permits many different character sets to be printed by the printer with the possibility of mixing character sets on a particular sheet. There is no graphic capability in terms of graphical curves, but it would certainly be possible to provide that capability with suitable software modifications by IBM. The output speed depends on the size of the form and the number of lines per inch utilized in the printout and ranges from 8,180 lpm to 20,820 lpm. The cost is $310,000, and there is a maintenance charge based on the number of forms used per month.

In order to utilize a printer with a speed capability and with the cost of the IBM 3800, the user should have a volume greater than 1½ million copies of printout per month. The pricing of the printer is such that it becomes cost effective if the user does have volumes this high or greater, and utilizes a considerable amount of pre-printed forms. Computer operations which utilize more than 3 high-speed computer output printers, are candidates for these high-speed non-impact xerographic printers.

DIGITAL PLOTTERS

Digital plotters provide graphical output in the form of lines on paper from digital inputs. Digital plotters utilize writing instruments, such as pens to mark the paper, which are moved in two directions to generate the graphical output. Another type of plotter is available, which utilizes the technique described under electrostatic printers.

There are two basic types of moving pen plotters: the flatbed plotter and the drum plotter. The flatbed plotters plot on a flat sheet of paper which is held in place, and the pen is moved in two dimensions to draw lines from one point to another. Roll sheets can also be used which consist of paper, vellum or plastic. The paper sizes range from 11 x 17 in. to 54 x 76 in. Pen speeds range from 3 in./sec. to 100 in./sec. The number and types of pens range from 1 to 8 including liquid ink, ball point, fiber tip and scribe. The prices range from $4000 to $200,000 depending on the size of the equipment, number of pens, flexibility and accuracy.

Drum plotters utilize paper motion to provide one direction of motion and the pen to provide the other. In addition, the drum can be moved in either the forward or reverse direction to achieve complex graphical output. Very long graphical outputs can be achieved by using roll sheets and continuing the drawing over many sections. Paper sizes vary from 11 in. to 30 in. in width. The plotting speeds range from a minimum of 200 steps/sec. to a maximum of 5000 steps/sec. The types of recording media used and pens are similar to that which is used with the flatbed plotters. The number of pens ranges from 1 to 4. The prices range from $3,500 to $23,000. The majority of plotters used in the
Electrostatic plotters use a row of styli in the horizontal direction to produce dots. These range in density from 80 to 200 dots/in., and plotting widths range from 81 to 72 in. Vertical plotting is performed by moving the paper as in a drum plotter. The plotting capability is similar to that which could be achieved by using as many pens as are needed for a drum plotter. The principal advantage of these plotters is speed. The horizontal plotting speed is one scan in the time it takes to move one vertical increment. Since paper speeds vary from 0.5 in./sec. to 7 in./sec., the horizontal plotting speed can be as high as 6000 in./sec. The time for plotting is not dependent on the complexity of the plot, but only on the paper speed. For pen plotters, the speed also depends on the pen velocity, the number of pens, and the complexity. Prices for the printer/plotter mechanism range from $6,000 to $52,000. Complete systems which interface to computers add from $2,000 to $12,000. Dielectric-coated paper ranges from two to four times the cost of plain paper.

The required physical characteristics of the graphical output produced by plotters are described in terms of the accuracy, resolution, and repeatability of the device. The accuracy of the plotter is the error between where the points should be and where they actually are. Accuracy is expressed either in terms of a percentage of the total span of the graph, or in terms of absolute accuracy in inches. Accuracies range from .001 in. to .012 in., and from .05 percent to .1 percent vertically, or from half a step to a single step vertically. Resolution determines the minimum dimension which can be drawn and the minimum distance between lines. This ranges from .001 in. to .005 in., or from 50 points/in. to 200 points/in. Repeatability refers to the ability to return to a previously plotted point. The ranges for repeatability are based on the resolution and accuracy, and are generally closer in value to the resolution than to the accuracy.

The method of plotting for pen plotters depends on the command structure available in the software and can effect the quality of the output plot. One of the most widely used methods is to move the pen one increment to the right, the left, up or down, or diagonally right-left-up, or diagonally right-left-down. This is a total of 8 different kinds of motion which are possible. Another approach uses dots placed at given locations determined by coordinate addresses. A third method utilizes straight lines drawn between two specified points. The quality of the final output depends on the resolution of the system and the kinds of commands which are available. If the resolution is fine enough, the jagged appearance of curves looks smooth to the viewer.

There are a multitude of choices available to the user. Once the requirement for the graphical output is decided upon, one can find a plotter which meets the needs. The size and type of paper needs to be specified, the number of pens required (perhaps with different colored inks), the accuracy, the resolution, the repeatability and, finally, the speed. If there are incompatible requirements, such as a speed requirement which is too high for the capability in terms of resolution, then judgments must be made as to what parameters are really the most important.

THE FUTURE

The characteristics of various alternatives to obtaining hard copy from computers have now been discussed. The changes in price/performance for existing products in the past few years have been primarily due to improvements in large scale integration (LSI), new materials technology, and in production automation. New products using new technologies, such as the ink-jet printer and the laser beam electrophotographic printer, are based on the refinement of new inventions and concerted investment in new development.

The expanded use of LSI and the emergence of microprocessors has not only made dramatic improvements in existing products, but has also affected the way in which we conduct our day-to-day affairs. Electronic hand calculators are available for under $10.00. Microprocessors have been applied to control the automobile engine so that more efficient fuel utilization occurs as well as producing fewer pollutants. The utilization of LSI microprocessors, inexpensive semiconductor ROM's and random-access-memories has caused computer capabilities to be distributed with networks and low cost terminals.

The use of microelectronics in hard-copy output equipment has not only reduced the cost for electronic control, but it has provided more flexibility and the increased use of electronics to perform functions which were previously handled by mechanical or electromechanical equipment. The reliance on a paper tape reader for vertical format control was replaced by Dataproducts when lower cost shift registers became available. These are planned to be replaced by microprogrammed logic to provide additional flexibility. Dot matrix formed characters, which have the appearance of being produced from shaped character impact fonts, are possible due to the lower cost of storage. The IBM 6640 uses a dot structure of $24\times40=960$ dots now, as compared to other dot structures as low as $5\times7=35$ dots to produce characters.

The possibilities for lower cost production techniques, using more plastics and less metals, are emerging in products for the marketplace. The hammer bank for the Dataproducts 2230 printer, using the Mark IV hammer actuator, has been designed so that the hammers and the magnets are mounted in plastic parts which are attached to tubular segments. New magnetic materials are available which provide magnetic fields which are 50 percent stronger than those currently used. This means reducing electromagnetic fields and, hence, lower currents, less power, and simpler driving electronics. New plastic materials and new epoxies also mean lower cost mechanisms. Hence, new versions of the 2230-type printer will appear with much lower costs.

The emergence of the laser beam as the energy source for
character generation has affected both non-impact and impact printing. The very high-speed non-impact printers will use laser character generation, and other printers besides IBM will be available in the next few years. Although high-speed impact printers are available today which print at 2000 lpm, it is expected that future high-speed impact printers will peak at 1500 lpm, and that the higher speed printers will be non-impact printers. The impact printers in the 1000 lpm speed region will continue to be cost reduced as the technology for the cost reduction of the lower speed printers is applied to higher speeds.

The emergence of the IBM 6640 printer is an example of a new product based on technology available today and a concerted investment in new development. Ink-jet printers had been in the marketplace, but they were not successful because of reliability problems and non-competitive price/performance ratios. IBM decided to invest in ink-jet technology and found solutions to many of the problems causing poor reliability. The electronic sophistication required to produce the high quality print of the 6640 could only be possible with the use of microelectronics available today.

The use of finer dot matrix structures for printing has had an effect on graphical output. The use of electrostatic technology for printing or plotting is an already established and accepted technique. Not many impact dot matrix printers have been used for plotting, but they could be if they were modified to handle the task. Both the laser beam electrophotographic technology and the ink-jet technology have the basic capability to do a respectable plotting job comparable to drum plotters. Whether or not these techniques will be used for graphical output depends on the demands of the marketplace. If there is a real need which could develop into a sizable market, then manufacturers will commit their resources to the developments required to satisfy the need.

In conclusion, the future will provide improved products based on the printing technologies used today with even higher price/performance ratios, better reliability, and increased output flexibilities. Additional graphical capabilities exist in many forms of output equipment, but they will not be made available to users without sufficient pressure from them. Impact printers will still dominate the marketplace, but there will be increased use of non-impact printers for specific applications.

REFERENCES
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