Implementation of the resistive ribbon technology in a printer and correcting typewriter

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This paper describes key technology implementation details and performance characteristics of a printer and typewriter using the resistive ribbon technology. The work describes the first commercial application of this print and correction technology. Key parameters necessary for proper system function such as current, various forces, velocities, and component integration are discussed. The rationales behind various compromises and problem solutions are given. A discussion of the characteristics of the print produced, along with application strengths and weaknesses, completes the paper.

Introduction

This paper describes the technology implementation and printing and correcting characteristics of the IBM ®QUIETWRITER Printer and IBM ®QUIETWRITER Typewriter, which use the resistive ribbon technology. The discussion is an in-depth look at how the various components of the technology are integrated into a working system and the requirements necessary for proper function. (Any discussion about correction applies only to the typewriter.) Problems encountered during the development cycle are described along with their solutions. The complex nature and immature state of the technology required extensive use of designed experiments in all phases of the work. Areas which are not covered extensively include the ribbon, hardware, fonts, and controls. These are given treatment elsewhere [1, 2].

The system described is the first implementation of the resistive ribbon technology to reach the marketplace. Several early patents [3, 4] describe systems which use the concept for printing. There is no previous work describing the concepts used for correction. Here, correction is accomplished with the same ribbon used for printing [5]. Other matrix print technologies such as thermal transfer, ink jet, wire matrix, etc. have similarities in print characteristics but do not have the ability to do correction.

In the most basic terms, the print technology consists of a printhead, ribbon, and paper [**Figure 1(a)**]. Electrodes in the printhead [**Figure 1(b)**] supply current to the ribbon to cause heating of the ribbon structure and softening of the ink, which then bonds to the paper and forms the image.

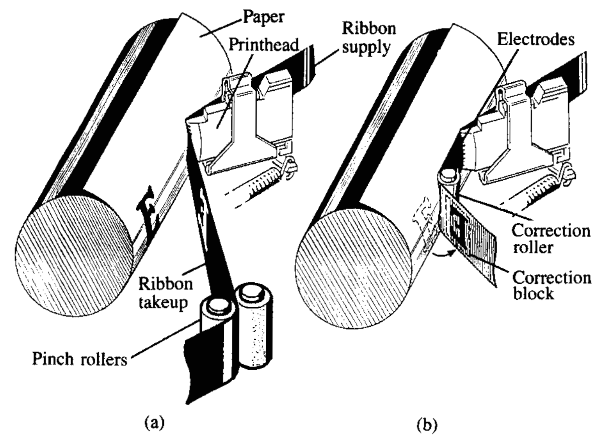

Figure 1

Basic components of the resistive ribbon technology: (a) printing process; (b) correction process.

Formation of the image is controlled by motion of the printhead, current supplied to the electrodes, and peeling of the ribbon from the paper. The ribbon is essentially at zero velocity relative to the paper. The printhead motion is typically 0.1 m/s (4 in./s) relative to the paper, resulting in a printing speed of 48 characters per second for 12-pitch characters. The addressability is 240 dots per inch vertically and 360 dots per inch horizontally for this implementation. **Figure 2(a)** shows a photograph of the printed image on the paper and the region of ribbon where the image originated [**Figure 2(b)**].

The resistive ribbon technology is unique in that correction uses the same ribbon as printing. An unused section of ribbon is positioned over the image to be corrected. The printhead is then swept over the ribbon as if to print a block image over the character to be corrected [Fig. 1(b)]. The energy applied to the block is lower than that used for printing but is sufficiently high to produce a bond to the image to be corrected. A correction roller is introduced to delay peeling of the ribbon from the page. This allows formation of a stronger bond between the ribbon and the image to be corrected before peeling occurs. **Figure 3(a)** shows a corrected region of paper which had previously been imaged with a row of uppercase letter Es. The actual character E which was removed can be seen bonded back onto the ribbon in **Figure 3(b)**. Other factors such as peel delay time, energy control, and surface energies are also important and are discussed in more detail in this article.

The resistive ribbon technology has a number of attractive characteristics which make it suitable for letter-quality printers and typewriters. Plain paper high-resolution printing is easily achievable with only minor limitations (which are discussed). Since printing occurs without impact, low acoustic levels are possible [<55 dB (average)]. The all-points-addressable nature of matrix printing combined with electronic storage of font information gives great flexibility, as well as the potential for large character sets. Correction is a definite advantage for typewriter applications and in the past was done only on impact printers. The main functional disadvantage with resistive ribbon, as with other nonimpact technologies, is its inability to make carbon copies.

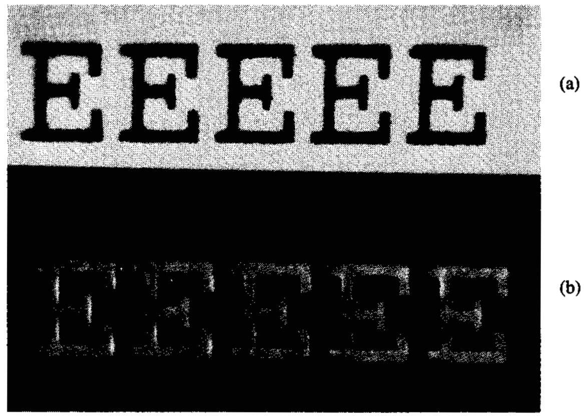

Figure 2

Optical microphotograph (7.5 ×) of a typical resistive ribbon printed image on paper (a) and the ribbon used for the actual printing (b). The ink side of the ribbon is shown. The dark region is unused ink and the light region is the aluminum which shows where ink has been transferred.

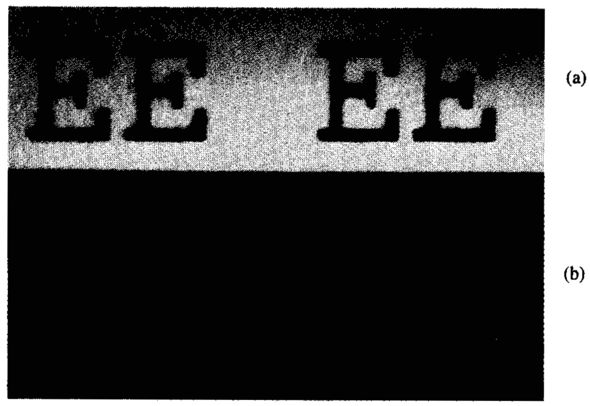

Figure 3

Optical microphotograph (7.5 ×) of printing after correction, showing the letter E removed from the paper (a) and bonded back onto the ribbon (b). Originally five letter Es had been printed. The ink side of the ribbon is showing toward the viewer.

The main body of the paper concentrates on two areas: implementation of the technology in either a printer or typewriter, and characteristics of the printed image. Technology implementation is discussed in two sections, one concerned with print and the other with correction. The discussion of print includes a description of the printhead, print cycle, and timing of the various components necessary for print. A description of key parameters including printhead velocity, ribbon velocity, printhead force, ribbon tension, peel mechanics, and print energy is given. Correction is given a similar treatment, including essentially the same parameters as print with the addition of bond-to-peel delay time and double correction. The section concerning print and correction characteristics discusses print quality, correction quality, abrasion, and copier document feed concerns.

Implementation requirements of the printing process

Printing with the resistive ribbon technology is a process of transferring ink to the paper in a regulated fashion. The printhead must be scanned across the paper, the ribbon transported to the paper/printhead junction at a controlled rate, and electrical energy supplied to the ribbon in synchronism with these motions. The printhead, control of the motions and forces acting on the printhead and ribbon, and control of electrical energy to the system are discussed in the next several paragraphs. An attempt is made to give some flavor for the decision process that shaped this implementation.

- *Printhead*

The printhead consists of a vertical array of 40 electrodes equally spaced on 0.106-mm (0.004167-in.) centers [6]. The electrode areas in contact with the ribbon typically are 0.0508 mm (0.002 in.) high by 0.0381 mm (0.0015 in.) wide, where width is the dimension horizontally along the writing line. The geometry for the electrodes is achieved by photo-etching a sheet of tungsten. Contact pads used for electrical connections are etched at the same time as the electrodes.

Materials in the printhead (tungsten for the electrodes, polyimide and silicone rubber for the support layers) are selected to provide temperature resistance, wear resistance, and compliance. A 45° angle between the printhead and platen is also used to improve compliance. Compliance is required to achieve good electrical contact between the printhead and ribbon, as well as uniform pressure between the ribbon and paper. The 45° angle complicates the geometry between the electrodes and ribbon. Due to the use of a round platen, a compound curvature of the electrodes is required to cause their contact with the ribbon to form a vertical line on the paper.

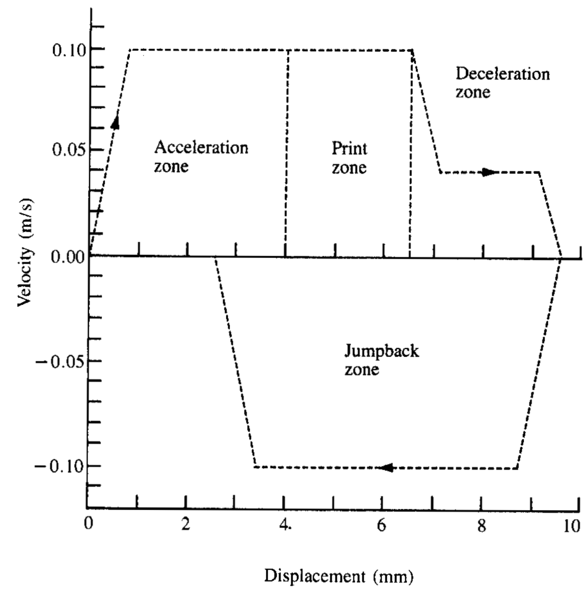

Figure 4

Ten-pitch print cycle—carrier velocity vs position.

- *Printhead motion for printing*

The print mechanism uses a carrier to transport the printhead and the ribbon feed system relative to the paper. A basic simplifying decision reached early in the development cycle was always to print while the carrier was at a constant velocity. Since acceleration of the carrier clearly cannot be achieved instantaneously, the print cycle for the printing of single characters requires zones for all of the following functions: carrier acceleration, character printing, carrier deceleration, and jumpback for proper positioning of the carrier to print the next character. These zones are identified in the print cycle diagram shown in **Figure 4**. The electronics controls the carrier motions based on emitter pulses received from an incremental encoder mounted to the carrier drive motor, one pulse for each horizontal picture element (pel). Characters are formed by gating current to the 40 printhead electrodes on and off at pel boundaries as dictated by the font.

After the last pel is printed, the carrier is decelerated in a two-step operation. First, the speed is maintained at 0.04 m/s until the controlling processor receives feedback that the printhead electrodes are disengaged from the platen. Then the carrier is brought to a stop. This procedure is necessary because even very small backward displacements of the carrier as it settles out while stopping are sufficient to damage the electrodes. The lower speed is used to minimize the amount of overtravel. To complete a print cycle the carrier is moved backward (jumpback) so that the net motion of the carrier during the cycle is just one character spacing.

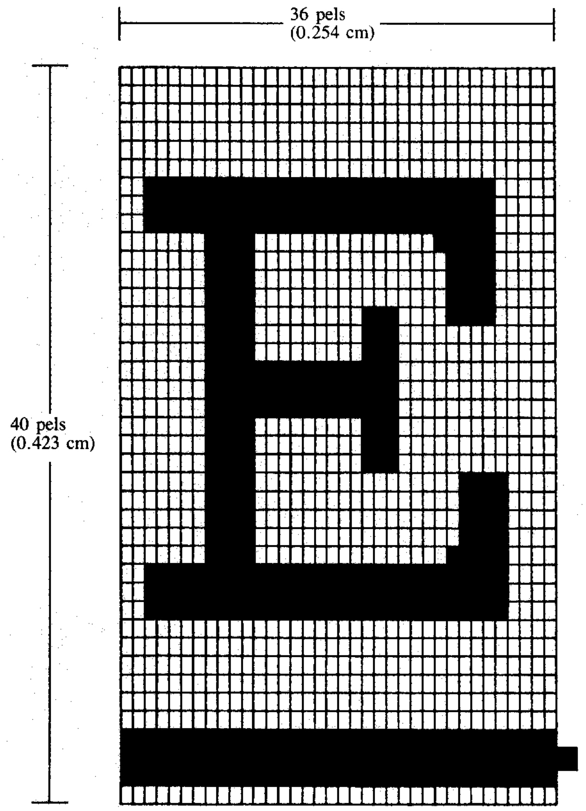

Figure 5

Ten-pitch print matrix.

These carrier motions consume a considerable amount of time, resulting in a single-character print cycle of about a third of a second. When the interval between keystrokes is less than this, the carrier enters a continuous-print mode, where instead of decelerating at the completion of the first print zone, the carrier maintains its speed at 0.1 m/s and the next character is printed immediately. The maximum print rate is thus 48 characters per second for 12-pitch printing. In this mode, which is also used whenever text is played from memory, the print cycle is identical to that shown in Fig. 4 except that multiple print zones are inserted between the acceleration and deceleration zones.

The complex carrier motions described are obvious to typewriter operators. Also, because the single character cycle takes so long to complete, the carrier is frequently changing between single-character and continuous-mode printing. Initial human factors testing indicated that these attributes reduced keyboard entry rates. The typewriter now produces an audible pulse for each keystroke. This change gives the operator feedback which makes it seem that printing is synchronous with keying. Productivity with this device in place is as high as that achieved on ®SELECTRIC typewriters. The noise, not the motion, is the more significant factor.

- *Ribbon motion for printing*

The ribbon must be metered past the printhead such that the speed of the ribbon relative to the paper is nearly zero. This is accomplished with pinch rollers on the carrier which are driven by a capstan. A cable fixed to the machine frame turns the capstan as the carrier moves. The pinch rollers are coupled to the capstan through a clutch so that they are not tied to carrier motion during tabs, space bars, etc. Also, the rollers provide the only high-pressure electrical ground contact for the ribbon that minimizes contact resistance without adding friction to the ribbon feed [7]. These rollers are located on the takeup side [Fig. 1(a)] as close to the printhead as possible.

The placement of these rollers must satisfy four important constraints. Closeness to the printhead is dictated by two of these. First, since the ribbon is an elastic member, its motion must be controlled near the printhead if the ribbon motion there is to be the same as at the drive point. Second, closeness to the printhead also minimizes the resistance in the print current return path through the ribbon. Third, for a typewriter it is important that the print line be visible when the printhead is retracted. This limits the proximity of the pinch rollers to the platen. Finally, the angle at which the ribbon is peeled from the paper is important. The 30° angle implemented is a compromise between large angles, which ensure that the ribbon is peeled from the page before the ink cools, and small angles, which reduce the tendency of ribbon tension to pull the printhead away from the platen.

Controlling the speed of the ribbon relative to the paper is an important constraint. To aid in the discussion to follow, two terms are defined. First, *underfeed* refers to a condition in which the speed of ribbon moving past the printhead is less than the speed of the printhead relative to the paper. Similarly, *overfeed* refers to the instance in which ribbon is metered past the printhead faster than the printhead is moved along the page. Either significantly underfeeding or overfeeding can result in smeared print. For some implementations, underfeeding may reduce ribbon tension between the printhead and the pinch rollers and delay peeling of the ribbon from the page. When this occurs, the heated ink cools before the ribbon is peeled and less ink is transferred to the page, resulting in lower character area. Correction imposes other constraints on the feed rate, as discussed in that section of the paper.

- *System forces for printing*

The printhead is spring-loaded against the platen during printing, holding the ribbon in close contact with the paper. The force required was established empirically. The lower limit of force was selected to ensure low electrical contact resistance between the printhead and the ribbon. High contact resistance causes charred ribbon, which can build up on the electrodes and produce character voids. Too much head force increases the wear rate of the printhead electrodes. It has been experimentally determined that if printhead force is nominally 2.0 N, charred ribbon does not form and an acceptable wear rate is attained. This force also is sufficient to promote the ink-to-paper contact necessary for ink transfer.

Ribbon tension is required on the supply side of the printhead [Fig. 1(a)] to ensure proper ribbon tracking and to pull the ribbon off the page at the completion of print cycles. A maximum limit is required to ensure that the printhead is not pulled from the paper. These requirements are satisfied if the supply side ribbon tension is maintained near 0.3 N.

The tension developed between the printhead and the pinch rollers varies with changes in supply side tension, printhead force, ribbon metering rate, and friction coefficients at the printhead/ribbon and ribbon/paper interfaces. The principal requirement for this force is that it be high enough to peel the ribbon from the page immediately after the passage of the printhead. Controlling the factors listed achieves this result.

- *Print matrix*

Figure 5 shows the print matrix for a typical 10-pitch character. A single pel is rectangular in shape and addressable at 94.5 pel/cm (240 pel/in.) vertically and 141.8 pel/cm (360 pel/in.) horizontally. The smallest feature printed by this implementation measures two pels vertically and three pels horizontally.

- *Print energy control*

Individual constant current drivers are used for each of the 40 printhead electrodes [8]. During a print operation, current for each printing electrode is gated on or off according to the desired character pattern. Typically, a current of 26 mA is supplied continuously over the interval to be printed. The level of current supplied to the ribbon is used to control the power generated, and thus the heating of the ink. Moving the electrodes at a constant velocity down the ribbon distributes the energy uniformly. Increasing the print current level or decreasing the velocity has the effect of increasing the boldness of the print. Percent area, a useful measurement of print boldness, is the ratio of the actual measured area of a printed character to the ideal area as defined by the font. **Figure 6** shows a contour plot of current versus velocity with contours of equal percent area.

- *Print compensation*

There are several unique characteristics of the print system that require compensation. Because of the spreading of heat and current within the ribbon, useful energy is lost by electrodes which do not have an adjacent electrode printing. To compensate for this lost energy, the print current level is

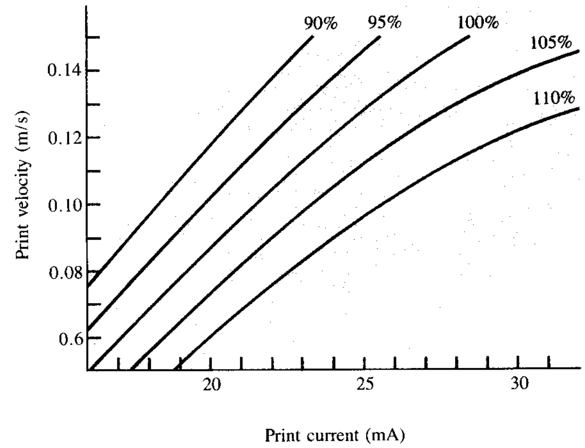

Figure 6

Contours of constant percent area.

boosted for electrodes whose adjacent neighbors are not printing by a circuit in the printhead driver [9]. An electrode with one neighbor printing receives a 16% current boost, while an electrode with no printing neighbors is boosted 33%.

The underscore is a particularly difficult character to print and correct because of its size and location. During keyboard entry, the underscore may be composed of many separate characters, all printed with different print cycles, which should join together in a single continuous line. To ensure that they join properly, one of the three underscore electrodes is extended for two pels outside the normal character matrix (Fig. 5). The current in the extended portion of the underscore is boosted to ensure that it bonds well to the page. If a subsequent underscore is printed, it overlaps with this extension, ensuring no gaps.

An underscore is also difficult to correct properly because it tends to remain connected to adjacent underscores, causing them to be corrected as well. To help minimize this problem, the current of the first two pels of each underscored character is boosted during printing. This bonds the underscore securely to the page at these points. Thus, when an underscore is corrected, it tends to break at the boosted points as desired.

Another characteristic requiring compensation is the effect of temperature and humidity on print boldness, as quantified in a later section. This effect is compensated by use of an operator control, a multiple-position switch which shifts the print current by small increments. The center position of the control gives best performance for the typical office environment. At higher temperature and humidity levels, the operator control switch can be set for a lower value to reduce the character boldness. Similarly for lighter print caused by low temperature and humidity, higher switch positions may

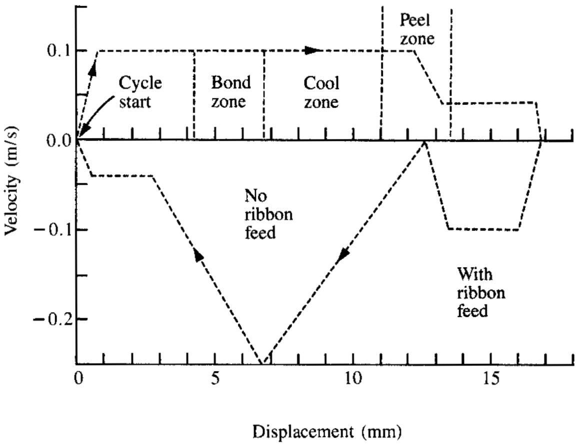

Figure 7

Ten-pitch correction cycle—carrier velocity vs position.

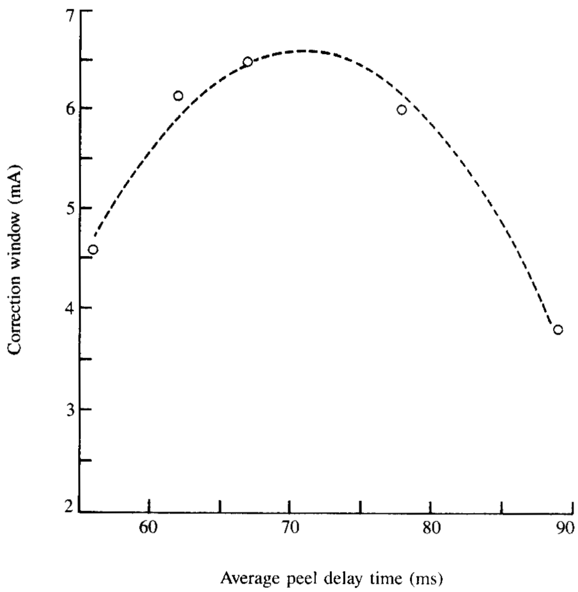

Figure 8

Correction window vs peel delay time at 23°C, 45% relative humidity.

be used. A test pattern is provided in the machine to help the operator select the proper setting for this switch.

Finally, boldness, or more specifically lineweight, varies from one typestyle to another. Fine typestyles printed on bond papers tend to show more voids in the print than bolder typestyles. To compensate for this, the font module which contains typestyle patterns also shifts the print current as required.

Implementation requirements of the correction process

Correction is achieved in three separate but continuous actions: bonding, cooling, and peeling. Bonding is similar to the print cycle, except that energy is supplied at a lower rate. Cooling is achieved by introducing a delay between bonding and peeling. A new mechanism, the correction roller [10] shown in Fig. 1(b), was needed to create the cooling delay time prior to peeling.

• *Printhead motion for correction*

The correction cycle (**Figure 7**) begins with a backspace (not shown) to position the printhead to the left of the character which is to be removed from the paper. The ribbon feed clutch is not engaged for this motion, so an unused section of ribbon is available for the correction cycle. Bonding of the ink on the ribbon to the ink on the page occurs during the bonding zone of the correction cycle. The quality of this bond is a function of both the way the electrical energy is controlled and the force of the printhead against the platen. In order to allow the bond to develop fully, the ribbon is not immediately peeled but is kept in contact with the paper by a correction roller located 6.8 mm from the printhead [Fig. 1(b)]. The carrier continues to move at 0.1 m/s during this cooling zone.

The peeling zone begins when the correction roller has reached the left edge of the character block being corrected. While the character is being peeled from the page, the carrier is decelerated to 0.04 m/s. These conditions result in a nominal cooling time of 70 ms. Cooling delay times can vary with changes in both the carrier velocity and the distance between the correction roller and the printhead. **Figure 8** shows how correction performance varies with delay time. The performance criterion shown is the correction window, which is the range of currents that can be used for correction with good results. This concept is developed more fully in the correction performance section of the paper. After peeling is completed, the carrier is stopped as described in the print cycle. Finally, the carrier is repositioned to print a new character.

• *Ribbon motion for correction*

During correction, ribbon motion is controlled much as in the print cycle, with the exception of the effect of the correction roller. This roller forces a condition of zero motion of the ribbon relative to the paper during the bonding and cooling zones. If the ribbon moves relative to the page, ink transfers where correction should have occurred. This failure is controlled by proper selection of feed rate and correction roller force. During the correction cycle, the feed rate at the pinch rollers is not necessarily equal to the feed rate at the correction roller. Small overfeed differences are absorbed by the elasticity of the ribbon. Any underfeed permits uncontrolled peeling and reduces correction quality. **Figure 9** shows how the correction window changes as feed rate at the pinch rollers is varied. Clearly, extremes of underfeed or overfeed are to be avoided. The nominal feed rate selected to prevent correction failures is one percent overfeed.

• *System forces for correction*
The force on the printhead during correction is subject to the same constraints as during print. In addition, the variability of correction performance can be reduced if the force during correction is nearly equal to the force during print.

The requirements for supply side ribbon tension are the same in correction as for print. On the takeup side, the tension in the ribbon between the correction roller and the pinch rollers is controlled by the metering rate and the stiffness of the ribbon, as long as slippage under the correction roller is prevented. It has been found empirically that a minimum correction roller force of 2.5 N against the platen is sufficient to prevent slippage. A positive tension is required to ensure peeling immediately after the correction roller has passed.

• *Correction block*
During the correction process, all 40 electrodes are turned on at a reduced energy level for the entire character matrix covering the character to be corrected. This block technique heats the ink to a temperature at which it permanently bonds to the character to be corrected but not to the surrounding paper surface. An advantage of the block correction technique is that any character may be corrected with a single pattern. The ability to correct was first demonstrated by reprinting the character to be corrected over the previously printed character. This required precise realignment as well as remembering the character to be corrected. It was found that the block technique could be implemented more easily.

• *Correction energy control*
Energy is reduced for correction by pulse width modulating (typically 50% duty cycle) the current to the electrodes. It is also possible to reduce this energy by lowering the electrode current level. However, due to the electrical characteristics of the ribbon, it is desirable to operate correction at approximately the same current level (typically 26 mA) as print [1]. Modulating the current also allows different energy levels to be supplied to different parts of the correction block. This is desirable in certain regions of the correction block, e.g., the underscore. Because of the current boost and extension during printing of the underscore, it is difficult to correct. Increasing the energy in the underscore region improves correction performance. The correction block begins one pel before the print matrix to ensure that the leading edge of the printed character is corrected properly.

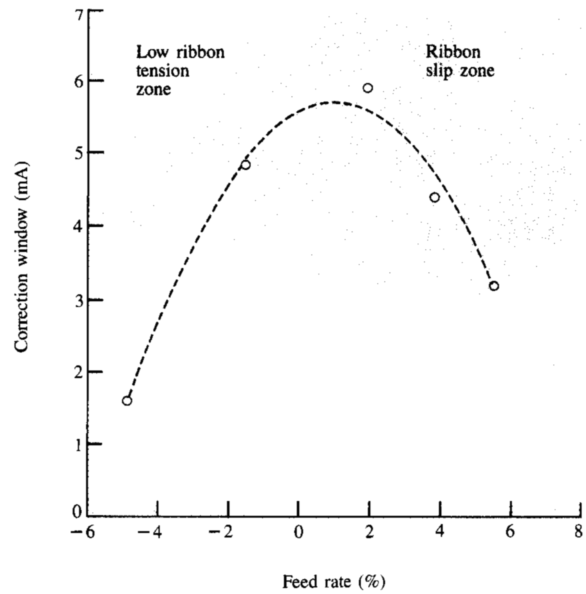

Figure 9
Correction window vs feed rate at 23°C, 45% relative humidity.

The block is also extended in the underscore region to allow correction of the underscore extension. The operator control switch alters slightly the correction current to compensate for environmental effects, discussed later, and to match the print current for each setting.

• *Double correction*
A double correction mode is available to improve correction performance under the adverse conditions described in the following sections. Essentially, a double correction cycle consists of two single correction cycles done at the same location on the paper. However, the currents used in the two cycles are different from that used in single correction. For the first pass, the correction current is boosted by one milliampere (mA) relative to the current used in single correction. For the second pass, the current is reduced by two mA from that used in single correction. These changes in current were found, experimentally, to give the best improvement in correction performance. On average, double correction improves the correction window by 50%.

Characteristics of the print and correction

Many of the print and correction characteristics required for a typewriter and a letter-quality printer were easily obtained in this implementation of the resistive ribbon technology. For example, resolution and optical density of the printed image are excellent. Also, the image does not fade and is water-fast. However, some of the required characteristics of the printed image were difficult to achieve. This section

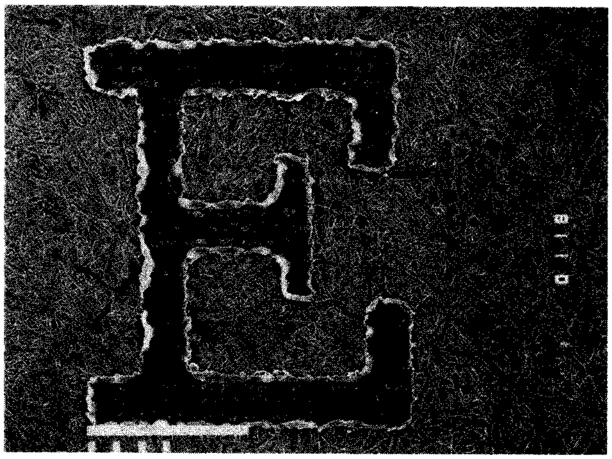

Figure 10

Scanning electron microscope photograph of resistive ribbon printed character.

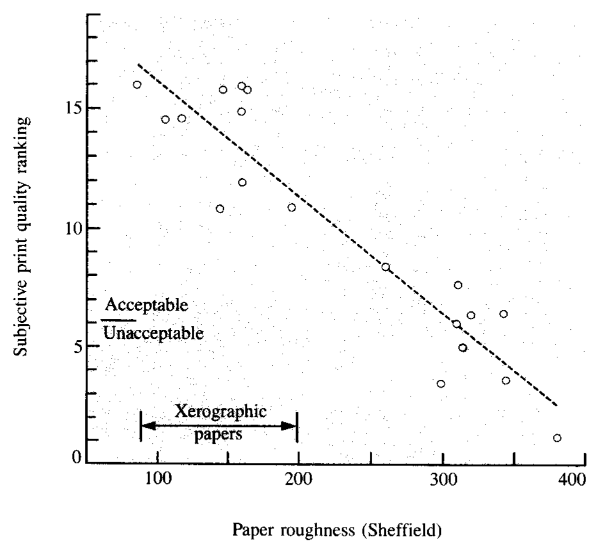

Figure 11

Relative print quality at lab ambient as a function of paper roughness.

discusses these problems and their solutions. The areas to be covered are print quality, correction performance, abrasion resistance, and compatibility with automatic and semiautomatic document feeders.

• *Print quality*

The term *print quality* is used in this discussion to mean the error-free printing of characters, not the aesthetic beauty of the font itself. The most common failure modes for resistive ribbon print are lines which are too wide or too narrow, character edges which are too ragged, or solid fill areas which have voids. Visual inspection of print provides a good means of evaluating ragged edges and voids, but it does not provide a sensitive measure of lineweight. Lineweight can be evaluated using computerized image analysis in which the area of a character is measured. Since all lines in a character get wider or narrower together, percent area is a good measure of lineweight. One of the primary factors affecting print quality is print current. Low currents may produce characters with narrow, ragged-edged lines and internal voids. High currents may produce bold characters with lines which are too wide. Other factors affecting print quality are paper roughness and environmental conditions of temperature and humidity.

Paper roughness is important because it is a factor in determining the extent of intimate contact between the ink and the paper. The roughness of the paper surface is of the same order of magnitude as the ink thickness (**Figure 10**). For a given print current, a rough paper has more areas of poor contact than a smooth paper. As the ribbon is peeled away from the page during printing, these areas of poor contact influence the tearing of the ink and can produce ragged edges and internal voids in the resulting characters. The effect of rough paper can be reduced by increasing the print current, but this is accompanied by an increase in lineweight. **Figure 11** shows the effect on print quality of many papers of different roughness, all printed with the same current. The relative print quality was visually evaluated by a group of people and the paper roughness was measured using a Sheffield roughness instrument. Acceptable print quality was produced on papers up to about 300 Sheffield points (large numbers represent rough paper). Resistive ribbon produces quality printing on papers that are much rougher than those required for thermal transfer printers, which incorporate resistive heating elements on rigid ceramic heads. This increased tolerance for rough paper seems to be a result of the compliance of the resistive ribbon printhead, which improves ink-to-paper contact as well as the sheet strength of the ink, allowing it to bridge areas of poor contact.

The resistive ribbon typewriter and printer must also produce letter-quality print over a broad range of environmental conditions. The two environmental parameters that affect resistive ribbon printing are temperature and humidity. Since resistive ribbon printing is a thermal process, it should be expected that the temperature of the environment would affect the printing process. However, humidity affects the printing process more than temperature. The humidity effect is due to the hygroscopic nature of the ink. Absorption of moisture from the air changes the mechanical properties of the ink, resulting in a larger image being transferred to the paper as humidity increases.

Figure 12 shows the effects of both temperature and humidity on the area of the printed image. The figure shows that the area of the printed image can vary from less than 95% of the desired area to 115% when printed at a fixed current in the environmental range of interest. During the development of the resistive ribbon technology it was shown that for resistive ribbon print to achieve letter quality, the area of the printed image must be between 100% and 110% of the design area. Printing at less than 100% produces a character which is not fully filled and may have voids. Printing at greater than 110% produces a printed image that becomes too bold and may cause adjacent characters to merge. Environmental effects are taken into account by providing the operator control switch previously discussed.

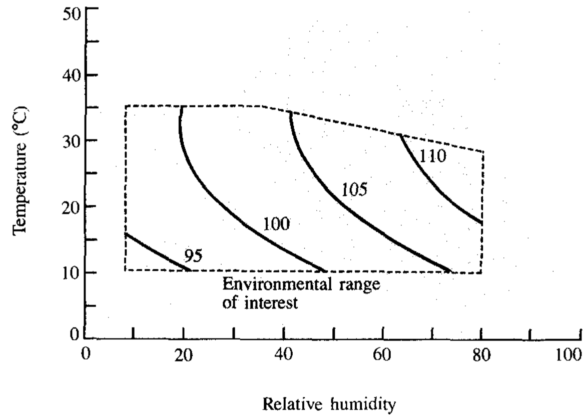

Figure 12

Percent area contours at 26 mA print current on IBM Multisystem paper.

- *Correction performance*

In general, correction quality for resistive ribbon is excellent compared to that of competitive technologies. After being corrected, the page shows no visible evidence of prior printing. Problems such as embossing in impact printers are eliminated. One measure of correction quality is the range of correction currents, i.e., the correction window, over which correction performs well. This range of currents is bounded on the low end by currents that are too low to provide good bonding between the ink on the ribbon and the ink on the page. This results in a character which is only partially removed. On the upper end, currents are so high that the correction ink is transferred to the page in portions of the character box around the character to be corrected.

For correctable resistive ribbon, the ink sits on the surface of the paper fibers (Fig. 10) and does not penetrate down into internal voids in the paper. Therefore, it is reasonable to assume that the adhesion of the ink to the page, and hence correction, is dominated by surface forces at the interface instead of mechanical interlocking between the ink and paper. Two primary factors which dictate the adhesion of the ink to the page are the area of contact and the relative surface energies of the ink and paper. Correlation between measured paper properties and correction quality shows a strong relationship between the London dispersion component of surface energy and the correction window, as shown in **Figure 13**. Papers with higher surface energy produce better adhesion of the ink and result in smaller correction windows.

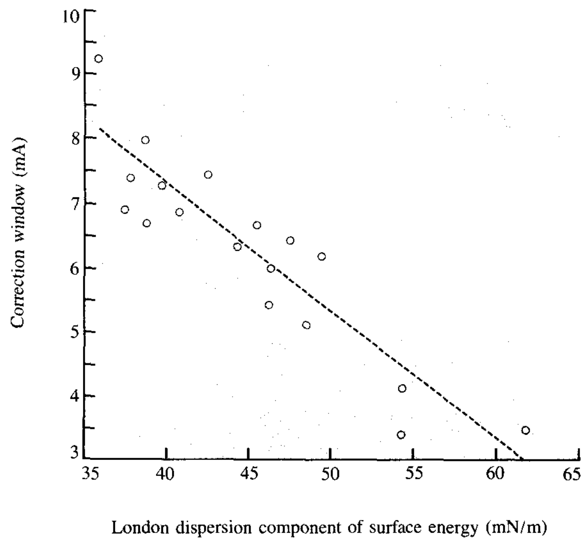

Figure 13

Correction performance at lab ambient as a function of paper surface energy.

The London dispersion component of paper surface energy was measured by using an inverse gas chromatography method developed by Dorris and Gray [11, 12]. In this measurement small paper disks are packed into a two-meter column and a series of n-alcanes in a gas state are injected into the carrier gas at very low concentrations. Ratios of retention times are then used to determine the London surface energy of the test paper.

Correction performance should be acceptable over the same range of environments as print quality. A limited range of ink temperature at peeling has been shown to maximize strength of the ink and improve correction. Failures of correction due to environmental temperature are similar to the failures discussed for current and peel delay. The changes of mechanical properties of the ink with humidity also affect correction. The acceptable correction currents for the center of the environmental range and two extremes are shown in **Figure 14**. The figure shows that the optimum correction

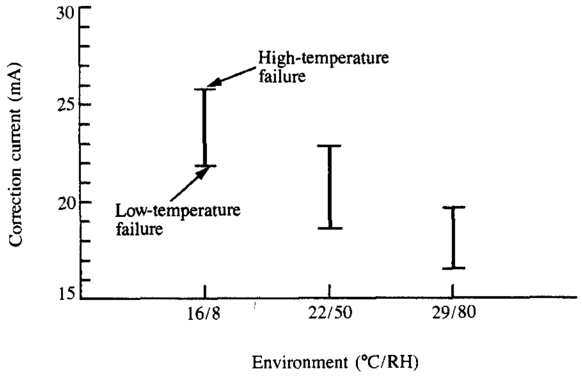

Figure 14

Correction window at three environmental points. Heights of vertical bars indicate currents at which correction is acceptable.

current varies with environments similarly to print current. Again the operator control switch is used to compensate for this effect.

• *Abrasion resistance*

Since resistive ribbon characters sit on top of the paper, the ink is susceptible to damage or removal by rubbing actions. Some examples of severe rubbing include manual erasing with a pencil eraser and some kinds of automatic paper handling machines which use abrasive rubber wheels to separate and feed documents and envelopes. An early experiment where envelopes were put through automatic mail-handling equipment indicated damage to the print caused by abrasion.

As with correction, the abrasion resistance of the printed image is a function of the adhesion between the ink and the paper and also of ink properties. If the adhesion forces are too low, the printed image can easily be removed from the paper because of an adhesion failure of the ink-to-paper bond. This failure mechanism also depends on the coefficient of friction and the tackiness of the top surface of the printed image.

Standardized testing of abrasion resistance is accomplished by using a modified ASTM procedure [13]. After being abraded by this procedure, the printed sample is optically compared to an unabraded sample and the percent of character removal is calculated. The primary factor in determining abrasion resistance is print current, with higher currents producing more abrasion resistance due to increased ink-to-paper bonding. Other factors of importance include paper, properties of the ink, and environmental conditions.

As with correction performance, the London dispersion component of surface energy is important. For correction purposes it is desirable to use papers with low London surface energy; for abrasion resistance high-energy papers are preferred. This does not mean that good correction and abrasion resistance cannot be achieved on the same paper. However, it does suggest there are upper and lower limits on acceptable paper surface energy. Surface energy is not specified by paper manufacturers and is free to vary from run to run of the same brand name of paper produced. The surface energy of paper is also affected by moisture content. Dorris and Gray [14] have shown significant reductions in the surface energy of cellulose as a function of increased moisture uptake. The above factors suggested that paper surface energy would best be compensated for at the time of use; hence, the operator control switch and test pattern mentioned earlier were implemented.

The coefficient of friction between the printed image and the handling mechanism also strongly affects the abrasion resistance of the printed image. If the coefficient of friction is high, the forces transmitted to the printed image by the handling mechanism are high, resulting in more damage to the printed image. The abrasion resistance of the printed image can be increased by decreasing the coefficient of friction of the printed image. Special additives to the ink both lowered the coefficient of friction and improved ink bonding to the extent that abrasion performance is now acceptable.

• *Document feeding*

In addition to affecting the abrasion resistance of the printed image, the coefficient of friction also affects the ability of a printed page to successfully pass through some automatic or semiautomatic document feeders. The problem was limited to a small percentage of copiers that use a belt for feeding the sheet of paper. These document feeders rely on the coefficient of friction between the belt and the back of the paper to feed the sheet of paper through the mechanism. When the coefficient of friction between the printed image and the document glass is greater than the coefficient of friction between the sheet of paper and the belt, the sheet fails to feed across the document glass. The coefficient of friction between the printed image and the document glass was quantified by adapting an ASTM standard [15]. To ensure no feed failures, the coefficient of friction between the printed page and the document glass must be less than 0.6.

Summary

The first application of the resistive ribbon technology in a printer and a typewriter has been discussed. For the typewriter a unique method of correction was developed which uses the same ribbon for both printing and correction. These nonimpact machines achieve fast, very quiet, letter-quality printing over a wide range of environments and papers. High-resolution matrix characters and electronic font storage are other strengths of the technology.

The implementation uses a carrier-borne 40-electrode printhead and ribbon feed. Metering of the ribbon is maintained at essentially zero velocity relative to the paper by using capstan-driven pinch rolls which also serve as the electrical ground for the ribbon. The printhead moves at 0.1 m/s, yielding a 12-pitch print speed of 48 characters per second. Printhead and ribbon motions are synchronized to conserve ribbon during print and correction cycles. During correction a peel delay time is introduced to improve ribbon-to-character bonding. Energy control to the electrodes is accomplished with constant current drivers. The currents can be adjusted by the operator to compensate for paper and environmental effects. Design compromises necessary for proper system function were made and the rationale behind these has been given. Several difficult engineering problems encountered during the development process have been discussed, together with their solutions. Among these were pattern sensitivity, temperature and humidity effects, paper, abrasion resistance, and copier document feeding.

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