

The IBM SELECTRIC Composer

Mechanical Print Quality

Abstract: The design of an impact printing device (one which produces aesthetically pleasing copy) must include an optimal combination of mechanical design and supplies (ribbon and paper). This paper describes the evolution of design for both mechanisms and supply parameters which has led to the present standards of mechanical print quality in the IBM SELECTRIC Composer.

Introduction

In the early development phase of the IBM SELECTRIC Composer, print quality was recognized as that output parameter which most conclusively defined the success or failure of the machine. Print quality and mechanical reliability were the variables which were to be optimized; thus, in order to optimize print quality a workable definition of "perfect" print quality had to be made. Perfection for an individual character, then, is defined as a character having (1) those proportions, within itself and relative to other characters with which it must associate to form a word message, which are aesthetically acceptable; (2) a precise location on the printed plane (paper) relative to associated characters; (3) uniform optical density of the image face within the character and relative to associated characters; and (4) a clearly defined sharp edge which is (5) devoid of background dirt.

This definition, therefore, allowed print quality to be categorized into (1) graphic design, (2) alignment, (3) character coverage or fill, (4) edge definition and (5) dirt. During this developmental process the separation of type design from machine design responsibility required that the machine designer's criterion be gauged by asking, "How well does the printing machine produce the type designer's concept of the character font?" This separation of type design from machine design added the criterion of character growth (ribbon spread in the case of impact printing) to the machine designer's list of print quality parameters (alignment, coverage, dirt, and edge definition). Then machine design responsibilities were further separated into alignment and character coverage. Character coverage and character

growth were the author's major responsibilities and are treated here. The machine design, as it relates to these two print quality parameters, will be considered first.

Supply parameters will then be considered. In this section the effect of these parameters on edge definition and dirt will also be discussed.

Machine parameters

Character coverage was particularly critical for the SELECTRIC Composer. If an image were gray on the original it would photograph with an uneven edge and shrunken line stroke width. If voids were present within the face of the image they also would be reproduced by the photo-offset printing process. A similar problem existed with the direct impression offset masters. If the image were not tightly stuck to the master it could be washed off when exposed to water or by the abrasive action of the offset duplicator. The design specification for character coverage required that the character face be black without any visually discernable voids and that the intensity be uniform within the type font or style. (Intensity is that variable which makes the printed page look uniform or spotty and is defined as the product of optical density (blackness) and line stroke width.)

If we assume that the type designer's concept of character stroke width is correct, one additional variable that will affect intensity is line growth. A variation of line growth will cause some characters to look more intense than others. This is sometimes referred to as poor color balance. The machine was intended to produce printwork with a uniform line growth or spread.

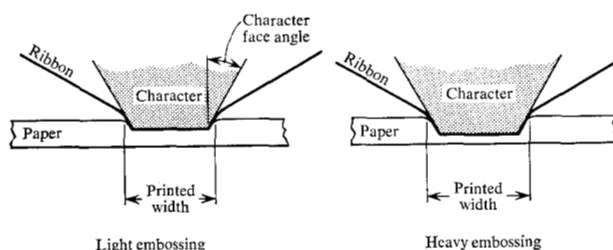


Figure 1 The mechanism of ribbon spread.

It was decided that the SELECTRIC Composer would have three print impact levels, rather than two as in the SELECTRIC Typewriter, because the face areas of large type styles designed for the Composer were to cover a range approximately five times greater than type styles for the SELECTRIC Typewriter. Three levels were necessary in order to achieve full character coverage on the largest characters and yet maintain uniform character spread within the font. Character spread is related directly to impact. Figure 1 compares the line width of a character under light embossing (low impact) and heavy embossing (high impact).

The three print impact levels were selected by printing representative characters from an intermediate size font at varying energies from 0.05 to 0.90 in. lb. on two types of direct-image paper plates. These characters were divided into three groups by face area. The depths of the embossed holes in the plates were measured and plotted against impact energy for each character. The energies which yielded 0.0005 in. embossing for the smaller characters in each group were selected as the maximums for that font. If a crater is more than 0.0005 in. deep on a direct image offset master there is a tendency for the image to shell out. (Shell-out occurs when an image lies so far below the surface of the plate that the ink roll does not reach the image area; consequently, only the character outline, which is near the surface, prints.) The minimum energies were selected by noting that energy at which the largest subject characters in each of the three groups began to show lack of coverage. The final selection of each of the three print energies was a compromise between the minimum and maximum. The energies selected were 0.19 in. lb. for high impact, 0.06 in. lb. for medium impact and 0.007 in. lb. for low impact. The energy values for the type font under study were then assigned to the center position of the manual impression control (Fig. 2) because the face areas of this font were near the median for all fonts projected for the SELECTRIC Composer. The five positions of the manual impression control are used to raise or lower the impact as required by the type font being used.

These three selections were used to specify the design of the three print cam segments. It was decided that the cam

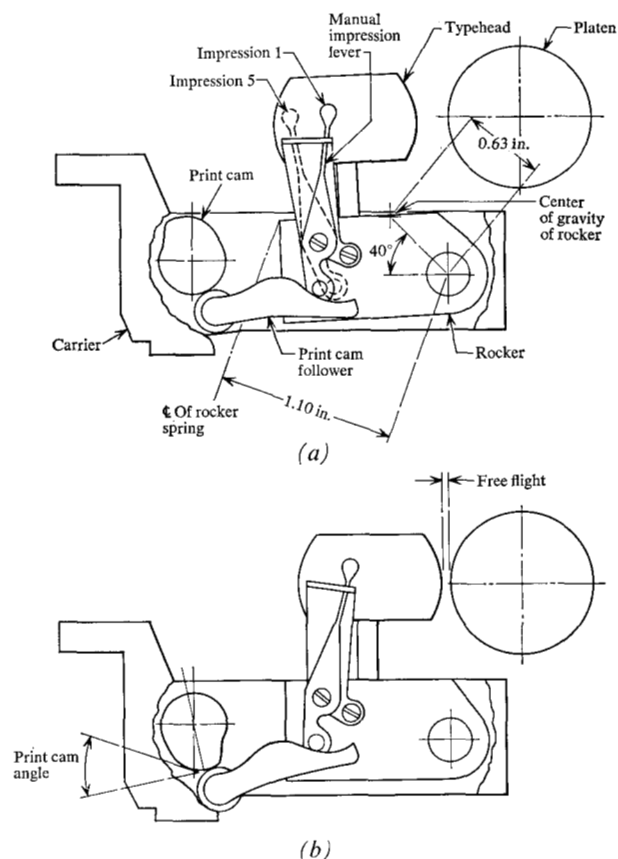


Figure 2 Print mechanism (a) in home position; (b) at beginning of free flight.

would not drive the typehead into contact with the paper because the position of the character face relative to the paper at the high point of the cam would be too difficult to control. The cam drives the typehead to a position short of print, and the typehead is allowed to travel in free flight to the paper contact position as shown in Fig. 2b. During the free flight portion of typehead travel, energy is lost extending the rocker return spring and lifting the rocker. Figure 2 shows the location of the center of gravity of the rocker, and the location of the return spring. The rocker return spring force at the "home" or down position of the rocker was determined by the fact that it must hold the rocker in position during type element replacement and manual impression selection. The spring force at the print position was determined by the spring rate and was used to help control print energy. The print energy could be written

$$E_p = E_f - E_r - E_s, \quad (1)$$

where

E_f = energy at the beginning of free flight in inch pounds,
 E_r = energy lost to raising the rocker in inch pounds, and
 E_s = energy lost to extending the rocker spring in inch-pounds.

Each of the independent energies was then written as a function of the design variables.

$$E_f = \frac{1}{2} I \omega_f^2, \quad (2)$$

where I is the rocker moment of inertia measured about its pivot, in inch pounds-seconds² and ω_f is the rocker angular velocity at the beginning of free flight in radians/second.

$$E_r = W f_c, \quad (3)$$

where W is the rocker weight in pounds and f_c is the vertical component of free flight measured at the center of gravity in inches.

$$E_s = F_f f_s + \frac{1}{2} k f_s^2, \quad (4)$$

where F_f is the rocker spring force at the beginning of free flight in pounds, f_s is the free flight measured at the rocker spring in inches, and k is the spring constant in pounds per inch.

Consider that ω_f is a function of the terminal print cam velocity and the lever ratio between the cam and the rocker, f_s and f_c are simple geometric functions of the free flight distance measured at the head and F_f is a function of the rocker spring rate and the force requirement on the rocker (stipulated above). The design variables were reduced to terminal cam velocity, the lever ratio between cam and rocker (variable through use of the manual impression lever), the free flight distance, and the rocker spring rate. The terminal velocity for the high impact cam was limited by the cam angle since the cam shaft velocity was determined by the machine cycle speed. A cam angle of 30° as shown in Fig. 2b was used. This gave a terminal velocity of 29 in./sec. measured at the cam.

The free flight for impression 5 remained unchanged from that of the SELECTRIC Typewriter. This determined a static free flight of 0.040 in. in impression 5 (see Fig. 2b). (The dynamic free flight will always be greater than the static free flight because the print cam follower roller will leave the cam before it reaches the high point. The dynamic free flight was used in calculations to determine print velocity.) There was a remote possibility that some users might attempt to print carbon copies, and 0.020 in. was therefore selected as the minimum free flight distance (impression 1 in Fig. 2). A smaller free flight distance might have permitted the combined paper-ribbon thickness to be such that the typehead would be driven into the paper. Such a print action would have resulted in excessive, uncontrolled embossing, and also character smear.

The median static free flight, 0.030 in., corresponded to the median manual impression setting of 3.

The rocker spring rate was established by calculating the energy that would be removed during free flight by each of several rates. The face areas of selected characters from small and large type fonts were measured. It was found that the low impact character areas did not vary as much with

font size as did those for the medium and high impact characters. The rocker spring rate was selected so as to make the range of print energy from impression 1 to impression 5 for low impact narrower than that for medium and high impact as illustrated in Fig. 3.

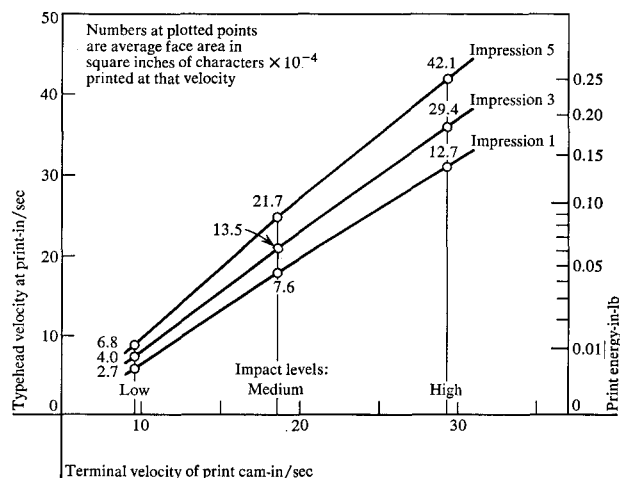
This selection of a spring rate required some trial and error calculations because the manual impression 3 ratio had to be such that it would yield a print energy of 0.19 in. lb. with a terminal cam velocity of 29 in./sec. The range of impression ratios was determined by extrapolating the information gathered from the median size type font, i.e., by applying the face-area measurements from the large and small fonts. (The actual type elements were not available at this time.) By examining the largest and smallest characters in each velocity assignment for the element studied and comparing their face areas with those for the characters measured from the small and large fonts one could calculate the print energies for these elements.

Once the free flight, rocker spring rate and manual impression lever ratios were established, the terminal velocities for the low and medium velocity cams were calculated. It was later found that the impression ratio range had to be made narrower because of the lack of space.

The print cam profiles were designed so that there would be an acceleration all the way to the cam apex in order to provide an inertial load to hold the roller cam follower against the cam. This assured that the cam follower would remain on the cam, resulting in a predictable impact velocity.

Figure 3 shows the print energies and velocities (measured at the typehead) for nine of the fifteen possible impact levels in the machine. On the impression ratio curves, the average face areas for characters assigned to that impact are listed. The smallest available typestyle is listed on the impression

Figure 3 Print impact curves for impressions 1, 3 and 5.



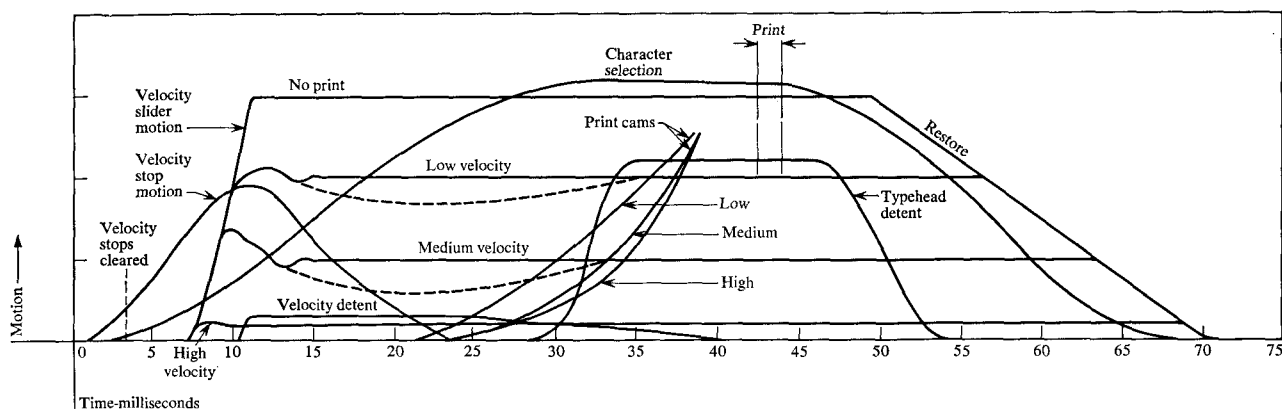


Figure 4 Timing diagram for print mechanism.

1 curve. The largest available style is listed on the impression 5 curve. The character face areas of the current design of the type element used in the original study are listed on the impression 3 curve.

With the cam design established, the problem of timing the cams was addressed. Figure 4 shows the sequence of events in the print and selection areas. A design of character selection and typehead detenting was provided which gave a selection detent—steady, fine typehead positioning—dwell of about 12 milliseconds. The object was to make all three print cam segments drive the rocker so that print occurred during this dwell. Furthermore, extra time was allocated in the early part of detent dwell to allow a maximum time for positioning of the element.

The first step was to calculate the time required for dynamic free flight travel for each of the three print cam segments (high, medium, and low impact). The assumption was that the forces retarding rocker travel during this free flight were constant. This allowed the simplified parabolic motion equation to be solved easily. It had been learned that the apparent spring rate of the impact system (platen and rocker assembly, including the typehead) was lower with the smaller characters; in fact, the average duration of print for several low velocity characters was 1.2 milliseconds. The average for several medium and high impact characters was 0.8 milliseconds. The point on each print cam segment at which free flight began was located by subtracting the print duration and the average free flight time from the time when the detents began to release the typehead. The cams were designed using these calculations. They were then instrumented for print timing. Instrumentation showed that the beginning of print for medium impact lagged that for low impact by two milliseconds, and the beginning of high impact lagged low impact by three milliseconds. (The ideal lags should have been about 0.4 milliseconds in each case.) Two factors contributed to this lag. The first was deflection of the parts between the print cam and the typehead. The second was inconsistent print cam shaft speed. The machine

loads were such that the shaft velocity was slower for medium and high velocity selections than for low velocity during the print drive time. Since the loads creating the deflections produced stresses well below the fatigue limits of the materials and since the drop in shaft speed did not adversely affect the print blow, the cams were retimed to compensate for the measured variations.

It is pertinent to note that the rocker journal bearings were replaced by ball bearings. This was done to reduce friction in these pivots and thus provide a more consistent print velocity; and to reduce character smear by reducing looseness at this critical point.

Automatic selection of a particular print cam segment from the keyboard is the function of the velocity control system shown in Fig. 5. The print cam with three print cam segments and a no-print segment and its associated follower roller are positioned in close proximity in the SELECTRIC Composer, but are shown some distance apart in Fig. 5 for structural clarity.

Print impression is varied by positioning the follower roller adjacent to one of the print cam segments (high, medium, and low impression) just prior to actuation of the print head against the document in each cycle. The high impact segment is home position for the follower roller. The follower roller position is varied by movement of an attached tape controlled by an impact control cam and an impact cam follower that are, in turn, controlled by associated velocity stops. The velocity stops are activated by the character interposer horizontal motion. The impact cam follower is not allowed to move until the stops are clear of the follower. Figure 4 shows the nominal time required to clear the stops. Additional time is needed to allow for maximum clearances between the filter shaft and interposer and between the interposer and the velocity bail. The deflection of the stop drive system is insignificant.

The available time to select one of the print cam segments is about 12.5 milliseconds. The print cam follower roller has to be in position at the beginning of the print cam drive.

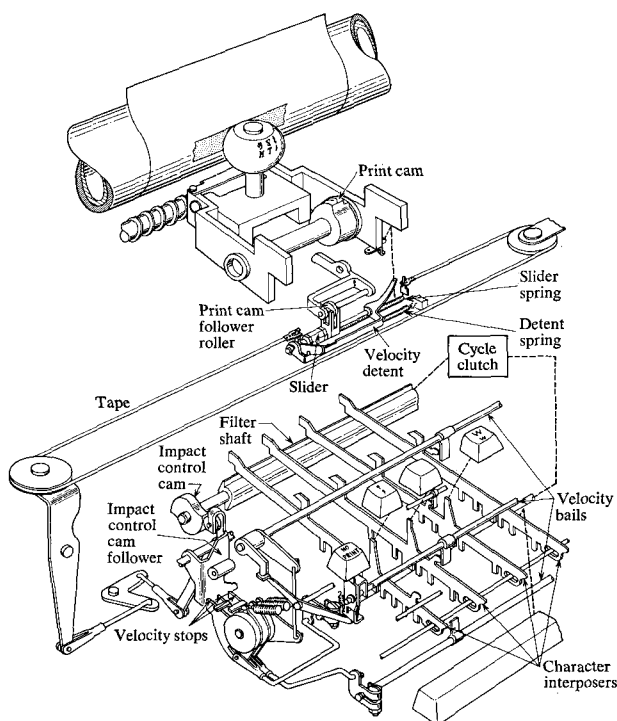


Figure 5 Impact selection system.

Each print cam segment is 0.125 in. wide. The print cam follower roller is 0.080 in. wide. The selection mechanism has to position the print cam follower to within 0.045 in. of nominal position within 12.5 milliseconds. The first design used a drop-off impact control cam. Under this condition the overshoot and undershoot were excessive, resulting in an occasional malselection. The impact control cam had a ramp added to reduce and control the velocity of the system; however, the print cam follower roller occasionally got caught by the wrong cam segment. Instrumentation showed that the slider was undershooting (shown by the dashed lines in Fig. 4).

The problem was that the spring rate in undershoot was only that of the slider spring acting on the slider and cam roller mass. The spring rate in overshoot was much higher, as it involved the elasticities of the tape and system linkage. The solution was to add the velocity detent (Fig. 5), which acts during undershoot as a high rate spring to reduce displacement and the period of vibration. Without the detent spring the stresses in the rigid detent were prohibitively high.

A no-print selection is made by depressing the spacebar or the no-print key. The machine cycle is the same as for a print operation, except that the fourth print cam segment is selected and does not drive the rocker far enough to cause typehead-paper contact.

The resultant design yields good consistency in character coverage without excessive embossing and line spread. It permits the use of a simplified no-print spacebar and provides manual impact control.

Supply parameters

The model SELECTRIC Composer machines performed well. As "printwork" from these machines was studied, however, it became increasingly obvious that ribbons and papers were extensive contributors to print quality. Edge definition, dirt, and character coverage were notably better on some papers than on others.

It has since been established that the best character coverage and edge definition are obtained on those coated papers which have a microscopic surface roughness. (This roughness is sometimes referred to as "tooth.") Papers such as the one shown in Fig. 6 are usually very good. Glass-smooth coated papers sometimes fail to hold the ribbon ink particles. This is especially noticeable at the character edges (Fig. 7). On the other hand, uncoated papers with fibers exposed at the paper surface will create character edges which take on the texture of the fiber structure. These fiber structures also create coverage problems.

As shown in Fig. 8, craters between the fibers are sometimes so deep that ribbon ink does not fill them. Also, ink is sometimes "pushed off" the large fibers so that they are exposed. These paper variables were not controllable during the SELECTRIC Composer development. However, this knowledge made possible the recommendation of "proofing" paper as the best paper for use with the Composer. Studies were also conducted to determine the effect of the ribbon on character coverage, for all types of paper. Character coverage was found to be a particular problem with the bold type styles.

The ribbon used initially would not release ink completely across the bold character faces and lost ink particles outside the character face. These particles often deposited themselves on the paper, creating dirty copy. This phenomenon is called flaking. (This ribbon was a polyethylene film coated with solid ink. Its ideal release mechanism was total loss of ink in the character area.)

The first attempt to improve character coverage was to increase the print energy levels. The energy was increased to the point where print-blow noise level was objectionable. The coverage on bold characters was still not adequate. As the problem was studied further it was found that an unplated plastic typehead when allowed to sit undisturbed for about an hour would give better coverage the second or third time any given character was struck than it would on the first strike. By cleaning the typehead before printing all the strikes gave equally good coverage. Lubricating the character face made ink coverage worse. Apparently the friction coefficient had something to do with ink release. A typehead which had been roughened by striking it against sandpaper was tried. The coverage was much improved.

In order to explain these observations, some static tests were run. Space does not permit a detailed analysis but the results are pertinent to this discussion. The total release, plastic film ribbons studied did not release fully under a



Figure 6 Character image on rough coated paper.

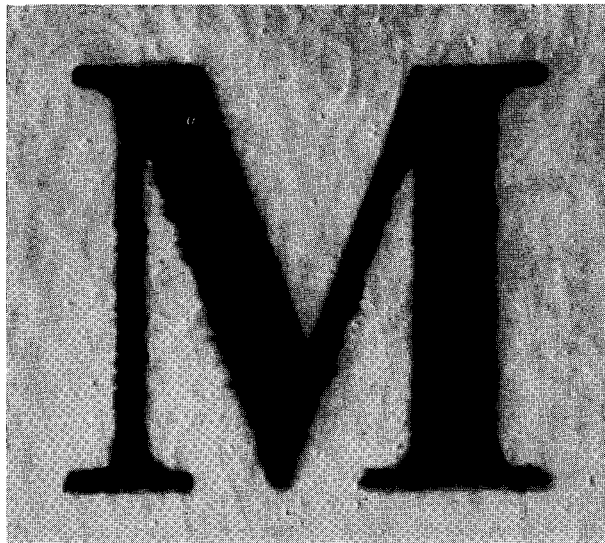


Figure 7 Character image on smooth coated paper.

normal pressure of 8,000 psi. They did, in all cases, release totally when the shear stress reached 450 psi.

From our discussion on papers and Figs. 6 and 7 we are able to see that the surface roughness of the paper is important. Our best current knowledge of ribbon transfer indicates that ink should be held in intimate contact with the paper by the coefficient of friction between the ink and paper. Likewise, the typeface and plastic film should be held in contact (no sliding) by the coefficient of friction. There must exist a shear force, parallel to the paper plane, sufficiently high to break the ink from the plastic film. The normal stress is important because it determines whether the printing laminate (paper, ribbon, and typeface) slips under the action of the shear force. If the ink slips relative to the paper the character will smear. If the typeface slips relative to the film, the image will not release. The normal stress is also important because it acts to smooth the surface of a rough paper.

There are many possible problem areas in using this philosophy. One is that the machine must present a shear force to the typeface in such a way that the character does not smear. Another is that the ink-film interface of the ribbon must have a bond which releases only under impact with the character. If it releases under too light a stress, it will flake in the feeding mechanism.

To create an acceptable roughness and hence the correct coefficient of friction, several plated typeheads were blasted with various sizes of grit. It was found that a 240 grit was about optimum. A finer grit did not cause the character to cover as well; a coarser grit left visual evidence of roughness around the character edges. Later, a plating was developed which had the same surface characteristics as the grit-blasted heads. This plating is now used on all SELECTRIC

Figure 8 Character image on uncoated paper.



composer typeheads. This advance, however, did not alleviate all the printing problems. Character coverage was not good on marginal papers and ribbon dirt continued to be excessive.

The ribbon development program was therefore examined, and ink chemists submitted ribbons for trial which showed promise. The author evaluated every ribbon and rated each by subjectively evaluating each quality parameter on the printed page. A graded rating system was used and a weight factor was applied to each parameter. In this way a working relationship between ribbon formulation and print quality was obtained. When machines became

available, this rating system was used to evaluate ribbons on a "real environment" basis. The resulting ribbon is a special-use product matched to the SELECTRIC Composer.

Conclusions

The output quality of the SELECTRIC Composer is a result of matching supplies and machine for a specific desired result. That match has helped to achieve an impact printer which approximates more costly methods of setting type.

Acknowledgments

W. M. Voit's cable-oriented impression control apparatus in the SELECTRIC Typewriter provided a significant base for

later development efforts. W. O. Cralle's participation in the development of the device described herein was invaluable. M. Prewarski provided the design of the selector and detent cams which made the print cam design feasible. His technical assistance in the printing mechanism design added to the machine's capability. G. T. Wilder and C. A. Queener participated in the development of the special plating technique for better character coverage. K. E. Edds and K. Kirkland worked to develop a ribbon which met the mechanical specifications that were required by the mechanism.

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