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The IBM SELECTRIC Composer

Justification Mechanism

Abstract: This paper describes the development and design history of the SELECTRIC Composer justification mechanism. The authors present a brief definition of justification and how it relates to the printing industry; the requirements imposed upon a justification device that are peculiar to the SELECTRIC Composer; a description of the justification mechanism and its design, development and testing; and a final evaluation of the design relative to the attainment of its designated objectives, both as a mechanism and as a component of the SELECTRIC Composer.

Introduction

Within the printing industry, justification is defined as the process of spacing type so that lines within a printed column will be of equal length; i.e., will have even margins. Most type-setting equipment used today is provided with a device which either assists the operator with justification or justifies the text automatically. The sophistication of the justification device, or justifier, depends largely on the nature of the type-setting machine to which it is attached. Regardless of its complexity, a justifier is expected to provide finished copy with lines of exact, equal length.

There is one prime characteristic of the IBM SELECTRIC Composer that dictated the design of the justifier more than any other factor—its proportional escapement, which features characters varying in width from three through nine units.[1] The aesthetic quality of type printed with the SELECTRIC Composer can be assured only by requiring that characters within a word be placed side by side without any intervening spaces. To justify a line of type printed with the SELECTRIC Composer, it is necessary to vary the amount of space between words (but not between characters within a word) to maintain the proportionality of the characters. Further, the spaces must be varied in a fashion that enhances the overall appearance of the finished copy.

With the initial determination that justification would be accomplished by varying word spacing rather than either character spacing or a combination of both, a variable spacebar[2] was provided which utilized the escapement selection system, allowing spacebar escapements of three through nine units. Following this, it was necessary to establish a method for assisting the operator in justification. Several basic decisions were required: How could the variable spacebar be used most efficiently? Should justification be automatic or semiautomatic? How can information be transmitted simply between machine and operator during justification?

Use of variable spacebar

Of prime importance was the fact that neither operator nor machine can determine the length of a line of type before it is printed (not, at least, without time-consuming counting and/or computation). This led to the decision to type each line twice—one rough typing to determine what words a line would contain, and a second, justified typing. To make the process systematic, it was decided that the first typing of a line would contain fixed-width word spacings only. Further, since efficiency requires that words be placed as closely as legibility and appearance will permit, the initial word spacing was set for the minimum escapement available on the SELECTRIC Composer—three units. Finished copy was to be obtained via a second typing by varying the original word spacing in a systematic fashion.

These decisions led to others: The use of the minimum (three-unit) space in the first printing of a line requires that the line end at or (more often) short of the predetermined right margin. This is imperative because the spaces in the justified line will of necessity have at least equal (and in the

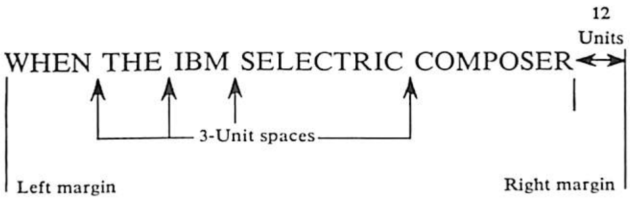


Figure 1 Example of spacing in an unjustified line.

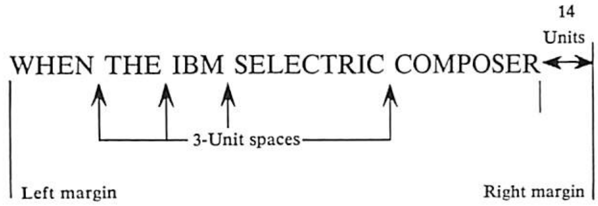


Figure 2 Example of Fig. 1 retyped using different escapement pitch.

great majority of cases, greater) escapement values than three units and thus will usually expand the line.

The variable spacebar's use in justification can best be illustrated by examples: Assume the line in Fig. 1 has been typed with the SELECTRIC Composer in preparation for justification. As may be seen, the line ends twelve units short of the right-hand margin. The twelve units at the end of the line may be distributed most evenly by dividing them equally among the four spaces within the line:

12 units ÷ 4 spaces = 3 additional units/space. (*Example 1*)

If, in the second printing, four six-unit spaces are used, rather than the initial three-unit spaces, the line will expand to the right margin.

As a further example, assume that, after a type element change and the resultant pitch change,[1] the line in Fig. 1 was retyped (again using three-unit spaces). In this instance, the line ends fourteen units short of the right margin, as shown in Fig. 2. The fourteen units at the end of the line will not be distributed as evenly as were the twelve units of Example 1.

14 units ÷ 4 spaces = 3 additional units /space + 2 units remainder. (*Example 2*)

If, however, in the second typing two seven-unit spaces and two six-unit spaces are used, the line will extend to the right margin. This distribution of spaces was chosen rather than, say, one eight-unit space and three six-unit spaces to create a more uniform appearance.

Automatic vs. semiautomatic justification

The justifier was designed as a semiautomatic device as a result of estimates that compared the relative size, cost, and complexity of fully automatic and semiautomatic justifiers. In every instance, the semiautomatic justifier was found to be more satisfactory for the basic SELECTRIC Composer.

Semiautomatic justification, of course, demands more of the operator than would an automatic mechanism. From the previous examples it can be seen that the number of spaces in a line and the number of units between the end of the line and the right margin must be known before justification can be attempted in a second typing. Further, a computation must be made and the results applied, using the variable spacebar. In system terms, a semiautomatic justifier must provide an information output to the operator, and the operator, after making the required judgments, must provide a control input to the machine.

The SELECTRIC Composer's justifier operates exactly in this manner. An indicating mechanism, mounted at the right margin, measures the distance between the end of the line and the right margin; a counting mechanism, triggered by the spacebar, counts the number of spaces in the line, and the interaction of these mechanisms makes the computation. The results are indicated to the operator. The operator then enters the appropriate information into the variable spacebar mechanism and retypes the line. The "programmed" spacebar thus provides the justification.

A more complete description of the mechanism and its operation is presented in the sections that follow.

Design specifications

Implied in the discussion above are several design criteria for the justifier. These, as well as other criteria, were established through examination of market requirements and a study of SELECTRIC Composer features, industrial design, and human factors. Specifically, they were determined on the following bases:

(a) The SELECTRIC Composer must be capable of justifying any line of twenty word spaces or less that ends to the left of and within three-quarters of an inch of the right margin, for all settings of that margin.

(b) The SELECTRIC Composer must be capable of producing justified columns varying in half picas (from a minimum column width of nine picas to a maximum of seventy-seven).

(c) The justifier must collect and display required information so that the need for operator judgement is minimized.

(d) The variable spacebar must receive and apply operator instructions in a way that will minimize operator effort.

(e) The justifier and variable spacebar must provide three types of justification: (1) parallel, in which the initial and justified lines are printed sequentially, side-by-side on the

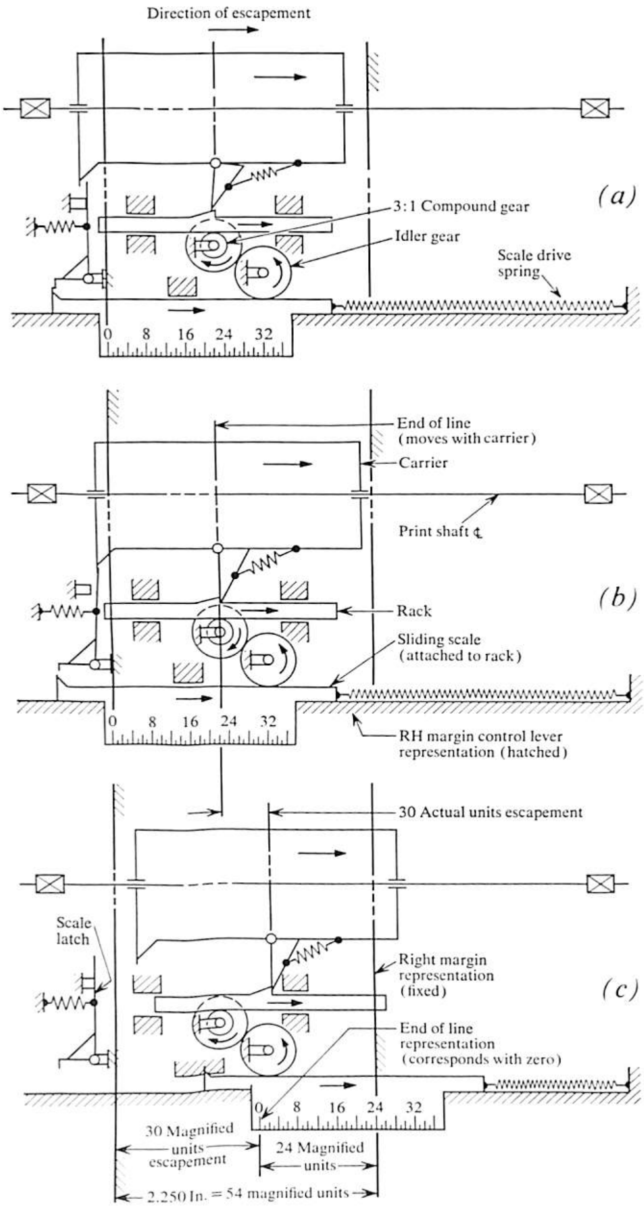


Figure 3 Simplified sketch of sliding-scale indicator.

same sheet; (2) serial, in which the entire text to be prepared is rough-set and then justified on a separate sheet; and (3) no-print, in which the initial typing is done in no-print and the justified setting is completed on the same sheet.

(f) The justifier must be entirely reliable in that, during the life of the machine, it must produce justified copy for any margin and escapement selected, without requiring alteration in operator judgment or effort.

(g) The justifier and variable spacebar mechanisms must be designed so that they do not impair the operation of related mechanisms, and so that operator error will not damage the machine.

(h) The justifier and variable spacebar mechanisms must be so designed that external portions of the machine which are exposed are consistent with industrial design criteria, and so that error will not injure the operator.

Description of design

It is pertinent to mention that the uniqueness of the SELECTRIC Composer required that its justifier be designed with only a concept as a starting point. No mechanism existed which could serve as a design guide.

The design of the justifier began late in the development program, and only one solution was attempted. Although it was subjected to modifications, the basic scheme was successful and has never been changed.

The basic mechanisms are the indicating and counting mechanisms, the combined action of which determines the number of spaces in a line, the number of units between the end of that line and the right margin, and the distribution of these units in the printing of the line; and a variable spacebar mechanism which properly distributes the spacing in both justified and unjustified copy.

The usual method for obtaining justified copy requires that the operator (1) select the desired column width with the margin controls and set the lever that actuates the indicating mechanism; (2) type the first line, starting at the left margin, using three-unit spaces, and ending the line to the left of and within three-quarters of an inch of the right margin; (3) read the information displayed by the indicating mechanism; (4) enter this information into the variable spacebar in such a manner that the second typing is justified (this information must be recorded rather than entered into the variable spacebar if serial justification is to be used); (5) type the line a second time; and (6) reset the machine so that the next line may be typed in a similar fashion.

Obviously, the operator cannot be expected to consistently perform all of these operations. The justifier and variable spacebar, therefore, have been designed to assist the operator as much as possible.

- *The indicating system*

The indicating system is composed of a sliding scale, which measures the number of units between the end of a line and the right margin, and a counter, which counts spacebar operations.

The sliding scale is attached to the right margin control so that it measures units in a 3:1 magnification, after the carrier has entered a justification zone starting three-quarters of an inch to the left of (and ending at) the right margin. Figure 3a illustrates the carrier, as it approaches the justification zone; Fig. 3b as it enters the justification zone, initiating scale motion; and Fig. 3c as it stops within the justification zone, 24 units short of the right margin (for this example), as indicated on the sacle.

The counter is a ratchet-driven shaft, mounted above and to the rear of the keyboard and in front of the carrier. The

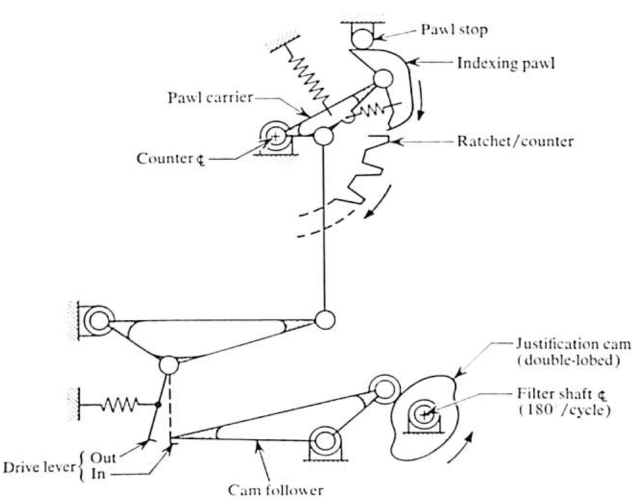


Figure 4 Ratchet counter mechanism.

ratchet advances one tooth at each spacebar operation. A schematic side view of the counter is shown in Fig. 4. During a spacebar operation the initial rotation of the filter shaft[2] drives the spacebar interposer[2] toward the front of the machine. The interposer motion positions the drive lever underneath the cam follower (as seen in Fig. 4), where it is latched in place until the end of the indexing cycle. After the drive lever is latched in place, the cam follower starts up the ramp of the cam and the ratchet advances one tooth. The transfer of the motion of the cam follower to the ratchet may be traced through the links shown in Fig. 4.

As stated previously, the counter and the scale indicate the number of spaces in the line and the number of units between the end of the unjustified line and the right margin. With this information the operator can make a computation (Examples 1 and 2) to justify the line. In order to save time and the possible error involved in making a computation, the sliding scale and the counter have been designed so that the combination of their individual motions makes the necessary computation using the process of graphic division.

Given a simple division problem,

12 ÷ 4 = 3,

the divisor and the dividend may be given linear representation as shown:

1 = |—|
4 = |—|—|—|—|
12 = |—|—|—|—|—|—|—|—|—|—|—|—|

(Example 3)

Twelve may be graphically divided by four by superimposing a continuous end-to-end sequence of lines representing four upon the line representing twelve. The quotient is obtained by counting fours:

12			Dividend
4	4	4	Divisor
3	2	1	Quotient

(Example 4)

If the dividend is not a multiple of the divisor, a remainder will result:

14 ÷ 4 = 3 with remainder of 2

Graphically, since the number one may be represented as a line (as shown in Example 3), the remainder is obtained by superimposing, in continuous end-to-end sequence, the divisor upon the dividend, counting whole divisors, and counting ones past that point:

14					Dividend
1	1	4	4	4	Divisor
2	1	3	2	1	Quotient & Remainder

(Example 5)

Thus, fourteen divided by four equals three with a remainder of two. (The reason for counting from right to left will be evident later.) In Example 5 the number fourteen and its physical representation can be considered equivalent to the number of units between the end of the line and the right margin. In the mechanism this is shown on a sliding scale. The scale (shown in Fig. 3) therefore represents the dividend in the justification computation as well as the units of space remaining at the end of the line.

The rotating spacebar counter provides the divisor for the graphical division process. If for each position of the counter a line is started at a common reference line, extended to the left, and graduated in elements of width proportional to the number of spaces represented by the counter position, then each line represents the continuous end-to-end arrangement required for divisors in graphical division. Further, if the common starting point for all positions of the counter is representative of the right margin and the graduations on the lines are multiples of the graduations on the sliding scale, then the computation required for justification may be obtained by superimposing the graduated counter lines upon the sliding scale. Figure 5, in which the following division operations are shown graphically, illustrates this process:

14 ÷ 1 = 14
14 ÷ 2 = 7
14 ÷ 3 = 4 & 2 remainder
14 ÷ 4 = 3 & 2 remainder
14 ÷ 5 = 2 & 4 remainder
14 ÷ 6 = 2 & 2 remainder *(Example 6)*

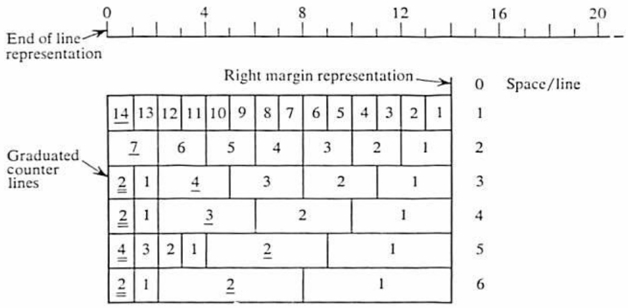
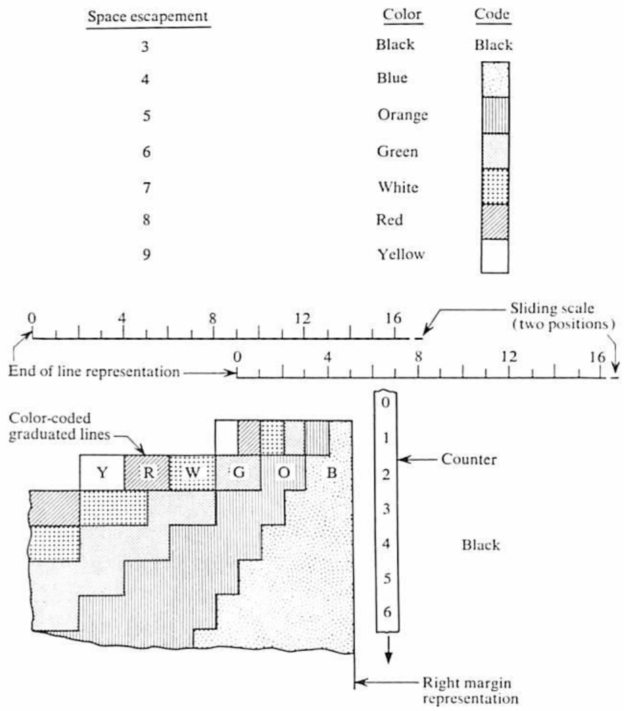


Figure 5 Graphic representation of Example 6.

Figure 6 Relationship of color-coded indicator to sliding scale and ratchet counter.



Consider the portion of Fig. 5 for which the counter indicates that six spaces have been used and fourteen units remain between the end of the line and the right margin. The justified line would be most evenly spaced by using two six-unit spaces and four five-unit spaces. For five spaces, four six-unit spaces and one five-unit space should be used. For four spaces, two seven-unit spaces and two six-unit spaces should be used. For three spaces, two eight-unit spaces and one seven-unit should be used. It may be seen, then, that a pattern has developed:

(1) Spaces of only two different escapement widths that differ by one unit are used in the justified typing of any line.

(2) The spaces with the larger escapement appear first in the justified printing.

(3) The number of the larger escapement spaces is equal to the remainder in the division process.

(4) The escapement value of the larger escapement spaces is obtained by adding the quotient (in units) from the division process; three units—the escapement value in the initial typing; and one unit to each space until the total of the single units added is equal to the remainder (in units) of the division process. As is evident from (3) and (4) above, the remainder units in every case are added one per space to the spaces in the justified setting, rather than to one space alone. This pattern lends itself to coding so that the operator is not required to count the divisors nor to determine what escapements are needed. This coding allows a simple transfer from the indicating mechanism to the variable spacebar.

Figure 5 is now redrawn in Fig. 6 using color coding; this is the basis for the Composer's justification system.

• *Justification Mechanism*

It is evident from Fig. 6 that the length in units of each color-coded segment on a counter line is equal to the number n of spaces in the typed line, and that six segments are required on each line (one segment for each available spacebar escapement greater than three). The length in units of the justification zone for each counter position is thus 6 segments $\times$ n units/segment, up to the specified limit of $\frac{3}{4}$ inch, which represents 72, 63, or 54 units depending upon the escapement pitch (1/96, 1/84, or 1/72 inch., respectively).

Examination of Fig. 6 reveals that an operator, after an initial typing of the line, can read the color immediately to the right of zero along the line indicated by the counter and the graduation on the scale at which that color changes. This establishes the escapement value, and the number, of larger spaces to be used in justifying the line. It may be assumed that other spaces in the line will be one unit less in escapement.

Consider the case in which fourteen units remain at the end of a six-space line: The operator reads "Green-2" (Fig. 6), indicating that two six-unit spaces and four five-unit spaces are required in the justified line. For a further example, consider the case in which five units remain at the end of a four-space line: The operator reads "Orange-1" (Fig. 6), indicating that one five-unit space and three four-unit spaces are required in the justified line, etc.

The mechanism as described to this point is visible to the operator as two concentric tubes mounted above and to the rear of the keyboard and in front of the carrier. The inside tube is fixed laterally, but is free to rotate (Fig. 7). It is this tube which serves as the spacebar counter and about which are oriented the graduated and color-coded counter lines, one set for each pitch, spaced along the length of the tube.

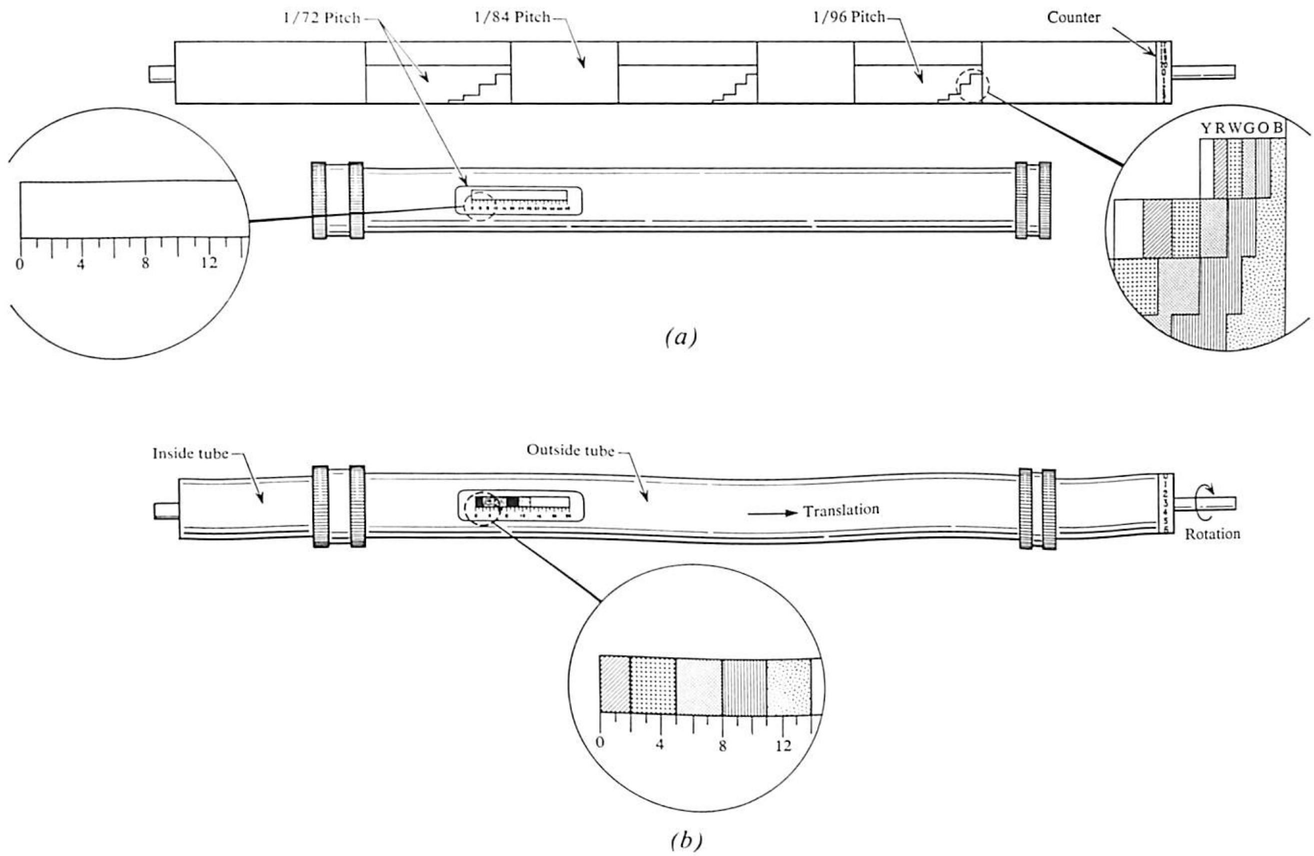


Figure 7 Indicating mechanism as used in composer.

The outer tube is fixed rotationally but is free to move laterally, using the inside tube as a bearing. This tube carries the sliding scale, which is positioned at the edge of a small slit designed to display only one color-coded line for each escapement pitch. There are three scales, one for each pitch, spaced equally about the circumference and in lateral agreement with the corresponding set of color-coded counter lines. The outer tube is detented rotationally so that the scale for a particular pitch may be selected and held in proper relation to the spacebar counter. This tube is connected to the carrier through a gear train with a 3:1 magnification (Fig. 3) that is necessary to allow the operator to read a scale which is graduated in units. One unit—1/96, 1/84, or 1/72—at the carrier is magnified three times at the tube, where one unit equals 1/32, 1/28, or 1/24 inch, respectively. The gear train is mounted to the right margin, along with the tube release mechanism (Fig. 3). The entire right margin mechanism is designed so that it may be placed at or between positions 12 and 77 on the margin set scale, while the outer tube remains stationary.

- *Selection System*

The justifier selection system consists of the variable spacebar mechanism in combination with a dual ratchet indexing mechanism. To justify, the operator feeds information from the indicating system through the selection system. This selection system is visible to the operator as two vertically stacked dials at the right side of the keyboard. These dials are coded to match the readings displayed by the indicating system.

In justifying, the value dial is set to match the color read from the indicating system. The quantity dial is set to match the number read. Typical settings are "Green-2," "Orange-1," etc. After making the setting the operator is not required to reset the dials until after the reading for the next line is taken.

Consider the following example: The operator has typed a four-space line and five units remain between the end of the line and the right margin. One five-unit and three four-unit spaces are required to justify the line. The operator reads this information as "Orange-1," makes the setting on

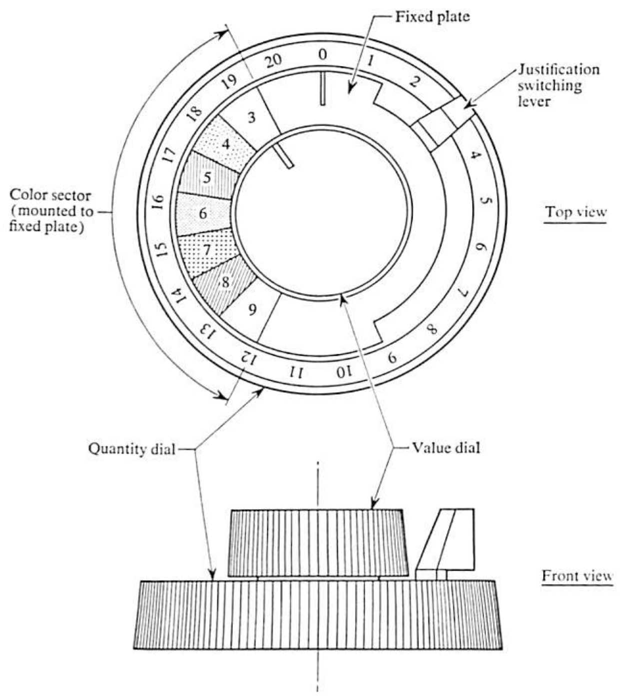


Figure 8 Selection dials.

the selection system dials, tabs, and types. The first space will be a five-unit space. The dual ratchet system then "steps down" the value dial to a blue (four-unit) setting, and the remaining spaces in that line will contain four units.

The stepdown function makes operator changeover from one variable spacebar setting to another unnecessary during the typing of a line. Changeover is accomplished with the dual ratchet indexing system mentioned previously.

Attached to the shaft connecting the value dial and value pinion[2] is a ratchet having teeth with angular spacing equal to that on the color sector (Fig. 8). Attached to the quantity dial is another ratchet of essentially equal dimensions. The ratchets rotate independently about a common center. About this center also rotates the carrier for the indexing pawl (Fig. 9). The pawl is doublenosed. The nose which drives the quantity ratchet is sufficiently long to hold out of engagement the nose driving the value ratchet. Thus, as the quantity dial is indexed, the value dial remains stationary (both dials are detented for all positions of their respective ratchets).

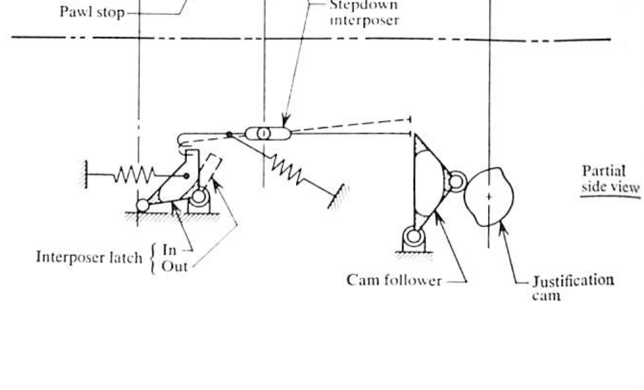
In response to the motion of the spacebar interposer, the stepdown interposer is moved into the path of the cam follower (Fig. 9), in a manner similar to the motion of the the drive lever in the counter mechanism (Fig. 4). The stepdown interposer is then latched in place and remains so until the end of the cycle. This interposer is driven forward by the cam follower and, in turn, causes the pawl carrier to rotate clockwise. The quantity ratchet is thus indexed one tooth with each spacebar operation, and since the angular positions of the numbers on the quantity dial correspond to the teeth on the ratchet, the dial setting is reduced one number with each spacebar operation. Only the quantity dial indexes until the motion from position 1 to position 0 is accomplished. As the long pawl nose engages the quantity ratchet at this position, it encounters a tooth space sufficiently deep to allow the short nose to engage the value ratchet. Thus, as the quantity dial is moved from 1 to 0, the value dial is moved from its setting to the next lower position. The change in setting is transferred to the variable spacebar and the escapement is altered accordingly. The motion of the spacebar interposer activates both the spacebar counter and the stepdown spacebar. It is not required, however, that the counter and the stepdown spacebar operate simultaneously. On the contrary, the variable spacebar must always be set and remain at position 3 when the counter is in operation. Further, some applications require neither counting nor stepdown. A three-way switching arrangement has therefore been provided. By means of the lever shown in Fig. 8, the operator is permitted to select one of three operations: (1) an operation where only the indicating system is activated; (2) an operation where only the stepdown spacebar is activated; and (3) an operation where neither (1) nor (2) is in effect, thus allowing the use of the variable spacebar.

The indicating system is also designed to reset when the carrier is returned so that operator effort is not required.

Testing

Testing of the justifier was completed in four phases: (1) Prototype testing, the purpose of which was to test function and feasibility, (2) semiproduction testing, the purpose

Figure 9 Spacebar stepdown mechanism.



of which was to determine the manufacturability and the continued ability of the mechanism to withstand wear and breakage while remaining functional, (3) production testing, the purpose of which was to check for retention of all favorable aspects of previous design levels and for incorporation of all modifications found to be necessary in earlier testing, and (4) engineering testing, which was run concurrently with all other test phases with the expressed purpose of thorough and complete analysis of the entire mechanism at all levels of design.

The problems encountered were varied. The mass of the indicating system in conjunction with its operating speeds led to high acceleration and impact forces. Redesign was required in most of that area either to reduce the loads or to strengthen the affected parts. The performance of the stepdown spacebar was good and thus required little redesign.

Since both the indicating and selecting systems are visible to and controlled by the operator, several changes in appearance and "feel" were made to satisfy the industrial design and human factors requirements. Particular effort was made to see that all controls were simply operable and that the indicating system was accurate and easily read, as well as to ascertain that excessive glare would not reflect into the operator's eyes, and that colors and lines were compatible with the overall design of the machine.

Conclusions

Evaluation of the final justifier design may best be accomplished by judging it against the stated design criteria:

The justifier is capable of justifying any line, of twenty spaces or less, that is nine to seventy-seven picas long, if that line ends within the justification zone at the first typing. Special techniques may be used to justify a line with more than twenty spaces, providing the line ends within 3/4-inch of the right margin at the first typing. The justification zone expands proportionally to the number of spaces from a minimum of six units to a maximum of 3/4-inch.

The SELECTRIC Composer is capable of producing columns varying in width by half-picas from nine to seventy-seven picas, except when the left margin is set at zero on the margin set scale, when the minimum column width is twelve picas. The justification mechanism can be used to justify any column within these specifications.

The justifier collects, displays and receives information through a color-coded indicating and selecting system. The operator is required to read a color and a number and to transfer each to the dials of the stepdown spacebar. There was some initial difficulty due to random inaccuracy of the indicating system; however this has since been sufficiently reduced to allow accurate justification.

Three types of justification are available: parallel, serial, and no-print. The most frequently used method is parallel, which allows direct transfer of justification data from the indication system to the selection system (data must be recorded if serial justification is used).

The justifier is reliable to the extent that it functions properly for the expected life of the machine, requiring only normal maintenance.

The justifier is simple to operate, requiring little training time.

The justifier design is compatible with related mechanisms: carrier, variable spacebar, tab, and carrier return, all of which provide input for, or receive output from, the justifier. No damage can be caused by operator error.

The design is consistent with human factors, industrial design, and safety requirements.

It may therefore be concluded that the SELECTRIC Composer justifier performs well its intended function. It is nevertheless expected that improvements in accuracy, efficiency of operation, appearance, and manufacturability will result from experience gained through use.

Acknowledgments

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References

1. B. W. Miles and C. C. Wilson, "IBM SELECTRIC Composer Proportional Escapement Mechanism," *IBM Journal* **12**, 48 (this issue).
2. B. T. Crutcher and D. E. Sederholm, "IBM SELECTRIC Composer Letter Keyboard," *IBM Journal* **12**, 15 (this issue)

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