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Paper Path of an On-Line Computer-Output Printer

Abstract: This paper describes the development of a paper handling system designed to move paper at a speed of 81 cm/s in the IBM 3800 Printing Subsystem. During the development of the printer a number of unique problems arose from the interaction among paperline components. The various approaches and solutions to these problems, including paper path alignment, character stretch, registration within the fuser, and path error detection, are discussed and illustrated.

Introduction

• *Design objectives*

Ideally, a computer-output printer should print on any size paper from top to bottom and from edge to edge. It should require a minimum of operator intervention and should be able to indicate erroneous machine conditions that occur. The IBM 3800 Printing Subsystem attempts to provide as many features of the ideal machine as possible using an electrophotographic process.

A user survey was made early in the program to determine the most desired printer capabilities. From this and related design studies, conventional fanfold paper was chosen as the printing medium. Also, the most-used sizes and range of paper weights were established. A nominal paper speed of 81 cm/s (32 in./s) was selected as an attainable goal. This speed is approximately five times greater than that of previously available IBM printers.

Certain constraints on the paperline were brought about by the printing process. For example, the process drum is wrapped with a light-sensitive material that is periodically renewed from a spool inside the drum. This required a gap seal over the opening where the material could be fed out and simultaneously taken up on the spools. Since the paper must contact the light-sensitive surface while printing, it is necessary to stop the paperline and raise the paper off the drum for 60 ms to allow the gap seal to pass beneath.

Another significant constraint involves the mechanics of starting and stopping of the paperline. This subject is discussed in detail by Cameron and Dost [1]. It is sufficient to say here that a space of 1.27 cm (0.50 in) is provided at the top and bottom of each page to allow time for acceleration and deceleration of the paper in the path. The same amount of space is required at the fusing station because stopping the paperline with print between the fuser and backup rolls causes some of the print to adhere to the hot roll. It is then offset one revolution of the roll later. An in-depth discussion of the fuser design is presented by K. D. Brooms [2].

• *Forms design constraints*

Originally, the printer was required to handle all manufactured forms within the stipulated size and weight restrictions. As the design progressed, however, certain parameters became critical and needed control. For example, the perforation strength must exceed certain minimum values; otherwise, the forms burst during acceleration. The vertical perforations sometimes used to remove the carrier strip from printed output were also troublesome because paper is inherently weak in this direction. Use of these perforations is therefore not recommended.

Wrinkles within sheets are a significant problem for a continuous form printer. Slight wrinkles often cause poor transfer of images from the process drum because intimate continuous contact cannot be maintained. Large wrinkles cause paper jams in the forms tractors. This, of course, is a problem with all printers using continuous forms, and the problem becomes more acute at high speeds. Great care was exercised to eliminate all adverse surface conditions and discontinuities in the hardware to prevent paper jams.

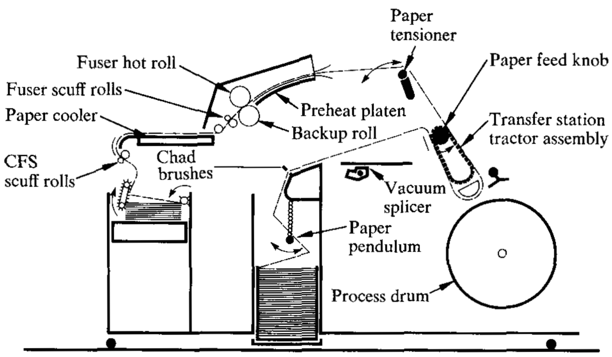

Figure 1 Basic paper path of the printing subsystem.

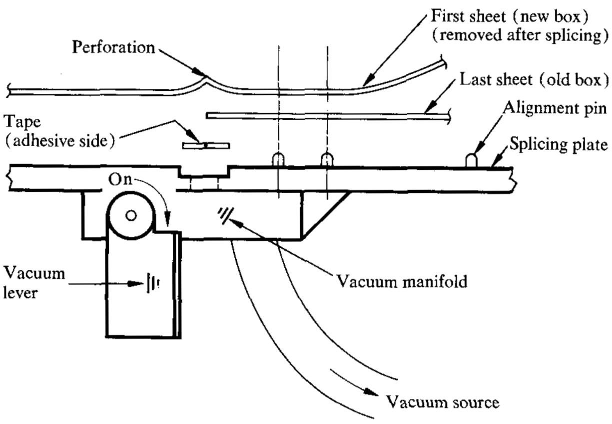

Figure 2 Forms splicing configuration.

Because high speed and printing throughput are of paramount importance, it is necessary that forms be spliced between boxes rather than rethreaded. This criterion required certain dimensional control from box to box to prevent jams when splicing. To insure good refolding performance, the forms perforation configuration had to be limited. More detailed information is given in the section dealing with the design of the continuous forms stacker. A complete summary of forms requirements is covered in the Forms Design Reference Guide for the IBM 3800 Printing Subsystem [3].

Functional overview

• *Paper input*

At this point, a brief description of the paperline is warranted. Figure 1 shows its significant features. Paper is fed from either a carton or a free stack. When it is fed from a carton, clearance must be provided around the paper stack to prevent a vacuum from forming beneath the web as it is pulled from the carton. Such a vacuum creates very high restraining forces on the web, which can result in paper jams, transfer servo registration errors, and overload errors.

When paper is packaged within the carton, it is sometimes crimped at the folds in such a way that several sheets of paper can be pulled from the carton simultaneously. When this occurs, the paper pendulum and chad brushes help to separate the sheets. Severe cases of this packaging problem result in paper jams.

When more than one box of the same size form is being run, splicing is preferable to rethreading. A precision butt splice is required to preserve paper path integrity. Forms splicing presents two types of problems: tape alignment to the splice, and tape/adhesive material compatibility with machine process characteristics. The tape is held in a precision slot by the air vacuum system. The adhesive side is exposed, allowing paper to be placed over it with fixed pins in the front for alignment, as shown in Fig. 2. No mechanical adjustments are required by the operator except for applying and removing vacuum before and after splicing. The machine process requires the use of a special paper tape and adhesive.

• *Paper feed*

The stringent paperline acceleration and deceleration requirements made it necessary to minimize inertia and friction forces in the tractor system. This inspired the development of a double-sided tractor drive system shown in Fig. 3, as opposed to the conventional single-sided system. The input side of the tractor pulls paper from the box and feeds it into the transfer zone. The output side pulls paper through the transfer zone and around the 3.18-cm (1.25-in.) radius transfer guide. The direct coupling of the input and output paper webs also minimizes print misregistration.

The paper web is carried on steel pins 0.3950 cm (0.1555 in.) in diameter via the familiar carrier strip holes. The length and tip geometry of the pin are designed to provide smooth pin transition as it enters and leaves the paper carrier strip. The pin is short because the printer uses single-ply forms. The tractor pin is molded into a plastic yoke which is, in turn, secured to a precision timing belt with roll pins. The yoke is given clearance along its paths except for a slip fit between the yoke flanges and the pulley. This assures horizontal print registration and minimum relative motion between the pulley and yoke. The pins are carefully supported from below to prevent vertical oscillation of the pin. This oscillation can cause burring of the carrier strip holes, and paper jams.

The design of the paper feed system incorporates hardware to prevent paper chads from clinging to the paper in the print zone. Chads can block the proper transfer of the toner image from the drum to the paper web before the paper enters the feed system. However, chads often cling to the periphery of the holes and are pushed free by the tractor pins. A brush with metallic bristles encourages this action. Channels within the tractor covers route the chads to a trap below.

As the paper web leaves the output tractors, it enters a taut buffer loop. The web must not be allowed to oscillate or wrinkle at this point since the toner is only loosely attached to the paper. Web tension is maintained by a spring-loaded low inertia system. The requirements of the buffer loop are covered in the section entitled "Character stretch."

Paper is pulled from the buffer loop by a servo-driven fuser hot roll. The toner is fused to the paper as the web passes over the fuser platen and through the hot roll/backup roll nip. Tension in the web beyond the fuser nip is maintained by a set of scuff rolls. The web is then cooled by forced air after it leaves these scuff rolls and before it enters the continuous-forms stacker. A second set of scuff rolls feeds paper into the stacker.

- *Continuous-forms stacker*

The printer contains a unique stacking device by which the paper is fed onto a table at a particular attitude and allowed to form a rolling cylinder. The cylinder collapses at page perforations, assisted by a series of moving chains and belts (Fig. 4). This makes for an asynchronous system and greatly simplifies operator adjustment. The operator must ensure only that the paper is refolding the same way it came from the carton.

The table height is controlled by a system of incandescent light photodetectors and a motor-driven elevator. A series of compactor belts and wheels keep the fold perforations compressed. Oscillating plates at the front and rear of the stack keep the edges of the forms aligned and the stack vertical. A mechanism within the stacker provides adjustment for the various form lengths and widths that are handled.

Since stacking performance depends on the collapse of the rolling cylinder of paper, abnormally strong perforations must be avoided. Internal (unfolded) perforations must be stronger than fold perforations to prevent premature collapse of the cylinder. Though these parameters have received little attention on former printers, form manufacturers have responded well to 3800 requirements.

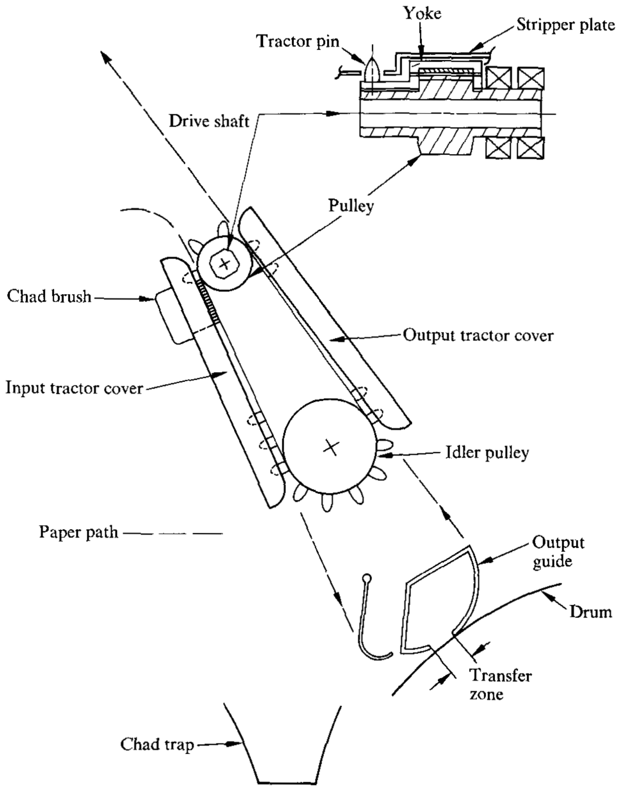

Figure 3 Transfer station double-sided tractors.

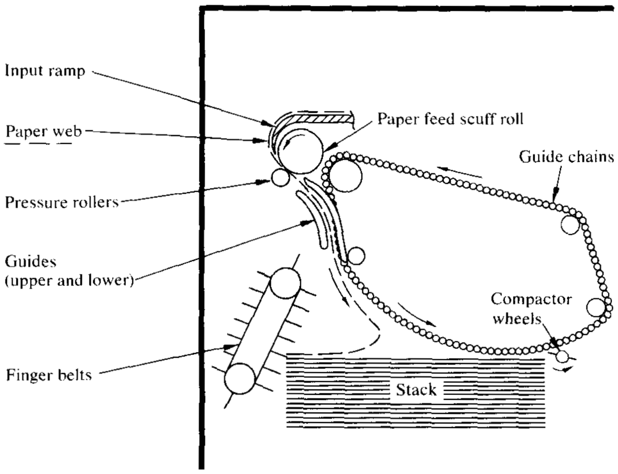

Figure 4 Continuous-forms stacker using moving chains and belts.

Unique design problems

The development of the paperline required the solution of many difficult and unique design problems. Several of these problems are described below in an effort to give some insight into the interaction among paperline components.

- *Paper path alignment*

The paper path in data processing impact printers has always tended to be short. Significant design challenges existed simply because of the length of the IBM 3800 paper path. The paper path structure was initially discontinuous between the transfer and fuser stations since these elements reside separately in the process frame and paper

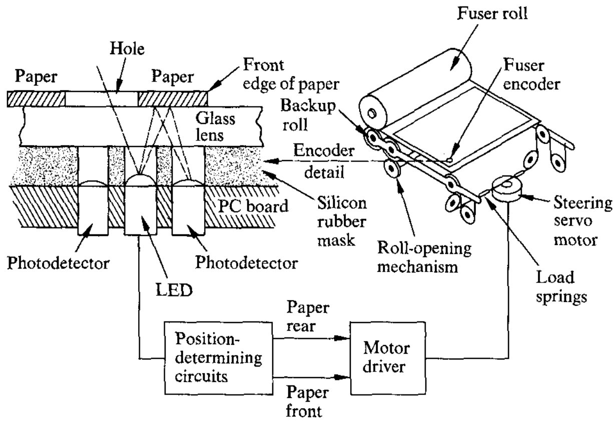

Figure 5 Web steering servo system, showing mechanical detail.

transport frame, respectively. This was required since packaging the entire paper path in one frame would have created problems in transporting the machine as well as in maneuvering it through doorways and elevators.

Analysis of an early prototype showed paper path alignment to be essential but difficult to attain unless carefully designed into the hardware. Alignment of components within their respective frames, followed by subsequent frame-to-frame alignment, was unsuccessful. Frames cannot be adequately stiffened to prevent changes sufficiently large to degrade performance. Changes of 0.076 cm (0.03 in.), parallel to the axis of the fuser hot roll, are definitely measurable in terms of paperline performance.

This problem was solved by supporting the process frame, containing the drum and transfer station, on three points. The fuser and stacker castings are rigidly coupled to the drum castings and are supported by a large counterbalance spring below the casting center of gravity. In this way, any change to the process assembly is transmitted uniformly to the remainder of the paper path, and changes to the transport frame have no effect on the paper path.

Structural alignment of the fuser station proved to be insufficient to control the lateral web position during printing. A web steering servo system was introduced for this reason and is shown in Fig. 5.

The loading mechanism for the backup roll provides an approximately equal force to each end of the roll. This is accomplished by applying the force from the same source. A servo motor at this source can then change the force equilibrium and consequently alter the lateral position of the paper. The motor is controlled by a position detector operating on the paper carrier strip holes. When the paper is out of position, a current is passed through the fuser servo motor to create an imbalance in the backup roll loading system. The distortion of the backup roll causes the more heavily loaded end to generate a higher velocity than the low force end. The paper entry angle changes because of this difference in velocity and the position of the paper changes as it progresses through the fuser. Steering motor voltage is proportional to the position error. The servo system signals an error, which stops the paperline when the lateral paper position deviates more than 0.22 cm (0.09 in.) from the nominal value.

This system does not damage the printer forms. Pure mechanical systems using the carrier strip holes or the paper edge often damage the forms before gaining control over the moving web. The steering system, combined with the paper path support system and several precise factory adjustments, allows straightforward field installation and a minimum of field adjustment.

- *Character stretch*

The distortion called "character stretch" is usually caused by relative motion between the paper and the drum surface during transfer of data. The particular condition discussed here involves abnormal motion of the paper due to a mechanical disturbance.

Figure 6 shows the loop accommodation system between the transfer and fuser stations. The length of paper between the transfer zone and the fuser roll nip varies from 42 to 44 inches on the United States machine. This relates to an integral number of sheets 7 inches and 11 inches long, respectively [4]. From a standpoint of paper handling and fuse quality, it is important that the paper path conform to the boundaries shown in the figure for long and short loops. This constraint defines the exact spatial geometry for the loop tensioner and the fusing station with respect to the transfer station.

During one of the many tests of the printer, it was found that the third or fourth print line occasionally contained stretched characters. The characters were often 0.0127 cm (0.005 in.) to 0.0508 cm (0.020 in.) taller than the prescribed nominal height. Further analysis showed this condition occurred only on the first page after acceleration of the web from rest. The stretch did not occur, however, if the loop tensioner was removed from the system. Close observation, using high speed photography, precision shaft tachometers, and an accelerometer, showed the loop dynamics to be incompatible with the loop tensioner. The tensioner lost contact with the paper because of the high paper acceleration and caused character stretch when it reestablished contact. The obvious solution was to change the system such that the tensioner never lost contact with the web. Though the constraints listed above prevented this solution, the impact force was reduced to an acceptable level. Changes were required in the transfer station acceleration time, the start delay between the fuser and transfer stations, and the loop tensioner loading system.

As discussed in [1], the transfer acceleration is controlled by a microprogram. The paper must be at its steady state velocity within 1.27 cm (0.50 in.) of paper travel. To allow time for transients to settle, the paper was brought up to speed in 0.478 cm (0.188 in.), but the acceleration was found to be overly conservative and was changed to 0.792 cm (0.312 in.) by means of changes to the microprogram. Though this was a significant improvement, it did not eliminate the problem.

Since the time delay between the paper accelerate command in the fuser station and the accelerate command in the transfer station is also under microprogram control, it too was easily modified. This required the testing of many paper lengths, widths, and weights for choice of optimum timing. The short loop configuration was found to be the worst case, as were the lightest paper weight and the most narrow width. This was logical, because tension in the web was highest in this configuration and impact forces had the greatest effect on the web containing the lowest mass.

This portion of the design effort led to the redesign of the loop tensioner loading system to provide equal web tension independent of loop length. This was done by using an over-center spring arrangement. The inertia of the tensioner was also further reduced. With all of these changes and the optimum fuser start time, a slight amount of character stretch was still observed under worst-case conditions.

The final solution came with the incorporation of circular leaf springs around the tensioner tube. When the tensioner does leave the paper, its force is now reintroduced gradually and paper is not affected at the transfer zone.

This problem, like almost all problems encountered in the development of the paper path, did not lend itself to an analytic solution. A mathematical model was not practical in this case because of schedule constraints as well as the difficulty brought about by a slack paper web. This is an excellent example, however, of the advantages of a dynamic process under microprogram control. Significant changes were tested immediately in a machine where major mechanical and electrical redesign was costly and time consuming.

- *Paper registration within the fuser*

Another unique problem encountered during the development of the printer stresses the importance of testing and characterizing all possible variables. One of the biggest variables in the paper path is, of course, paper.

The 3800 printer was developed in the United States to use paper from a very large number of forms suppliers and mills. As the program matured, paper was characterized to the point that every order was tested for certain characteristics and was serialized.

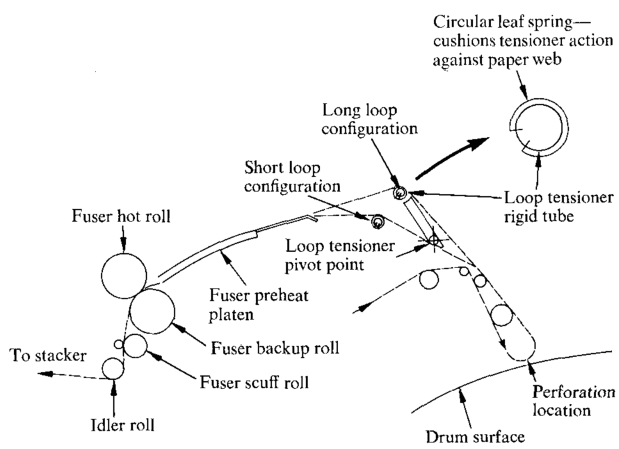

Figure 6 Loop accommodation arrangement between transfer and fuser stations.

During the testing of forms from various foreign manufacturers, a form was encountered that exhibited very low drag on the fuser platen. Extensive testing of this paper has never conclusively revealed the particular constituent(s) that create(s) the decrease in friction. Subsequent machine testing has identified several of these papers from several different countries and manufacturers.

The fuser servo system depends on a certain amount of friction drag at the platen. Since the troublesome constituents in these papers could not be identified, the forces in the path beyond the fuser had to be carefully controlled. Originally, the scuff rolls in the machine were designed to slip on the paper and were driven at a speed sufficient to maintain a taut paper web. Since the coefficient of friction between these particular types of paper and the roll surface was low, scuff roll forces were not predictable. The roll was redesigned to include an internal slip clutch system with no slippage at the roll-to-paper interface.

Though the servo system was changed to control the paper position more accurately as it stopped at the fuser, paper still occasionally slipped during the unloading and loading of the backup roll, causing the loss of registration. A solenoid-activated paper clamp was added above the platen to prevent this slippage. Lastly, the fuser idler roll, shown in Fig. 6, was modified. During tests, this roll did not stop with the paper web. A calculation of the potential increase in web tension generated by this undesired slippage yielded approximately 13.3 newtons (3.0 pounds). The inertia was reduced by an order of magnitude and the bearing drag was reduced. The roll now stops with the paper and the paper stops reliably within the fuser for all known types of paper.

Other problems were found to be unique to particular types of paper and sometimes to particular paper mills. The printer was redesigned whenever possible to resolve problems associated with the normal commercial variation of paper parameters.

- *Paper path error detection*

Paper jams in a high speed paperline can be very serious because forms damage normally requires job rerun. An effort was made to detect malfunctions as early as possible and thereby avoid paper damage.

The paperline stops within 1.27 cm (0.50 in.) for two types of detected paper path errors: 1) an error indicating that paper will wrap around the fuser hot roll or 2) an error indicating that paper has burst between the transfer and fuser stations. Any data that have been exposed on the drum but not transferred to paper are lost and must be rerun.

Other sensors in the paperline detect such parameters as the presence of paper in the tractors, servo motor overloads in the transfer or fuser stations, a slack web between the fuser and stacker, or improper paper motion within the stacker. The microcode stops the paperline after all data are transferred from the drum. A detailed description of the printer control architecture is given by Findley et al. [5]. Vahtra and Wolter [6] describe the printing process.

Concluding remarks

A description of the development of a system for moving paper at 81 cm/s (32 in./s) has been presented. The description includes some of the design history, and, in some cases, justification for other hardware required for the satisfactory performance of the printer. It is interesting to contemplate the extension of electrophotographic printing technology to a higher performance machine. The paper problems associated with such a machine would be extremely challenging. Problems of paper acceleration and deceleration could become quite serious because acceleration forces would approach or surpass the tear strength of some papers. The magnitude of the acceleration and deceleration is dependent on the paper speed and the margin on the top and bottom of each page. Obviously, as paper speed increases and the margins remain fixed, acceleration forces increase. The demands on hardware also become more severe as inertia forces increase.

As paper speed increases, the motion of the web becomes less predictable and more difficult to control. This leads to paper jams, resulting in loss of data due to severely wrinkled and torn forms. Refolding paper at higher speeds would also become more difficult since air resistance would become more critical. There is undoubtedly a limit above which the paper must be positively refolded such that it cannot deviate from a strictly defined configuration.

Acknowledgments

The development effort described in this paper required the dedication of many people over several years. It is not possible to detail the accomplishments of each individual; therefore, I attempt only to identify those individuals who conceived the unique aspects of the paper path or played a key role in the production design.

The production design of the tractors in the transfer station resulted from work by K. Staudenmeir, C. McVicker and R. Lightbody. McVicker also assisted the author in writing this paper. R. Crawford designed the steering system mechanism in the fuser station and was also involved in the initial design of various areas such as the transfer station and fuser scuff roll system. The production design of the continuous forms stacker is the innovation of W. Bartz, S. Baio, and D. Olsen; W. Seaward provided the managerial direction required to develop the hardware and solve the problems in the paperline, continuous-forms stacker and the fuser station, respectively.

References and note

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