

Design of the Fusing System for an Electrophotographic Laser Printer

Abstract: This paper discusses the development and design of the fusing system used in the IBM 3800 Printing Subsystem. The design solutions provide satisfactory fusing of powdered toner print images to paper at a processing rate of 81 cm/s under a variety of operating conditions.

Introduction

The satisfactory fusing of electrostatically attached thermoplastic toner characters to the rapidly moving paper of the IBM 3800 Printing Subsystem was the primary task of the fuser development group. Early program requirements dictated that the fusing system must eventually be capable of providing fusing of consistent and reliable quality, and that it must meet the following additional requirements:

- Operate at a fusing process speed of 81 cm/s (32 in./s).
- Handle most of the continuous paper forms sizes, weights, and types found in industry.
- Operate under a range of environmental, temperature, and humidity conditions.
- Accommodate rapid start and stop movements of the paperline.
- Accommodate large variations in print density, e.g., the amount of toner per character.
- Provide maintenance-free operation for relatively long service intervals.

An enormous amount of design analysis was involved in the development of a fusing system that met the above requirements. This paper presents a description of unique engineering problems encountered during the state-of-the-art development, and describes the criteria and rationale employed in pursuing particular design approaches.

Selection of a fusing system

In the electrophotographic printing process as described by Vahtra and Wolter [1], print images are formed by depositing powdered thermoplastic toner onto selected

areas of paper. These toner particle images, which are held together and attached to the paper by residual electrostatic forces, are passed through a fusing system that permanently solidifies the images and causes them to adhere to the paper.

Early program researchers considered the merits and disadvantages of alternative fusing systems. Further details of the following and other fusing systems are discussed by Schaffert [2].

1. Vapor fusing by softening and flowing of images, using freon and other solvents, was categorically rejected because of solvent flammability, toxicity problems, and replenishment requirements.
2. Mechanical compaction fusing using high pressure rollers was dismissed because of paper calendering (fiber crushing and weakening), paper handling difficulties, and fusing of inferior quality.
3. Thermal convection and radiation fusing using ovens was rejected because of slowness of fusing and large requirements for power and space.
4. Thermal radiation fusing using detached infrared sources was pursued but abandoned because of potential fire hazards during paper jams, and because of the difficulty of fusing small isolated particles of background toner.
5. Thermal conduction fusing, from a heated platen through the paper thickness to the toner images, was found to be inefficient because the process consumes much power and produces excessively hot paper.

Copyright 1978 by International Business Machines Corporation. Copying is permitted without payment of royalty provided that (1) each reproduction is done without alteration and (2) the *Journal* reference and IBM copyright notice are included on the first page. The title and abstract may be used without further permission in computer-based and other information-service systems. Permission to *republish* other excerpts should be obtained from the Editor.

6. Thermomechanical fusing via direct transfer of thermal energy from a hot roll backed by a deformable pressure roll was found to be the most promising design approach.

Hot roll fuser

Subsequent research efforts were directed toward developing a hot roll fusing system using dry release. The hot roll approach was chosen primarily because the direct transfer of fusing energy was most suitable for efficient high speed fusing with relatively low power consumption. The dry release method was chosen over conventional wet release systems to avoid the complexities and prohibitive costs of a reservoir and mechanism for continuous application of an offset-preventing film to the hot roll surface.

The fusing mechanism in the dry release hot roll system shown in Fig. 1 is described as follows: The unfused print is passed between an internally heated hot roll with a thin rubber coating and a deformable backup roll. As the copy enters the nip, or fusing zone, the resilient coating of the hot roll provides direct conforming contact and capacitively discharges the surface thermal energy into the thermoplastic toner characters and paper. The rubber coating of the backup roll produces a zone of contact or footprint, under the force of engagement, of sufficient width to provide enough time and pressure to allow the now-viscous toner particles to flow together, down into and around the paper fibers. When leaving the nip, the characters cool and solidify with the base, becoming fused in the paper fiber matrix.

The hot roll design consists of an aluminum cylinder 4.78 mm (0.188 in.) thick, with an outside diameter of 10.16 cm (4.00 in.), heated with long infrared tungsten filament quartz lamps located near the center. This method of radiation heat transfer from a stationary source to the rotating roll was chosen to avoid the complex electrical contact apparatus required for heating elements directly attached to the hot roll.

• Hot roll coating

A dry release hot roll coating was developed for satisfactory fusing at a processing speed of 81 cm/s. Although toner eventually melts at 96°C, a much higher hot roll temperature of 218°C with 35 psi average pressure was required for rapid and thorough heat transfer and fusing to take place during the 11-ms passage through the nip zone. The material found most capable of withstanding continuous high temperature operation while sustaining dry release was a special formulation of silicone rubbers. The coating was applied to the hot roll and vulcanized by special processes developed by the IBM San Jose engineering and research groups.

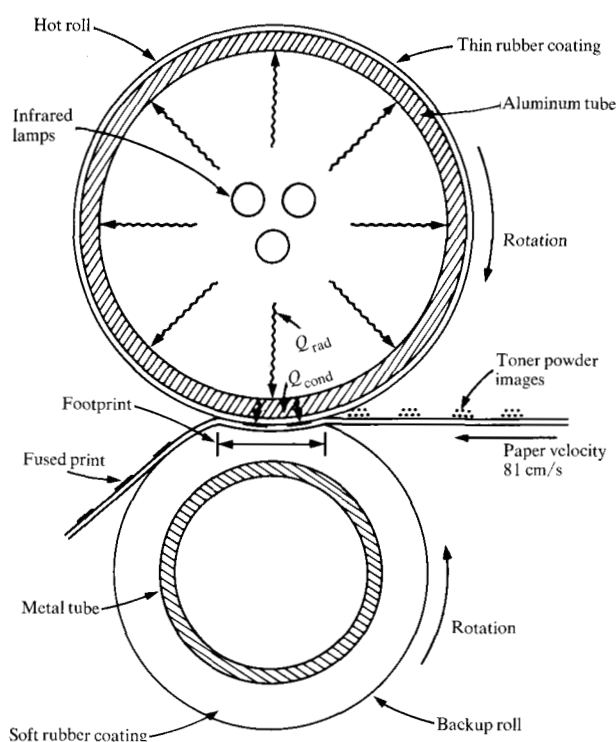
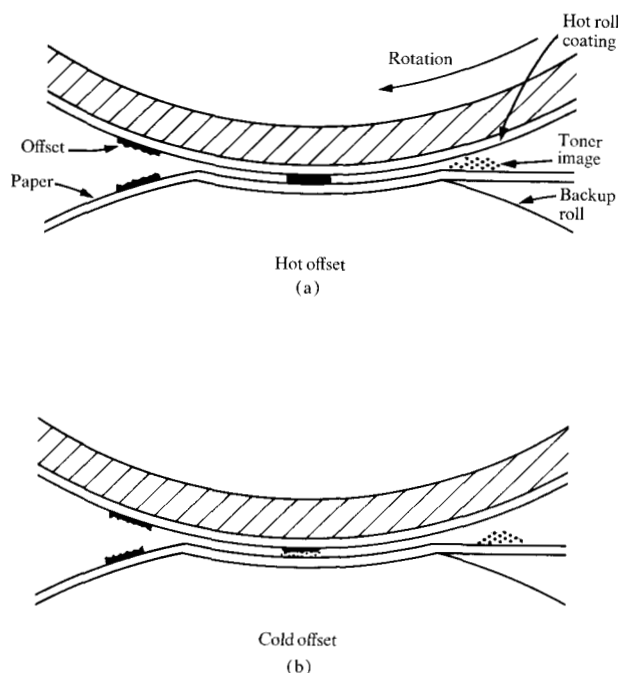


Figure 1 Basic design of the dry release hot roll fuser.

Figure 2 Offset of toner material on the hot roll coating. (a) "Hot offset" occurring when adherence to the hot roll exceeds cohesion of molten toner on the paper. (b) "Cold offset" occurring at lower temperatures because of poorly fused copy.



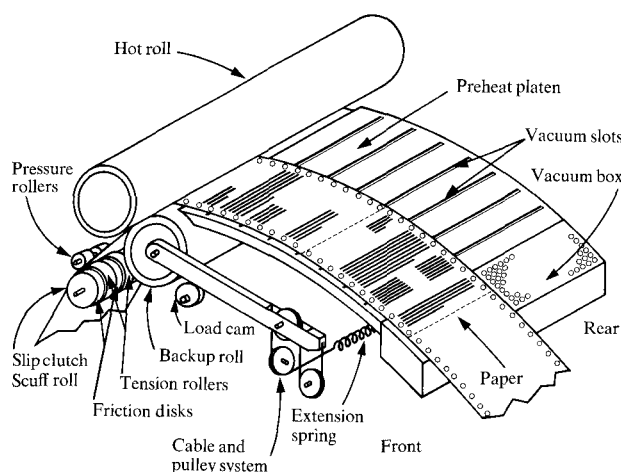


Figure 3 Configuration of the multiwidth paper fusing design.

A major problem with the silicone rubber coating was its short usable life before the start of offset, necessitating costly frequent replacements. The high temperatures, coupled with the deteriorative effects of the environment, caused rapid heat-age hardening of the coating and loss of surface dry release capabilities, resulting in hot offset. The hot offset occurs when the hot roll surface tack exceeds the cohesive binder strength of the molten toner character, resulting in partial separation and adherence of the toner to the hot roll coating as it leaves the nip, as shown in Fig. 2(a). After successive revolutions, the offset toner is redeposited onto subsequent pages where it causes unacceptable ghost characters.

A reduction in operating temperature results in poorly fused copy or, in some cases, cold offset. The cold offset occurs when insufficient heat penetration to the base of the images results in separation at the weak semi-powder zone, causing the images to adhere to the hot roll surface, as indicated in Fig. 2(b).

• *Preheat platen*

The problem of short hot roll life was alleviated by the incorporation of a preheat platen, located immediately ahead of the hot roll nip. The design consisted of a 2.29-mm perforated aluminum plate with electrical resistance heater elements bonded to the underside between thin layers of rubber insulation. A box was attached underneath, and a vacuum was applied through the holes to provide physical contact for adequate heat transfer through the paper and into the toner characters. Consequently, the preheated characters required less thermal energy from the hot roll for viscoelastic coalescence and complete fusing. This ultimately allowed a reduction in hot roll operating temperature from 218°C to 179°C. This provided a substantial improvement in the length of time

a hot roll can operate without offset. The preheat platen also significantly enhanced the overall quality of fusing. This improvement is important in helping to overcome adverse combinations of paper, toner, machine, and environmental conditions.

Multiwidth paper printer

The early printers were intended primarily for demonstrating and developing printing capabilities, and were designed for processing only paper 37.8 cm wide. The departure from a single-width model to development of a printer capable of processing many discrete paper widths between 16.5 and 37.8 cm required major hardware and thermodynamic design changes to the fuser system.

• *Zone heated platen*

The early preheat platen design was not suitable for processing multiple paper widths, primarily because of excessive temperature gradients in the thin platen regions not exposed to the heat-extracting paper. The design was changed to a curved solid aluminum plate 1.59 cm thick, with discrete heater zones. Figure 3 shows how the paper passes through a vacuum section before passing by the preheat platen regions.

The early heater design concept had proven feasibility and was modified to increase power capacity and to eventually provide seven independent heater zones. The number of adjacent zones heated is based on the best thermodynamic match with the paper width being processed.

The five heater zones initially used were found to be insufficient to provide uniform preheating of all nine paper widths. For processing 15-lb paper 30.48 cm wide, a heating zone overlap of 4.19 cm beyond the rear edge of the paper (Fig. 3) resulted in a temperature of 118.9°C at that edge, as shown in Fig. 4. A similar situation existed with paper 24.13 cm wide, in which a 3.89-cm overlap resulted in a temperature of 119.4°C at the rear edge. These upper extremes of the temperature range shown in Fig. 4 caused excessive toner preheating and increased the risk of local offset regions on the hot roll. This problem was resolved by creating two more independent heater zones at the overlap regions, so that unnecessary heat input adjacent to the edges of these paper widths could be eliminated. The result is a maximum paper temperature of 112°C for all paper widths.

The continuous network of welded nichrome heater ribbons was replaced with an etched grid pattern of stainless steel heater sections. The reduced film thickness of iron-oxide-filled silicone rubber insulation, separating the heater elements at 208 V from the grounded platen, was the key to the increase in power capacity. The relatively low temperature gradient across the insulation film allowed power densities significantly higher than those that were commercially available.

The plate thickness was increased from 0.229 to 1.588 cm for greater thermal "inertia," to minimize temperature control fluctuations, and for better transverse thermal conduction. The thicker plate minimized temperature gradients in the rear platen region where the paper edge does not necessarily coincide with the heated zone boundary. To eliminate the problem of moist paper dust clogging, the vacuum ports were moved from among the heater elements to a 10.16-cm-long vacuum section immediately preceding the platen (see Fig. 3). A motor-driven shutter system confines the vacuum to the section that coincides with the width of paper being processed. The concept was to provide sufficient paper tension between the vacuum drag section and the hot roll nip to produce good paper contact over the curved preheat platen surface.

A large temperature differential between the paper and platen surface led to the discovery of a dynamic air foil cushion between the paper and platen, which inhibited heat transfer. This air gap was caused by the steam vapor pressure resulting from the liberation of paper moisture by heat, and also by a dynamic air foil bearing effect. The steam barrier thickness was found to be related to paper stiffness, moisture content, paper tension, and paper and platen temperatures. The problem was resolved by the inclusion of 15 vacuum slots traversing the curved platen surface to reduce the effective air gap to less than 0.025 mm. This allowed a reduction in platen operating temperature to 104°C while maintaining a nominal 104°C paper bulk temperature at the point where the paper leaves the preheat zone. The reduced platen temperature also eliminated the problem of first-page hot offset onto the hot roll caused by excessive preheating and melting of toner images onto sheets that were momentarily stopped over the platen.

The vacuum slots were also instrumental in minimizing the paper bubble problem. During paperline stops at intervals longer than one second, the page over the preheat platen lost sufficient moisture to produce shrinkage. This caused raised corrugated ripples to appear between the heated page and the next sheet upstream. Subsequent processing of this upstream sheet yielded poor fusing in previously raised areas that had insufficient time to contact the preheat platen. This problem was diminished with a microprogramming modification that provided an additional 390-ms pause, to allow the wrinkled page to be pulled down by the vacuum slots against the preheat platen for uniform heating.

● Multiwidth hot roll

The design of a hot roll for single-width paper revealed several problems of thermal control that had to be avoided in the subsequent development of a hot roll for variable paper widths.

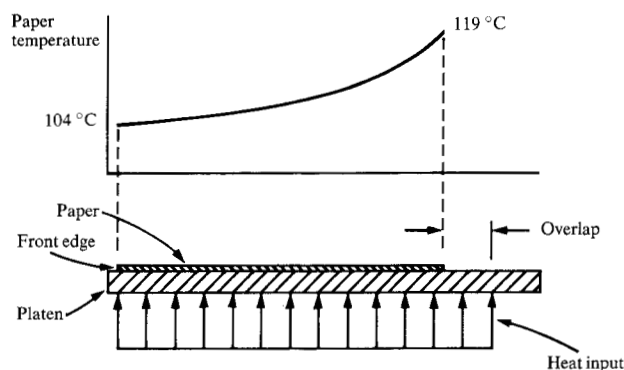


Figure 4 Lateral temperature gradient of paper as it leaves the platen.

In the redesign, an expensive gold-plated copper lamp support module for facilitating lamp replacements was eliminated along with the associated air cooling apparatus. The variable reflectivity and temperature depressions associated with the bare aluminum hot roll interior were also eliminated. After steady state running of 24-lb paper 37.8 cm wide, the center of the hot roll developed a nominal 17°C depression below the 179°C control temperature. This depression gradient varied considerably, apparently depending upon the hot roll interior surface machining and oxidation characteristics. The roll interior was coated with a high temperature black paint that exhibited a fairly uniform absorptivity of 95 percent over the entire wavelength spectrum of the infrared lamps.

Although the new coating did eliminate the depression of steady state temperature at the center of the roll, it also adversely affected the temperature distribution at the end of warmup. The infrared lamps emit a parabolic energy flux distribution with 25 percent greater power density at the center. With the virtual elimination of hot roll heat distribution via internal radiation reflections from the previously reflective walls, more thermal energy was directly absorbed at the center. This factor, coupled with heat conduction losses from the hot roll ends through adjacent hardware, resulted in hot roll center temperature excursions over 221°C at the end of warmup periods. Subsequent processing of print was susceptible to hot offset at the hot center. This problem was diminished by replacing the polished reflectors at both ends with heat absorbers, shown in Fig. 5(a). The exposed surfaces were painted black to provide auxiliary heat conduction into the roll ends, which reduced center gradients during steady state operation. The temperature overshoot in the center, at the end of warmup, was reduced by as much as 17°C.

Initial attempts were made to shift the bulk of the fusing task to the preheat platen and relegate the hot roll to an "adiabatic" pressure roll for compacting the toner images and completing any residual fusing. The near absence of

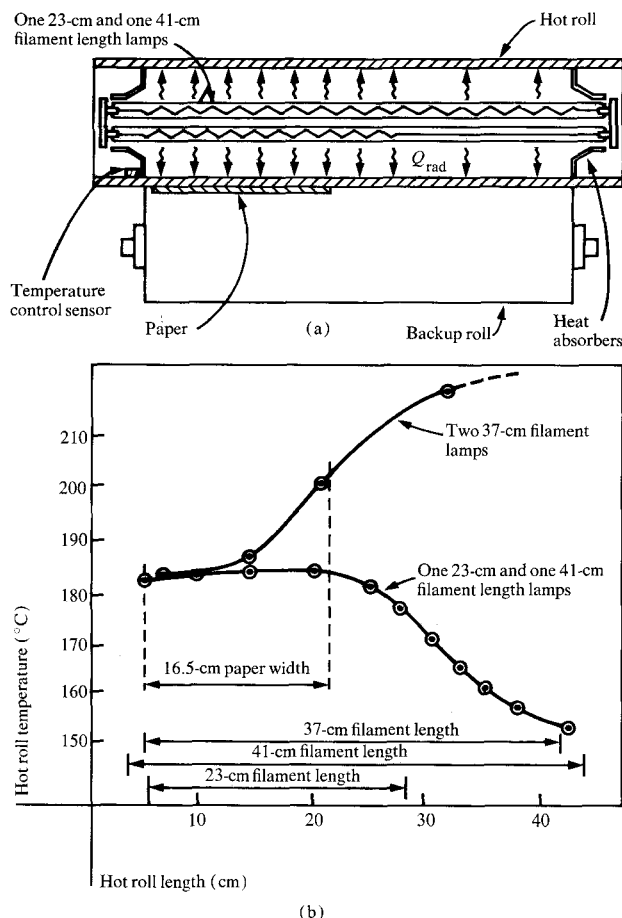


Figure 5 Heat distribution in the hot roll. (a) Design features of the interior of the hot roll to provide improved thermal distribution. (b) Temperature profiles before and after the redesign of the roll.

heat exchange between the hot roll and narrow-width paper would eliminate the need for hot roll zone heating and would thus avoid the added complexities and expenses of hardware and controls. Additionally, the lowering of hot roll operating temperature by 28°C to 33°C was certain to result in further improvements in coating longevity.

The platen operating at its maximum temperature was found to provide insufficient fusing energy for all required conditions. Incremental increases in hot roll operating temperatures to augment fusing proved unsatisfactory. The rate of local heat removal from the hot roll by the narrow-width paper was greater than the combined rates of thermal radiation and conduction from the adjacent region, where paper is not processed. The resulting hot roll temperature gradient, increasing with distance from the paper, increased the tendency for hot offset to occur toward the region at the rear edge of the paper [see Fig. 5(b), top curve]. Additionally, the higher running temperature toward the rear would accelerate thermal degradation of the elastomer coating and thus shorten any gain in life expectancy.

• Zone heated hot roll

To eliminate the problem of temperature gradients with narrow-width papers, the approach was taken to design thermodynamically a hot roll containing lamps, with shorter discrete filament lengths, to concentrate heat input only into the hot roll region exposed to paper, as indicated in Fig. 5(a). The 4.8-mm tube thickness was retained, since it was sufficiently thick to dissipate thermal gradients by longitudinal conduction, without being so massive as to require excessively long warmup periods, or to cause rotational inertia overloads on the servo motor.

Computer simulations of the hot roll thermodynamics indicated that five zone heating combinations, using lamps with filament lengths of 22.86, 27.94, and 40.64 cm, should provide satisfactory steady state hot roll temperature distributions for all required paper widths. Tests using a hot roll imbedded with thermocouples verified that steady state temperature gradients across the image processing width, for all paper widths, were contained to within $\pm 4^\circ\text{C}$ of the control temperature. Figure 5(b) illustrates the hot roll temperature profile when processing worst-case 15-lb paper 16.51 cm wide, both before and after the hot roll redesign.

• Fusing system power consumption

The integrated hot roll and preheat platen fusing system expends variable amounts of energy, depending on several factors. The most influential of these include the thickness, size and moisture content of the paper being processed; the kind of processing (intermittent or continuous); and the surrounding environmental temperature and humidity conditions.

When the machine is operated at nominal environmental conditions while processing 20-lb paper 37.8 cm wide, the fusing system expends approximately 4450 W total power at steady state. The platen, maintained at 104°C, typically accounts for 3300 W, of which 2800 W are consumed in heating the paper from ambient to a bulk temperature of 104°C. The remaining 500 W (15 percent) are attributable to steady state losses through adjacent hardware and to the environment. The hot roll, controlled at 180°C, consumes the other 1150 W. Of this, 680 W are dissipated as additional heat transfer to the paper. The remaining 470 W are lost as heat to the environment and through adjacent hardware.

• Backup roll

Although previous discussions have focused attention on the hot roll and preheat platen development, the backup roll is of no less importance to fusing. The primary function of the backup roll is to provide and maintain a balanced load and stable footprint width throughout the duration of the projected service period. This demands a roll

coating material that is soft enough at reasonable thicknesses to provide a sufficiently wide footprint at moderate loads. The material must also possess good dimensional and hardness stability at elevated service temperatures, and exhibit good release properties to prevent stray toner accumulation. The only material found adequate to fulfill these requirements was compression-molded silicone rubber. Most other elastomers intended for moderate service temperatures underwent excessive heat-age hardening and deterioration.

Unfortunately, silicone rubbers, especially those with Shore A hardnesses under 40, inherently possess inferior abrasion resistance to paper. Rolls were prone to undergo substantial wear and tapering toward the roll end, as shown in Fig. 6. The resulting locally diminished load and footprint at the worn paper edge ends caused paper edge wrinkling and creasing and sometimes reductions in fuse quality, necessitating replacement well before the intended service interval.

During the transition to multiwidth design, the decision was made to increase the outer diameter from 5.08 to 10.16 cm. The purpose was to double the wear surface area, and to reduce the amount of rubber engagement displacement required to produce the same footprint. A material coating investigation led to a change to a silicone rubber formulation with improved abrasion resistance. These modifications resulted in an extension in life expectancy sufficient to meet the intended service interval requirements.

• Scuff roll system

Early development machines were hampered by the problem of induced offset which, when severe, could develop into a fuser wrap. This occurred when the semimolten print momentarily remained stuck to the hot roll coating as it emerged from the nip. When the downstream paper tension was insufficient to overcome the print adhesive forces, the copy would adhere to and wrap around the hot roll.

This problem was resolved with the advent of friction rollers or scuff rolls (see Fig. 7). The apparatus is designed to provide continual tension on the paper web leaving the hot roll nip, by driving the lower scuff roller at a nominal tangential velocity 12 percent greater than the paperline velocity. The resulting frictional pulling force of approximately 4.0 lb, coupled with a factor-of-three increase in peel angle, has virtually eliminated the problem, except for some types of paper.

Several types of European-made paper were found to develop only 1.0 lb of tension, which was insufficient to prevent fuser wraps. This problem was solved by the design of a friction clutch scuff roll system, illustrated in Fig. 7. With this design, the scuffing takes place, not against the paper, but between alternating spring-loaded,

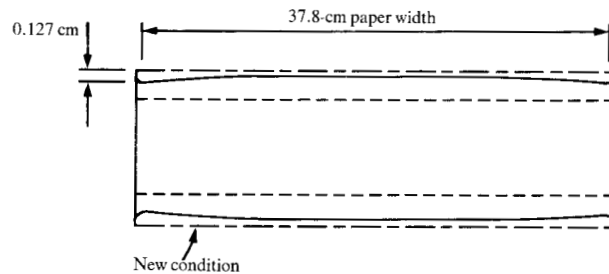


Figure 6 Typical wear profile of backup roll.

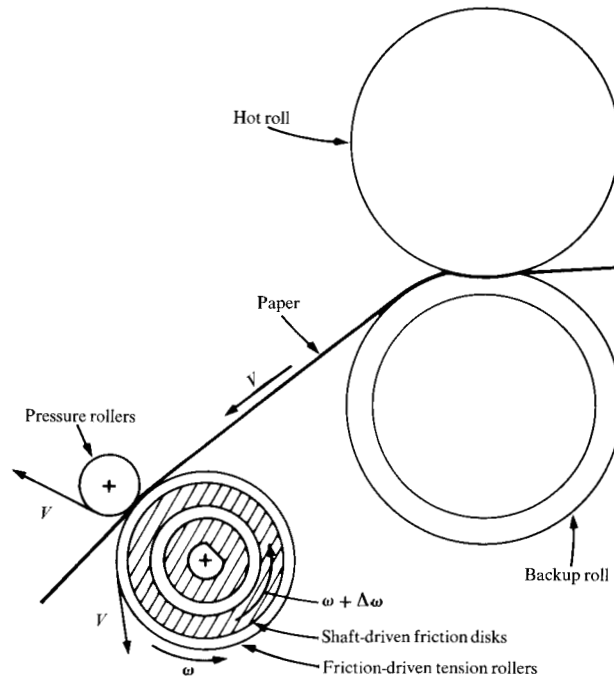


Figure 7 Use of scuff rolls in a slip clutch to provide tension on the paper web.

shaft-driven friction disks and scuffing tension rollers. The relative static contact between the paper and the higher-coefficient-of-friction tension rollers eliminated dependency upon paper friction, and provided constant tension. Additionally, the individual independent pressure rollers ensured uniform tension across the entire paper web, thus eliminating the problem of scuffing tension concentrations near one paper edge. The result is a uniform 3.5-lb tension for all paper types.

• Backup roll loading and steering system

The symmetric backup roll loading system that is integrated into the paper steering system is somewhat novel and bears mentioning. Uniform engagement of the backup roll into the hot roll is accomplished with the 180° rota-

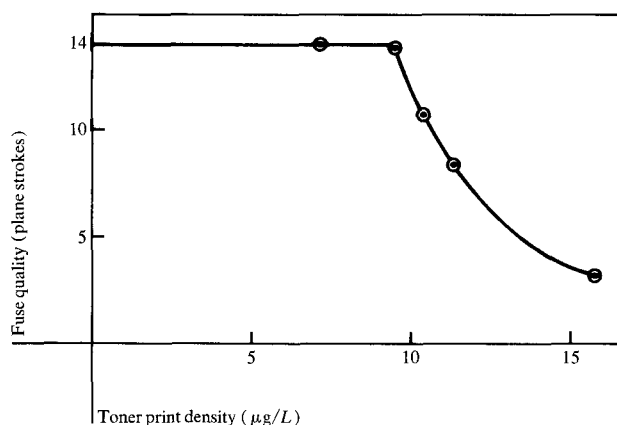


Figure 8 Relation of print density to fuse quality.

tion of two eccentric cams, which lifts the platen into position while raising the pivot points for the two backup load arms (Fig. 3). As the pivot points ascend, the short portion of the arms (containing the backup roll) rises so that the backup roll engages the hot roll, causing the long ends each to stretch an extension spring through a cable pulley system. The leverage geometry results in an eleven-to-one mechanical advantage, producing the required 240-lb total load with approximately 11-lb tension in each spring.

The steering system consists of a paper position servo control attached to the hub of the backup roll loading cables. Each extension spring is attached to a cable that wraps around and is anchored to a common steering motor pulley. When the paper strays beyond the tracking path limits, the system commands the steering pulley to rotate. This causes the spring extension equilibrium and backup roll loading to become imbalanced, producing a gradient in the soft backup roll footprint width across the entire length. This gradient causes a slight paper velocity differential across the paper width, resulting in lateral movement of the paper web back to the nominal tracking zone. Further details of the servo system are discussed by Svendsen [3], and by Cameron and Dost [4].

Fuse quality

The ultimate measure of fuser system performance takes the form of print fuse quality evaluation. Toner comprises particles containing polystyrene, an amorphous thermoplastic polymer that viscously flows together and into the paper when heated. The integrity of the fused toner images upon cooling must meet certain quality standards of durability and resistance to flaking or smearing. Standards are arbitrarily established, depending upon the type of test employed, and relative to what is deemed acceptable for customer satisfaction.

Porous filter paper was used in early tests to measure the surface smear resistance or Average Fuse Merit, but this was abandoned because of its inadequacy in measuring adherence at the toner/paper interface. Subsequent tests using a "calibrated fingernail" and relying on experienced judgment were too subjective and imprecise. Current methods use a plane tool with a lightly loaded blade to scrape and chip at the images. The number of successive shear strokes required to significantly degrade one of a group of characters is the measure of fuse quality. After 14 strokes, evaluation of fuse quality is terminated; this represents fusing of excellent quality. The relation to print density is shown in Fig. 8.

Fuse quality is primarily dependent on fuser operation settings such as hot roll and preheat platen temperatures, nip pressure and footprint width, as defined by backup roll characteristics, and loading force and platen vacuum. The balance among the controllable operating conditions is largely dictated by requirements for fusing under the most adverse combination of conditions. These conditions include paper weight or thickness and moisture content, toner image thickness or print density, toner melt properties, and ambient conditions.

A limitation on the allowable paper weight to 24 lb (0.117 mm thick) became necessary when the problems associated with increasing the fusing power required for heavier paper became apparent. A hotter platen would produce excessive toner preheating for the 15-lb paper 0.079 mm thick, and would increase the exposures to hot offset. A hotter hot roll would experience reduced elastomer coating life, and would have larger temperature gradients. Although dry paper produces slightly better fusing, there are no restrictions imposed on the allowable paper moisture content, which normally ranges between five and seven percent.

The print density is measured as the average weight of unfused toner per standardized "L" character in micrograms per L. When 24-lb paper is processed, print density increases beyond 9 μg/L, causing rapid decreases in fuse quality, as shown in Fig. 8. This necessitated the establishment of machine-controlled limitations on the allowable dark print setting to produce 10 μg/L for satisfactory fusing under all conditions.

• Temperature control system

The improved resolution provided by the more objective fusing measurement techniques revealed that fuse quality was sensitive to variations in the hot roll and platen control temperatures. Consequently, major modifications were made to the platen and hot roll control systems to improve accuracy and reliability. The platen sensing elements are imbedded internally. The hot roll sensors are imbedded in a graphite block slider of high conductivity, with the base contoured to the inside diameter of the roll.

The internal location was chosen to avoid the exposure of external mounts to surface contamination and mechanical damage, and to allow temperature sensing underneath the paper edge. This is shown in Fig. 5(a).

Temperature control accuracy was improved by replacing the thermocouple sensors (in which low signal output was inhibited by rf noise distortions) with higher-output precision thermistors. Previous control systems cycled the lamp power on and off between upper and lower temperature limits, producing sawtooth temperature responses. These were replaced with proportional controller systems having a rapid response. Continuous power is delivered to the heating elements until the desired thermistor voltage and control temperature are reached. Subsequently, heater power is pulsed through triac switching elements, in proportion to minute fluctuations in thermistor voltage, to produce a uniform control temperature. Other features incorporated into the new control systems include temperature error detection for each hot roll and platen heating element, symmetric and uniform power warmups to minimize cold sink gradients, and detection of hot roll slider nonsurface contact by means of open circuit sensing.

Concluding remarks

This paper is intended to provide an understanding and appreciation of the problems and obstacles encountered during the development of the fuser used in the IBM 3800 Printing Subsystem. Fuser functional problems have been resolved. The primary remaining development activities are in areas of further extending component life and reducing the associated hardware and replacement costs.

Throughout the course of the development program, gradual but substantial improvements have been made in reducing the wear of sensitive components to meet minimum acceptable life objectives. The hot roll and backup roll silicone rubber coatings are continually subjected to wear by abrasive paper at elevated temperatures, and undergo surface erosions and deterioration at much faster rates than other paperline components. These two rolls will continue to receive ongoing research and testing of alternate materials, designs, and processes in efforts to further extend longevity and reduce costs, while maintaining quality and reliability.

Acknowledgments

Many individuals have made significant contributions in the development of the fuser system over a period of several years. Only the principal contributors to the basic

conceptual engineering design of the fuser are mentioned here. These were instrumental in solving the most fundamental functional problems mentioned in this article. T. Mahurin is the engineer most responsible for the conceptual design and development of the integrated fusing system from the early prototype robots to the final production design. His principal contributions are the design and evaluation of the hot roll and preheat platen. H. Vermij is a universal technician model maker who worked primarily with Mahurin. His mechanical skills, aptitude and intuitive insight proved invaluable in resolving many engineering design problems throughout the course of the fuser development. R. Crawford designed the backup roll loading and paper steering system mechanisms and pioneered the initial scuff roll system designs. J. Cameron was responsible for designing and refining the servo controls for the hot roll drive and paper steering systems. A. Kluth was primarily responsible for the fuser subassembly hardware redesign to incorporate variable paper width processing capabilities. His modified scuff roll assembly design and cost reduction efforts contributed significantly to the final production design. R. Voge designed the proportional temperature controller systems, instituted error detection safeguards, and improved overall temperature control reliability. W. Seaward provided the managerial coordination and prioritizing of efforts that led to the timely resolution of many difficult and persistent problems.

References

1. U. Vahtra and R. F. Wolter, *IBM J. Res. Develop.* **22**, 34 (1978, this issue).
2. R. M. Schaffert, *Electrophotography*, Third Edition, John Wiley & Sons, New York, 1975.
3. R. G. Svendsen, *IBM J. Res. Develop.* **22**, 13 (1978, this issue).
4. T. J. Cameron and M. H. Dost, *IBM J. Res. Develop.* **22**, 19 (1978, this issue).

Received May 24, 1977

The author is located at the IBM General Products Division laboratory, 5600 Cottle Road, San Jose, California 95193.