Development of the HP DeskJet 1200C Print Cartridge Platform

The platform includes all of the parts of the print cartridge except the printhead assembly and the ink. It is designed to accept different printheads and inks to support different printer applications. It features a slim form factor, a spring-bag ink reservoir, and an ink level indicator.

by the Platform Development Team*

The print cartridges for the HP DeskJet 1200C printer and the HP DeskJet 650C large-format drafting plotter (Fig. 1) are derived from a common ink delivery system "platform" to which are added different TAB (tape automated bonding) and printhead assemblies and inks. The platform includes all parts of the print cartridge and packaging except the TAB/printhead assembly and the ink, and brings the following key benefits to printers and customers:

- Flexibility for a wide range of printheads, printing down or sideways
- Slim form factor to reduce the footprint and cost of multi-cartridge printers
- Volumetrically efficient "spring bag" ink delivery with tunable backpressure and ink design independence
- User-friendly ink level indicator usable in and out of the printer
- Ink containment robustness under environmental conditions (thermal, altitude, shipping), combined with environmentally sensitive packaging
- Assembly process improvements such as two times better head alignment and online print quality inspection.

The primary emphasis during development of the platform was design for manufacturability and assembly. This emphasis was key to achieving at least three of the four platform goals. The first goal, to achieve both large capacity and fast time to market, was achieved through simultaneous design, process development, and tooling from the beginning of the project, by early concurrent engineering with vendors, and by the use of "demo tools" for early demonstration of assembly processes and cycle times. The second goal, low cost, was achieved by reducing complexity in parts, processes, controls, and non-value-added steps, by leveraging proven HP assembly processes and designs, and by focusing on manufacturing cost drivers such as tolerances and direct material cost. The third goal, to ensure manufacturability for automated assembly, was achieved by means of "seam teams" made up of R&D and manufacturing engineers and charged with maximizing design for manufacturability and assembly, by organizing the manufacturing line module teams at the start of the project, and by including vendor engineers on the platform design team early in the project. The fourth goal, to meet the needs of multiple cartridges and

* See "Acknowledgments," page 54.

Fig. 1. Print cartridges for the HP DeskJet 1200C printer and DesignJet 650C plotter.

products, was achieved through a design convergence team for multiple printers sharing the platform, and seam teams for cartridge and printer issues.

Seamless and Concurrent Engineering

The design for manufacturability and assembly emphasis was implemented in several ways. The platform engineering team was formed nearly fully staffed, with strong manufacturing influence from the start. The overall team included both R&D and manufacturing engineers and managers. Engineering responsibilities were seamless, with no distinction between R&D and manufacturing engineers. Individual engineers owned broad part design, assembly process development, and tooling responsibilities throughout the project. In this way, design for manufacturability and assembly comes naturally since each engineer designing a part is also developing the assembly processes for that part, and will be responsible for the manufacturing machines to assemble that part.

A second way that the design for manufacturability and assembly emphasis was implemented was through the active concurrent engineering involvement of experienced manufacturing equipment vendors. The vendors' highly experienced engineers were an integral part of the platform design team early. Each month, the vendors' engineers participated in intensive working design review meetings. Between meetings, HP and vendor participants designed and investigated alternatives in preparation for the next joint working session.

Convergence of Platform Design Concepts

The key purpose of designing a platform print cartridge was to enable one common design to satisfy multiple customers in both the office printer and large-format markets. The requirements were to design a low-cost platform in terms of parts and assembly, yet allow for various TAB/printhead assemblies and inks for different products. A narrow form factor in the scanning direction was essential to allow multi-cartridge products a compact desktop footprint. Compatibility with the range of ink types needed for different product applications was also required, preferably decoupled from ink interactions altogether. To accommodate the different ink and architecture needs of different products and applications, the platform's ink delivery starting backpressure needed to be adjustable, both in engineering and on the manufacturing line. Moreover, the overall platform had to be robust and reliable for all products and all customers.

Immediately at the start of platform development a process was needed to set the fundamental design direction quickly for fast time to market, to resolve issues and select among competing concepts, and to ensure that the platform would meet the needs of multiple office printers and large-format plotters. The fundamental platform design direction needed to be set concurrently and interactively. The process used was the convergence team. Functioning within weeks after the project's start, the platform convergence team included representatives from each of the print cartridges and each of the printers. The team met weekly until the key design concepts that strongly affected both print cartridge and printer design were resolved. The key design areas addressed by the platform convergence team included:

- Dot-to-dot alignment requirements, modeling, and effects on print cartridge head and body alignment and printer carriage alignment
- Different print-cartridge-to-carriage alignment datum systems, and their effects on cartridges and printers
- Print cartridge operating orientation in different printers and plotters
- Disposable print cartridge ink volume trade-offs for cost per copy, printer size, and carriage acceleration
- Minimum print cartridge width (printer footprint) consistent with other needs
- Print cartridge form factor aspect ratio (depth-to-height ratio) and related form factor of printers and plotters
- Electrical interconnect configuration and compliance concept
- Ink level indicator needs for each printer and resultant design objectives.

Convergence of the platform design concepts allowed definition of a focused set of design goals to meet the overall platform goals of large production capacity, fast time to market, low cost, manufacturability, robust quality and multiple uses:

- Minimum number of parts and processes
- Narrow form factor for office desktop printing
- Precision alignment to meet print quality goals
- Reliable system electrical interconnect solution
- Inert ink reservoir with tunable backpressure
- Maximum delivered ink volume within narrow form
- Robust leak-free ink containment through shipping and drops
- Ink level indicator for users
- Environmentally friendly minimum packaging
- Print quality tested to specifications
- Quality assurance processes designed along with the print cartridge.

Narrow Form Factor

To meet the objective of a small-footprint desktop printer, the print cartridge size needed to be minimized, especially the width. Narrow width had to be traded off against minimum size for the desired ink volume and printhead layout. From the product objectives, two distinct sets of design features were developed. These sets led to the development of a two-material frame that includes a back-end design to accommodate the ink reservoir assembly and a front-end design to accommodate the printhead assembly (see Fig. 2).

The first set of design features focused on the external geometry of the print cartridge. While it was our goal to minimize print cartridge width, this minimum is constrained by the printhead design and its flexible electrical interconnect circuit. In addition to space for the printhead assembly, room is required for carriage locating features and print cartridge service station functions. Finally, manufacturing tolerances and tooling features must be included to ensure ease of assembly. Besides space constraints, the external frame needed to be rigid for stability in the print cartridge carriage, to withstand temperatures of up to 70°C, and for printhead attachment, to be manufacturable to very tight tolerances.

The requirements of the ink delivery system drove the second set of design features, which focused on the internal frame. The spring bag system required a heat-sealable material that was impervious to the ink and robust under environmental conditions, as discussed later. Tight tolerances and structural rigidity were less of an issue.

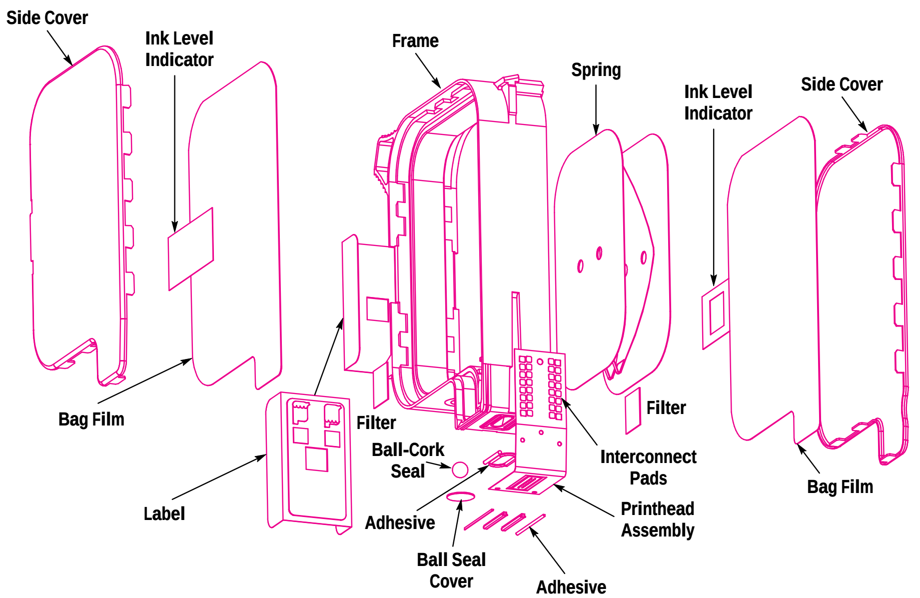

Fig. 2. Exploded view of the HP DeskJet 1200C printer print cartridge.

For both portions of the frame, manufacturability in high volume at low cost were driving objectives. Plastic injection molding is the technology of choice for print cartridge bodies because it meets the objectives of low cost and high volume and is capable of producing complex geometries in engineering materials. The desire to integrate two materials with two sets of design objectives presented an interesting challenge for the plastic injection molding process. Two-shot or "two-color" molding and insert molding have both been demonstrated as feasible.

The final design of the frame was driven not only by the two sets of design features for the external and internal frames, but also by the molding process. General plastic design rules regarding wall thickness and coring of thick sections were combined with the special tooling constraint of the insert and two-color molding processes to arrive at the final design.

The objective of building a thin print cartridge that delivers the most ink for a given overall volume meant that the walls of the reservoir had to be as thin as possible. The two side covers represent the majority of the surface area of the cartridge, which means that the amount of ink that can be contained within the structure is very sensitive to the thickness of the covers. Another key design objective is to keep ink off the customer. If the covers are too thin, a customer might force ink out of the printhead simply by squeezing it too hard during the normal handling expected for a routine cartridge replacement. This consideration led to the concept of "effective thickness," which is the sum of the actual material thickness plus the deflection of the covers under an applied squeezing load. To prevent ink from being forced out the printhead, the design rule stated that the inside surface of the covers could never touch the ink containment bag within the structure. When the covers were thin they could be squeezed more, which meant that more dead space had to be included between the covers and the bag to keep the deflected covers from touching the bag. Adding more thickness to the cover material made the covers stiffer, so the effective thickness was reduced and more ink could be held within the structure. The optimum cover thickness was the point where any additional increase in material thickness caused the effective thickness to increase also.

The amount that the covers deflect is primarily a function of the applied load and the material for a given wall thickness. After consulting reference material on ergonomics and performing some quick reality tests, it was determined that an average user would apply less than 10 pounds of force to the covers during normal handling. Covers of varying thickness were made from different thermoplastics and different metals were tested for deflection under the simulated maximum squeezing load. The side cover material that provided the lowest effective thickness and consequently the highest deliverable ink volume from the cartridge was determined to be steel. Prepainted, low-carbon steel was chosen because it meets the environmental requirements and is a standard material in the metal stamping industry.

Attaching the covers to the plastic cartridge frame in a manner that is consistent with high-volume, robust manufacturing objectives was always a concern during the cover development cycle. Adhesives and direct thermal or ultrasonic processes were considered depending on the particular side cover material being investigated. Making the cover from thin steel presented the opportunity to use a tab-in-slot system that requires only a simple mechanical press to attach the covers to the frame. The slot features in the plastic frame are designed to be molded easily and to help pull the frame toward the cover for a tight fit. The mating tabs spaced along the perimeter of the cover are wider than the mating slots so that plastic is displaced when the metal cover is pressed into the plastic frame. The resulting seam makes the system very rigid and is especially effective in resisting loads that tend to twist the cartridge. Tests have shown that the print cartridge structure is very stable at the extreme operating temperatures expected in the printer.

Printhead Assembly and Protection

Electrical contact between the printer and the thermal inkjet printhead is provided by a flexible conductive component called a TAB circuit, consisting of gold-plated copper traces on a plastic substrate. TAB is an acronym for tape automated bonding, the process used to attach the flexible circuit to the printhead, thus forming the TAB/printhead assembly. Low part cost was a major consideration in the

TAB circuit design. To achieve this, the circuit width was determined solely by the requirements of the trace layout instead of using a standard TAB width. The total circuit area, which is the most important factor in cost, was reduced by roughly 50% as a result.

The TAB circuit design also includes a system to protect the printhead from ESD (electrostatic discharge) damage during handling. The trace layout includes a ground ring surrounding the entire circuit with spark gaps going to each interconnect pad, providing a preferential path for ESD that does not go through the printhead.

The dimensions and locations of the TAB/printhead assembly interconnect pads were designed by a worst-case analysis of both print cartridge and printer part dimensions and the variances in the processes used to put them together. A Monte Carlo analysis was used because of the nonGaussian nature of certain processes and dimensions and because of distribution truncation resulting from inspection processes. Statistical models were created for each part and process based on the most conservative values of part inspection data, assembly process data, part tolerances, and assembly process specifications.

The optimization had to make trade-offs between print cartridge production yields, interconnect reliability, and proper print cartridge fit in the printer. A mechanical seam team composed of engineers and managers from both the print cartridge and the printer was used to balance the risks of all of the proposed changes suggested by the statistical analysis results. To help make these decisions, "What if?" scenarios were simulated for key tolerance variations.

TAB alignment inspection guarantees proper electrical contacts between the product interconnect and print cartridge interconnect pads. The solution is a vision system using a machine recognition algorithm known as blobal analysis to measure TAB position. The vision system binarizes the camera field of view based upon a set luminance threshold level. Once the reference target on the TAB is binarized as a blob, TAB position can be calculated with a precision on the order of micrometers.

The TAB circuit is bonded to the print cartridge frame on all four sides of the printhead by heatstaking. This process requires an intermediate film that adheres to both the print cartridge frame and the TAB circuit. The solution is an intermediate thermoplastic film that is laminated to the TAB circuit and heatstaked to the print cartridge frame. Alternatives such as adhesives and ultrasonic welding were ruled out as unwieldy or unreliable. By melting the thermoplastic during the heatstake operation, a mechanical bond is created between the print cartridge frame and the thermoplastic. The mechanical bond is a result of the thermoplastic flowing into the print cartridge frame's microscopic imperfections before solidifying. The heatstake operation involves a balance between time, temperature, and pressure such that the thermoplastic's integrity is not compromised on the one hand nor does poor bonding result on the other. The parameters were optimized by the design-of-experiments method to achieve the best peel force resistance.

Two adhesives are used in the print cartridge assembly. The first is a thermally cured epoxy that is dispensed on the plastic frame around the ink feed slot. The epoxy is used to attach the printhead to the frame and to provide a seal to keep the ink from leaking out of the ink reservoir and air from leaking in. The second adhesive is used to encapsulate the exposed TAB conductors that extend from the flexible circuit to the printhead. These beams are bonded to pads on the printhead to provide electrical connection from the TAB circuit. The dispensed adhesive flows around the conductors and provides a robust protective coating for the fragile TAB beams after it has been cured. The second adhesive is also dispensed along the edges of the TAB circuit to help adhere it to the cartridge frame.

Ink Containment and Pressure Control

The function of the ink delivery system is to contain the ink and deliver it to a thermal inkjet printhead at a predetermined pressure for the life of the print cartridge. The ink delivery system's major design objective was to be a platform to accommodate assorted printheads and thus permit the development of different print cartridges while keeping costs down. In previous-generation disposable print cartridges various methods of ink containment and pressure control were used, the main ones being the collapsible rubber diaphragm for the HP ThinkJet printer cartridges, in which ink is retained via the elastic nature of the bladder, and the porous foam material for HP DeskJet and PaintJet printer cartridges, in which capillary forces retain the ink. These print cartridges are adequate for their specific printer applications but did not qualify as the next-generation ink delivery system platform because of their larger size (especially in the printer scan axis), higher cost per page, ink compatibility limitations, and indirect backpressure control. Therefore, the print cartridge design group had to develop a completely different concept that would overcome the weaknesses and constraints of previous-generation cartridges while allowing the possibility of adding new features such as the ink level indicator. This new ink delivery system and platform is called the spring-bag design and is based on the principle that ink is contained in a flexible envelope formed of films and a mechanical spring is biased against these films, thus creating subatmospheric pressure within the system.

Spring-Bag Print Cartridge

Conceptually, the print cartridge is in a "tug of war" situation between the negative pressure generated by the spring of the ink delivery system and the capillary forces generated by the tiny nozzles of the printhead. The firing chamber acts as a micropump each time it ejects a droplet of ink and refills itself by capillary action. As droplets of ink are fired, the ink in the spring bag gets depleted and this process goes on during the life of the print cartridge to a point where the firing chambers cannot be refilled. The print cartridge is then replaced with a full one.

The major components of the spring-bag print cartridge are a molded plastic frame, two flexible plastic films, a spring assembly, two filters, two covers, and a ball-cork and patch (see Fig. 2).

The frame is molded using two different plastics. The outer shell is made of a stiff plastic because it is the skeleton of the design to which other parts will be attached, and the inner shell is made of a rubber-like plastic to permit a fluidic coupling to the outer shell and to allow for heatstake processes. The fluidic coupling is needed to provide a leak-free joint

Print Cartridges for a Large-Format Color Inkjet Drafting Plotter

While the DeskJet 1200C cartridge development team focused on applying HP inkjet technology to develop a desktop plain paper color solution, the DesignJet 650 cartridge design team used the same technology to introduce color into HP large-format inkjet plotters. The original HP DesignJet plotter[1] and the high-resolution DesignJet 600 plotter brought the print quality, reliability, and user friendliness of inkjet technology to the large-format plotter market. The full-color DeskJet 650C plotter opens up new applications that were not possible with single-color plotters.

The DesignJet and DesignJet 600 use two HP DeskJet print cartridges, which have proven reliable through many years of experience with the DeskJet family of products. When the DesignJet team set out to develop the first large-format color thermal inkjet plotter, the DesignJet 650C, the challenge for the print cartridge design team was to develop a four-print-cartridge system that would continue to meet or exceed customer expectations for print quality and reliability. The best way to deliver color inkjet technology into this marketplace was through a highly leveraged program that could meet the objectives with a quick time to market and minimal staffing levels.

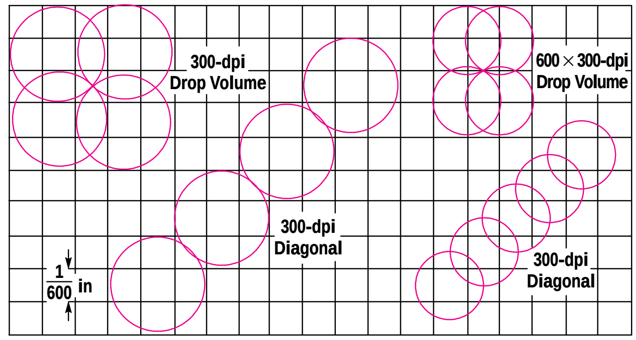

Fig. 1. In its monochrome enhanced mode the DesignJet 650C plotter plots vector data at 600-by-600-dpi resolution and filled areas at 600-by-300-dpi.

DesignJet 650C Black Print Cartridge

One of the main requirements for the black print cartridge for the DesignJet 650C plotter was to deliver uncompromising print quality and reliability at a relatively low cost. To minimize the expense and time invested in engineering, development, and marketing, the decision was made not to develop a new black print cartridge but to use the black cartridge developed for the DeskJet 1200C printer. This allowed us to take advantage of the media independence, water fastness, and light fastness of the new black ink, but it posed a challenge because this black print cartridge is optimized for a small-format writing system that employs a heater and a fan to minimize the print quality effects of the vehicle used in the black ink formulation. The objective for the DesignJet 650C plotter was to deliver optimal print quality on a variety of media including HP CX Series JetPaper (PaintJet paper), all of the plotter media (bonds, vellums, translucent), and a specially developed thermal inkjet film. The engineering development team focused on meeting customer expectations for large-format print quality without any sacrifice of environmental range or performance compared to previous products.

The drop volume of the DeskJet 1200C black print cartridge was chosen so that the ink put down in a full area fill will just cover the media surface (this is known as closure). Any additional ink would contribute to unnecessary cockling of the paper, color-to-color bleed, and excessive drying time. The drop volume was selected according to the DeskJet 1200C's goal of placing two black dots per 300-dpi pixel on plain paper. However, the DeskJet 1200C uses a heater to promote drying, and office-use media are typically more absorbent than large-format plotter media. Thus, the appropriate drop volume for the DesignJet 650C plotter is more nearly 1.75 drops per pixel. To achieve this noninteger density, the DesignJet 650C plotter implements a dot-depletion algorithm. It first rasterizes any vector data at 300 dpi and merges it with any 300-dpi raw raster data. It then doubles each pixel in the carriage direction (the scan axis), producing a 600-by-300-dpi bitmap. The plotter then examines the bitmap for regions with fill densities greater than 1.75 dots per pixel (the maximum will be 2 dots per pixel). When it finds such regions it turns off some of the pixels in the interior to reduce the print density, while preserving the pixels that define the edge of the fill. The algorithm is implemented as a user-selectable "contrast level" so that users can select maximum fill densities of 1.5, 1.75, or 2.0 drops per pixel according to the ambient conditions.

The DesignJet 650C plotter further exploits the small drop volume of the DeskJet 1200C black print cartridge in its plain paper monochrome enhanced mode (Fig. 1). As mentioned above, the diameter of the dots is approximately sized for 600-by-300-dpi printing. In enhanced mode, the vector data is rasterized at a full 600-by-600-dpi resolution. The printer can place a drop on any 600-dpi pixel by

between the outer shell to which the TAB/printhead assembly is attached and the inner shell to which the ink delivery system is attached. The two filters, used to stop particulate contamination from reaching the small fluid passages in the printhead, are also heatstaked to the inner shell.

The spring assembly consists of two flat metal plates attached to a pair of metal leaf springs. The flat plates are covered with a thick plastic shield to prevent the edges from cutting the films and to allow stabilization of the assembly relative to the films. The principle behind the spring design is to transfer the force generated by the spring to the metal plates which in turn push out on the films. This generates the backpressure in the system, which must be controlled very closely because it directly affects the print quality. If the system is at a backpressure less than one inch of water, there is a high risk that ink will drool out of the nozzles, and if the backpressure is greater than eleven or twelve inches of water, the time to refill the firing chamber increases and the volume of the ejected drop decreases, decreasing the print quality. Using Bernoulli's equation, these initial and final pressure values were used to determine the spring's force range. The challenge was to design a spring with a low spring rate and yet a relatively high starting force. This required a spring that would exhibit a constant stress throughout the beam for a given deflection. This was achieved by giving the leaf spring a diamond geometry so that the force generated by the spring as a function of the curvature of the spring remains constant during the life of the print cartridge (Fig. 3).

The films are heatstaked on each side of the inner shell of the frame. The film itself is a multilayer aggregate that strikes a delicate balance between flexibility and water vapor loss. Flexibility is needed to get the most ink out of the reservoir, while metallizing the film to reduce the amount of water loss and permit a low-cost, nonhermetic package design tends to diminish the delivered volume. The spring is introduced during assembly between the two films and begins exerting an outward force on them.

The two covers, which are made of metal for stiffness, are pressed into the outer shell and make the structure very stiff. Ink is then filled into the ink delivery system followed by the insertion of the ball-cork into the frame. Following this, the system is primed by removing all of the air through the nozzles and initiating their capillary forces.

half-stepping the media drive. It scans over the media, firing 96 nozzles on a grid that has 300 dpi vertically but 600 dpi horizontally. It then advances the media by 1/600 inch and scans again, filling in the swath to full 600-by-600-dpi resolution. (The printer actually advances the media alternately by 48.5/300 inch and 47.5/300 inch, moving back and forth between the two 600-by-300-dpi grids while also interlacing the printing passes by half a swath. This masks some mechanical errors in media advance and print cartridge alignment and mitigates some ink-media problems.) However, true 600-by-600-dpi density uses too much ink with a drop volume designed for 600-by-300-dpi printing. Therefore, before printing the data, the plotter depletes the interior of filled regions to an average of 600-by-300-dpi density, while preserving pixels that contribute to 600-dpi edge acuity. This leaves approximately 2 dots per 300-dpi square, or 0.5 dot per 600-dpi pixel. The data is then further depleted to a user-selected contrast level to promote faster drying. The result is a plot that is nearly indistinguishable from true 600-dpi output, using a minimal amount of ink from a print cartridge that delivers twice the drop volume of a 600-dpi cartridge.

DesignJet 650C Color Print Cartridges

Current plain paper color inkjet technology uses a heater and fan system to drive off excess water and dry the ink, as in the HP DeskJet 1200C printer. It was neither cost-effective nor technically feasible to put a heater and fan system on a large-format plotter, making a special paper color solution the best alternative. Since the DeskJet 1200C color print cartridges were being optimized for a plain paper color solution, they could not be expected to perform well in a DesignJet 650C.

The color inks and special paper used in the HP PaintJet printer[2] were directly leveraged into the DesignJet 650C plotter. Using preexisting ink and media provided some stability to the program but also removed the flexibility to optimize them for our new application. Any performance problems that arose would have to be solved elsewhere. Having this stability we could concentrate on developing the printhead architecture and ink delivery system.

The development of the ink delivery system is where the most leverage was obtained. As described in the accompanying article, the platform print cartridge is designed for successful leveraging. Most parts and processes are shared between the DeskJet 1200C and DesignJet 650C color print cartridge families. Only where absolutely necessary are there differences in parts or processes (i.e., TAB/printhead assemblies, inks, packaging).

The only area where there was a large amount of design freedom available was in the design of the printhead architecture. The flexibility in this area allowed us to meet the particular demands of the large-format market. The ability to create the thin, well-defined lines required in CAD applications is crucial for any technology trying to compete in this market. The ramifications of this requirement dictated a drop volume design center below any other HP thermal inkjet print cartridge to date. To meet the 0.13-mm linewidth specification required that the drop volume design center be set at 30 pl. For comparison, the original DeskJet print cartridges are designed to deliver 130 pl. The need to deliver such a small drop volume pushed the architecture to new limits by requiring very stable drop ejection to maintain uniform area fill quality. Advances in thin-film processing coupled with a new architecture design allowed us to meet these objectives. This proved to be an important effort, since the knowledge gained is directly applicable to higher-resolution inkjet designs.

Concern over excessive printhead temperature was another design area that needed attention because of the large-format nature of the application. Since this print cartridge would be printing 34-inch swaths for a duration of several minutes, the performance of the print cartridge had to be ensured at elevated temperatures. The approach that was chosen was to minimize the amount of heat buildup in the head by optimizing the architecture to deliver the ink in a thermally efficient manner.

Conclusion

The DesignJet 650C print cartridges have proven to be successful in meeting and exceeding customer expectations. Their level of performance was verified through extensive testing of the print cartridge and product system. This testing has demonstrated a significant improvement in writing system reliability compared to pen plotters. Pen plotters require frequent pen changes to keep plotting. The DesignJet 650C print cartridges have been designed to require less frequent customer interaction, making them more user-friendly. This provides customers the benefit of unattended use such as overnight plotting.

References

1. *Hewlett-Packard Journal,* Vol. 43, no. 6, December 1992, pp. 6-34.
2. *Hewlett-packard Journal,* Vol. 39, no. 4, August 1988, pp. 6-56.

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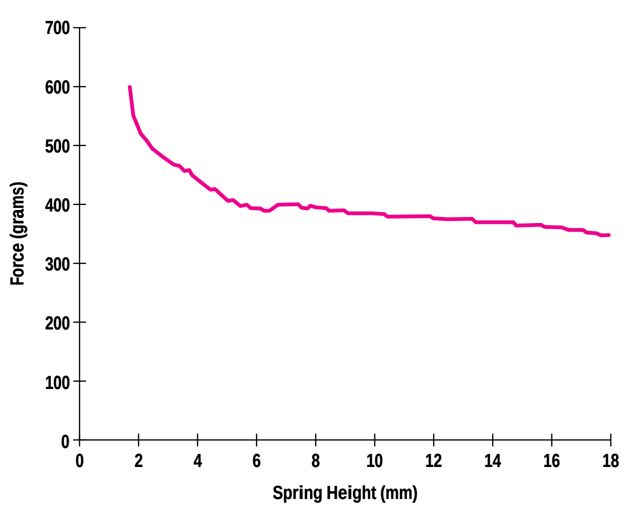

Fig. 3. The force exerted on the ink bag by the print cartridge spring is relatively independent of spring curvature.

Major Benefits of the Spring-Bag Ink Print Cartridge

The spring-bag design allowed us to meet and exceed many expectations we had set as goals. The design permits the use of known, controllable materials for the spring, frame, and film, and is compatible with many inks, thus making this design a platform. Using a spring-bag design results in a mechanically controlled system. The spring makes a tunable system possible, allowing selectable starting backpressure. The closed system is air-free and does not allow any air to get in. This makes the print cartridge very tolerant of environmental conditions such as thermal and altitude changes. The closed nature of the system and the multilayer film result in very low water loss through the membrane, making it possible to do away with the aluminum can shipping container in favor on a simple paper box which is environmentally sensitive (see “Environmentally Friendly Packaging” on page 53).

Environmental and Shipping Robustness

A key objective for the print cartridge is that the ink stays in the print cartridge and doesn’t get on the customer. To ensure this robustness in both design and assembly, frequent build/test/fix cycles were used. When tests were failed, causes were determined and a fix implemented even if that meant adding parts or engineering a custom material.

Early in the project, a test cycle to demonstrate robustness was defined and a design defect tracking system was put in place to keep track of all print cartridge problems (not just robustness-related ones). The tests fall into two major categories: survival and shipping simulation. Survival tests are done with the cartridge untaped and unpackaged and are designed to mimic customer abuse. These are severe tests and the requirement for passing is that no ink leakage or hazard (sharp edges, etc.) be observed. Shipping simulation tests are done with the cartridge taped and packaged and are designed to mimic the stresses the print cartridge will see in transportation and warehouse storage. The requirements for passing are that no ink leakage occur and that the print cartridge be printable, that is, capable of printing. The tests include free drops (multiple drops from one meter onto concrete in different orientations), vibration (both random and swept), temperature cycling (–40°C to +70°C), hot soak (65°C, 90% relative humidity for one day), and altitude.

The last related test is water loss, measured as water vapor transmission rate or WVTR. This is important because the ink will work correctly only over a narrow band of water content. There is no official standard, so one was developed. Our in-package shelf-life requirement is 18 months at 25°C. Our in-product goal is 6 months in heated printers (potentially with the heater in the standby "warm" mode around the clock) at well above ambient temperature.

The print cartridge performed well at high altitude or temperature in part because the vent-free, collapsible, flexible design minimizes trapped air volume and provides compliance against air expansion forces. Numerous small problems were uncovered and fixed, too many to cover here. Briefly, they included ink level shift (showing partially out of ink when full) after drop, spring hangups on the frame (stranding excess ink), air intrusion through the ball-cork seal after temperature cycling (causing loss of backpressure), and side covers popping out of the frame after drop (causing print cartridge alignment errors).

The four biggest problems were WVTR, ink leakage from the bag-film-to-frame seal, ink leakage from spring-induced tears in the bag film, and ink wicking under the nozzle tape. The WVTR problem was made easier to solve by the vent-free design (vents are usually a large loss path), and by the low-water-loss second-shot plastic. But it was complicated by the large bag film area and the need for the film to be extremely flexible for reasonable backpressure and delivered volume performance. Most applications require low water loss or flexibility, not both. This required a custom film structure. Standard materials and assembly processes were used. After numerous iterations the nine-layer film structure shown in Fig. 4 was selected.

The second major problem was the bag film peeling away from the frame at the seal joint during drop testing, causing major ink leakage. During a drop, a lot of ink is pushing down on the film near the seal just as the frame is pulling the frame up at the seal edge, producing a severe reverse peel (the worst kind of load) on the seal. The original second-shot plastic material was HDPE, which is not a very good

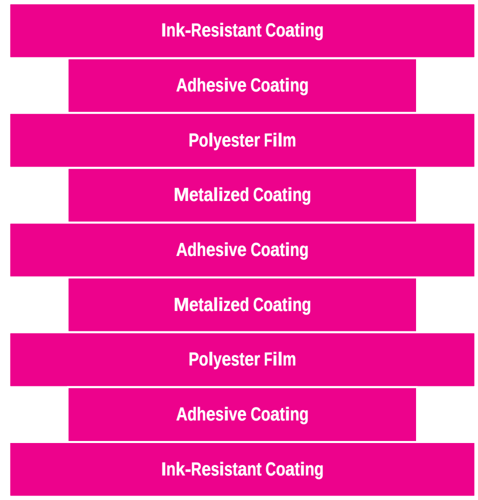

Fig. 4. Nine-layer bag film structure.

sealant. A burst test was developed to characterize seal strength (internally pressurize a sealed spring bag until the seal ruptures or the bag film breaks like a balloon). Optimization of the seal parameters (time, temperature, and pressure) and adjustment of the mechanical tooling tripled the burst pressure. At this point a single two-meter drop or four one-meter drops could be survived. This indicated that a single drop caused partial seal peel. While very few print cartridges were likely to see four drops, we hadn't tested millions of print cartridges, so the ultimate margin was not known. A material search was instituted and a new second-shot material was selected that has much higher seal strength. Burst strength tripled and the bag film breaks before the seal peels.

The third major problem was the metal spring piercing the bag film in drop or vibration testing, causing moderate ink leakage. The piston plate part of the spring is very thin and has a rough, burred edge that is right up against the bag film. Attaching the spring to the film eliminated the drop failures but aggravated the vibration failures (fixed the relative motion to one spot). The solution is a plastic shield over the spring piston plate (the shield is larger than the plate). Thus, no matter how rough the plate edge or how the bag film wraps the plate edge, direct metal contact is not possible.

Plastic tape is used to seal the nozzles during shipping and storage, thus preventing failure of the device as a result of orifices becoming clogged by contamination or dried and crusted ink. The tape must seal securely on the nozzle plate but must also be easily removed before use without damaging the print cartridge or leaving any adhesive residue on the nozzle plate. Tape manufacturing and alignment considerations result in the tape being considerably wider than the nozzle plate so that it extends over the encapsulant beads (see Figs. 5a and 5b). This resulted in a peeling load on the tape in the nozzle region. During high-temperature storage the tape peeled off over the nozzles, leading to wicked ink and some crusted ink nozzle plugs (Fig. 5c). The solution is two slits in the tape just before assembly to decouple the regions of tape over the nozzles and over the encapsulant beads (Fig. 5d). The free end of the tape is then wrapped over a printed paper customer pull tab to provide an easy method of removal.

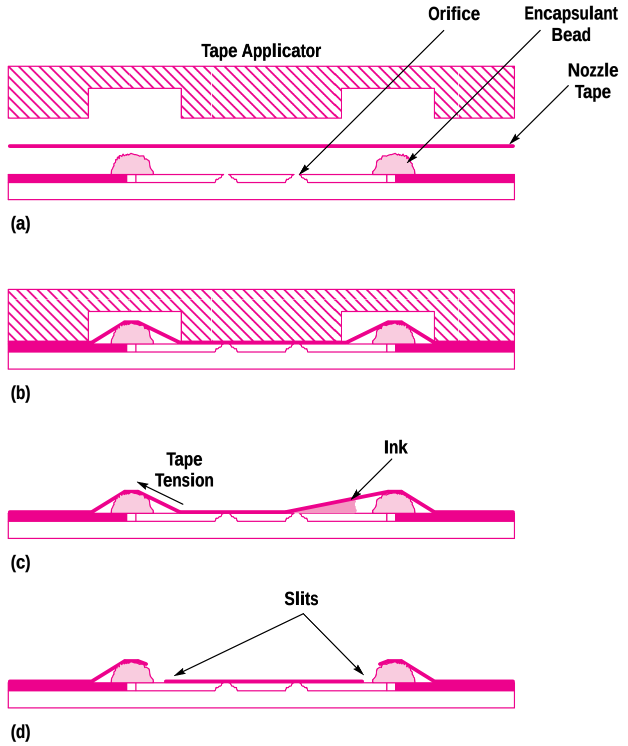

Fig. 5. (a) Tape is placed over the orifice plate of the printhead to prevent leakage during shipping and storage. (b) The applicator deflects the tape down between the encapsulant beads. (c) Residual tension in the tape at the beads tended to peel the tape up from the orifices. (d) Slits in the tape decouple the tape over the beads from the tape over the orifices.

Ink Level Indicator

During the initial design phase of the DeskJet 1200C print cartridge it was decided that the cartridge should have an ink level indicator. The primary intent of this indicator is to warn the customer so as to prevent losing a printed page because of a print cartridge that is out of ink. The DeskJet 1200C print cartridge will be the first HP inkjet print cartridge with an ink level indicator. Consumer demand for level information is increasing, fueled by indicators in copiers and laser printers showing toner cartridge life and by the larger volumes of printing customers are doing. Knowing a print cartridge is low on ink is helpful before printing a large number of graphics pages. It gives the user time to purchase a replacement print cartridge, provides an indication of which of the color print cartridges is empty, and identifies whether a print cartridge that does not print properly is out of ink or has another problem such as a deprime.

More than 20 methods of implementing an ink level indicator were considered but most either did not meet the required objectives or were too expensive. Building the print cartridge with clear covers and clear films would be very difficult to achieve, and even if achievable would not give the customer a clear ink level indication since the ink level does not drop in a spring-bag print cartridge. Measuring the bulk conductivity of the ink and counting the drops a print cartridge has fired were two of the leading alternatives. The current design has many advantages over these, a primary advantage being that the ink level indicator is independent of the printer.

Environmentally Friendly Packaging

The package design for HP DeskJet 1200C print cartridges represents an advance in thermal inkjet packaging with respect to both environmental friendliness and unit cost. Responding to customer needs and requests for less waste (and hence less landfill), it was an early design objective of the ink delivery system that the print cartridge itself should provide sufficient water vapor transmission barrier and shipping robustness without requiring additional layers of protection from the package. Meeting these objectives and designing the package concurrently with the cartridge results in a new package that has many advantages both for the customer and for HP.

The print cartridge package has only two parts: a paper insert for customer communications and a recyclable paperboard carton. The carton is a one-piece design with air cells protecting the cartridge on four of the six sides. The manufacturing process involves erecting the carton, inserting the cartridge and paper insert into the carton, and sealing the two ends of the carton with hot melt glue.

Fig. 1 shows exploded views of the existing package design and the DeskJet 1200C package. The DeskJet 1200C design reduces the number of parts from six to two, eliminates the expensive aluminum parts, reduces the number of materials from four to two, reduces the number of process steps and machines from two to one, and reduces the ratio of package to print cartridge volume and weight.

The DeskJet 1200C print cartridge package has received the approval of the Green Dot program in Germany for its sensitivity to environmental and recycling issues.

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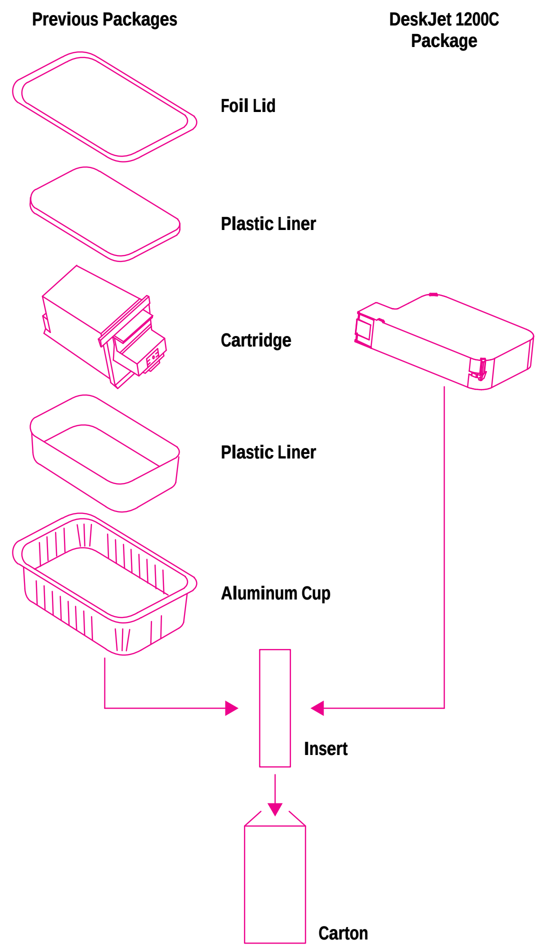

Fig. 1. Comparison of existing and DeskJet 1200C print cartridge packages.

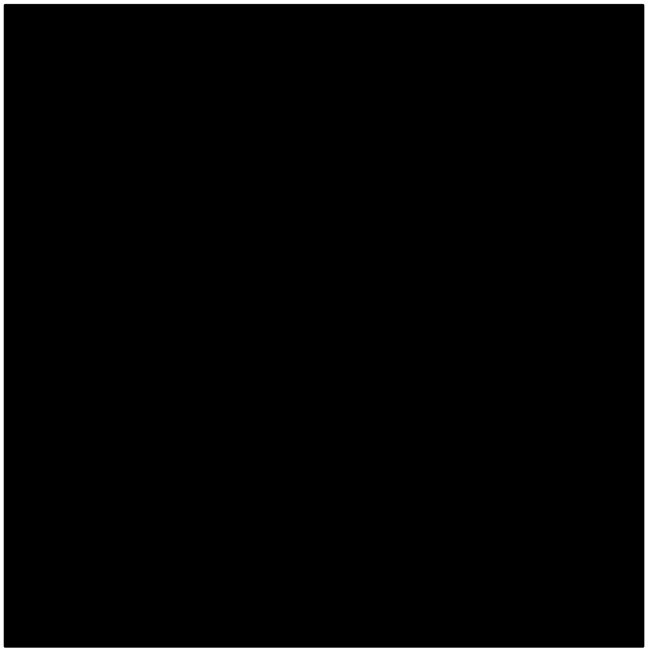

Fig. 6. Ink level indicator. (left) Full. (center) Partially empty. (right) Empty.

The design selected is called the dual-flag design (Fig. 6). It consists of two strips (flags) of film attached to either side of the spring bag. One flag is solid green and the other is black and has a rectangular hole cut in it. The flags overlap across the front of the print cartridge with the black flag over the green so that the green can be viewed through the hole in the black flag. An adhesive label covers both flags and provides a window to the indicator. As the ink volume decreases, the two sides of the bag collapse towards each other, moving the flags with them. The amount of overlap indicates the approximate amount of ink remaining in the print cartridge (Fig. 7). The amount of ink is indicated regardless of whether the two sides of the spring bag collapse together or not. When the print cartridge reaches low ink, no green is visible in the viewing window, only black. One half of the black rectangle in the viewing window is the black flag. The other half is actually the print cartridge body showing through the hole in the black flag.

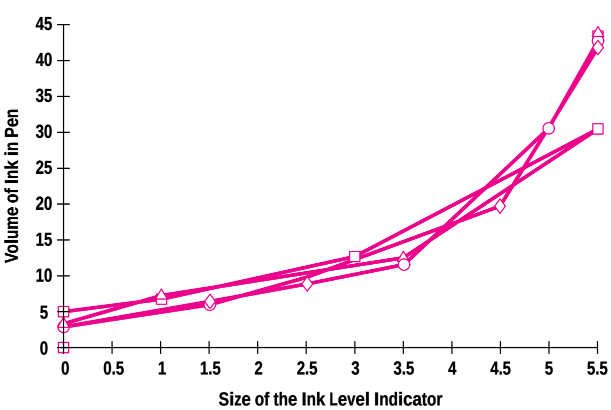

Fig. 7. Size of the green ink level indicator as a function of ink level.

The design objective for the ink level indicator was to show full (all green) when a print cartridge ships and low (all black) when the ink level is within ±10% of the low ink point. This is a reasonable goal that delivers information similar to an automobile fuel gauge. Any greater accuracy would be both unnecessary and difficult to manufacture.

Acknowledgments

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- Hendrick Brower, THA adhesive and encapsulant
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- Mindy Hamlin, frame design/molding and THA attach
- Dave Hunt, ink level sensor design and assembly
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- Tony Panah, spring design and assembly
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