THE TECHNOLOGY OF COLOR LASER PRINTING

1 Short History

The technology that makes laser printers work goes back to the first xerographic copiers, produced about sixty years ago. The inventor was a patent attorney named Chester Carlson. Chester collaborated with Battelle Memorial Institute in 1944 and then in 1947 with a small company named Haloid Corporation in Rochester, NY to develop the first copier. Haloid eventually changed its name to Xerox and called the technology 'xerography'. The first commercial copier was launched by this company in 1947 and the company has gone on to develop many copiers and printers using this technology. Generally other companies use the term 'electrophotography' or 'EP' rather than xerography to describe this technology.

For most of the fifty years or so that EP has been in use, it was used in monochrome copiers or printers. Monochrome means that the copier or printer can only produce a black and white image, even if the original is in color. Today, EP is used in printers and copiers that run from four pages per minute to hundreds of pages a minute and can print in color as well as monochrome. Laser printers are used to print from a few prints a week to more than a million prints a week.

EP was first used in a commercial color copier by Canon in 1973, but there was limited commercial success for color EP for many years until color inkjet printers had substantially developed the market by the mid-1990s.

Another important step in the development of EP took place shortly after the first color copier was introduced. In 1975, Xerox launched the Telecopier 200, the first commercial implementation of a laser EP printer. This development was so important that today, almost all EP machines use laser printing, even those that are primarily used as copiers. The main difference is that whereas the original copiers used a light reflected from a page onto a photosensitive drum in making the copy, laser printers use a laser to write with light on the photosensitive drum.

Another highly important development in EP came in 1981 when Canon introduced the first EP based copier that included a user replaceable integrated supplies cartridge. Prior to this time, the very complex EP process suffered from reliability issues that meant that a service engineer periodically needed to make adjustments and replacements to the machine. Canon identified the least reliable functions and components and placed them all in a single container that could be easily replaced by an unskilled user. At the time Canon engineers explained that they had tested each of the cartridge components to failure, identified the earliest failure component, and placed enough toner in the cartridge so that under normal use the toner would run out in some way before anything else would fail.

Today, many major companies have developed and launched successful color EP printers so that at least fifteen different companies now make and sell these printers. Less than half this number of companies makes and sells inkjet printers.

2 Basic Electrostatics[1]

In order to understand EP technology we need to have a few simple electrostatic concepts defined, because the technology depends very much on these concepts. We will refer frequently to these concepts later in the report.

2.1 Conductors and Insulators

We are mostly familiar with the concept that some materials conduct electricity and some do not. The EP process depends upon these differences in materials and uses both conductive and insulative surfaces, in fact, a crucial part of the process depends upon a material that is an insulator in the dark and becomes a conductor when light shines upon it.

2.2 Charge

Most of us have seen that you can rub a plastic rod, like a ball point pen, on a shirt sleeve and that the pen can then be used to 'pick up' or attract small non-metal items such as paper fragments and so on. What has happened is that electrostatic charges have formed on the pen due to its interaction with the sleeve and the charges can be used to make other things 'stick' to the pen. Charges cannot really be measured directly, but we can measure the force that the charge exerts for example on the tiny piece of paper that is attracted to the charged surface. We can measure the mass of the paper and the acceleration between the paper and the pen, and when we multiply these together we know the force exerted by the charge.

These charges may be 'positive' or 'negative' depending upon the materials. Positive and negative here refer to electricity and are the same as positive and negative used when referring to a battery. As in magnetism, positive charges attract negative charges, and repel positive charges. This is known as 'like charges repel, unlike charges attract'. So in the case of the pen and paper, one of the items has a charge that is either opposite or greater than the other and so there is a force of attraction between them.

2.3 Electric Field

If we take two flat metal plates and arrange them so that they are parallel to each other, but separated, we can connect one side of a battery to one of the plates and the other side of the battery to the other plate but nothing will happen. That is, no current will flow between the plates because the air between them is an insulator. There is an invisible condition that exists between these plates however that is known as an 'electric field'. The higher the voltage applied, the greater is the field, and also the smaller the distance between the plates the greater or more intense is the field.

If we further coated the plates with an insulator such as a varnish or paint, and were still able to connect the plates as before, the electric field would still exist between the plates.

If we left this set up in a dusty room, we are likely to find that over time, dust would accumulate more on one of the plates than on the other. This is because the dust particles became charged more positive than negative (for example) and became attracted to the plate that has the negative battery terminal connected to it. This demonstrates that small charged particles move under the influence of an electric field.

[1] Physics: Starling and Woodall, Longmans Green and Co Ltd, 1964

2.4 Bias

In the description of electric field above, we would call the voltage that the battery applied the 'bias voltage'. Another term that is frequently used for this voltage is 'potential'.

3 The Document Creation System

A laser printer is part of a system that can produce prints from a digital file. The printer itself includes the print engine, which is comprised of the electrophotographic unit, laser exposure system, fusing system, transfer belt, power supplies and paper feeder, as well as software, firmware and other devices required to adapt the image for printing and enable networking and wireless capabilities. The whole printer system usually consists of a computer system, some software, and the printer. The computer is known as the 'host' and runs an operating system such as Windows, MacOS, Linux and so on. The computer may be a desktop, laptop, mainframe or other system. The particular software that is run under the control of the operating system and is used to create pages for printing is known as the 'application' software or program. This may be a common program such as Microsoft Word or Excel, Adobe Photoshop, OpenOffice, Mozilla Firefox, and so on, or it may be a highly customized application for a special purpose.

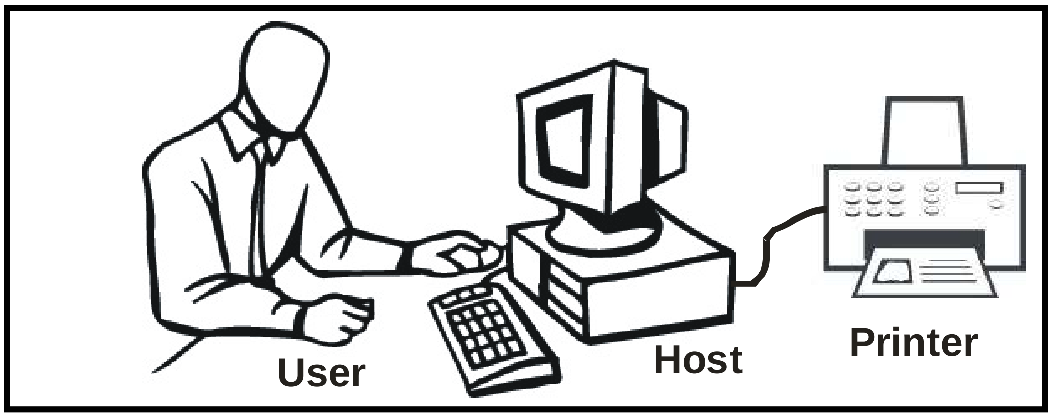

Figure 1 - Typical Laser Printer System

In the typical system the user uses that application software to compose the document, which may consist of one or more pages, and tells the printer to print the document. The printer supplier provides a program known as a printer driver that is loaded on the host computer and opens when the user selects 'Print' from the application program. The driver enables the user to select various print functions such as paper size, number of prints and so on.

4 Printer Electronics

When the user tells the driver to print, the document is sent to the printer in a special electronic format, known as a page description language. The part of the printer that receives the document in this format is known as the raster image processor or RIP. It is the job of the RIP to reformat the document into a form that the printer can print.

The RIP converts the pages into a series of electrical signals that represent the tiny dots that will be eventually placed on the printed page. For each color page, the RIP also separates the document content into the separate colors. For example, in a four color printer, the RIP creates four separate page images, one for each of the colors and these images are printed separately for each complete page.

The printer also includes electronics that can create the high voltages that are needed for electrophotography, and controls the start and stop of various electromechanical components that are used in printing the document. The electronics includes sensors that can detect various important functions in the printer such as when a paper jam occurs, when a user presses a button, or if one of the supplies such as toner is out.

Printer document management and engine management comprises a very complex set of tasks. In general printers use a microprocessor to manage all of the electronics, information flow, printer condition and so on. There may be one or more microprocessors and these microprocessors are very similar to those that control all of the operation of a personal computer.

5 Paper Handling

The purpose of the printer is to produce sheets that carry the images that the user created on the computer display. These images are usually printed on sheets of paper. Printers include a store of paper that can be replenished by the user. Some printers can accommodate several different sizes or kinds of paper, but in general, a given store or tray can only be loaded with sheets of the same type of paper.

In order to print a page, the printer must be able to take one sheet of paper from the store and move it through the printer, placing the image on the sheet and fixing it in place. This means that the printer must separate one sheet from the store or stack of paper and keep the remaining sheets in the tray. In addition, in order to make the printer compact and able to fit onto a desk or small table, the path that the sheet follows is usually not straight but may follow a C shaped path or even an S shaped path.

After the sheet has been printed and fixed, the printer moves it into an output tray of some kind so that the user can collect the finished print. For documents that have multiple pages, this process is repeated until the document is completed in the output tray. For a multi-page document, there may be several sheets being processed in the printer in sequence.

The paper handling system is recognized as being the most unreliable function in printers that use cartridges for the EP process. Electrostatic charges can build up on paper in a stack, making it very difficult to separate the sheets for feeding through the printer. This can give rise to paper jams in the feeder. Any small edge defects on a sheet of paper such as tears, folds, tucks and so on can engage with a mechanical part as the sheet feeds through the printer and can cause the sheet to buckle or skew, also giving rise to a paper jam.

6 The Electrophotographic Process

The electrophotographic process is one of the most complex systems that is in common use today. The process uses materials science, physics, optics, chemistry, mechanics, electronics, and now software in a highly sophisticated precision combination to produce the prints that we casually make and easily discard.

There are eight distinct and important elements or processes that make up the laser electrophotographic process. We will describe each in the approximate sequence in which they are used to create the printed page.

For ease of understanding, we include Figure 2 to will help locate the various items in the sequence. This figure is a highly simplified representation of an imagined EP process and does not represent any particular printer product; there are many variations from this configuration in practice.

In general, there is a charge roller, a laser scanner, a photoreceptor or OPC, a developer, a transfer roller, a cleaner and a fuser. The paper that is receiving the printed image is shown moving between the photoreceptor and the transfer roller toward the fuser. All dry EP systems have at least these functional elements, some in a different form. The toner is contained inside the developer unit.

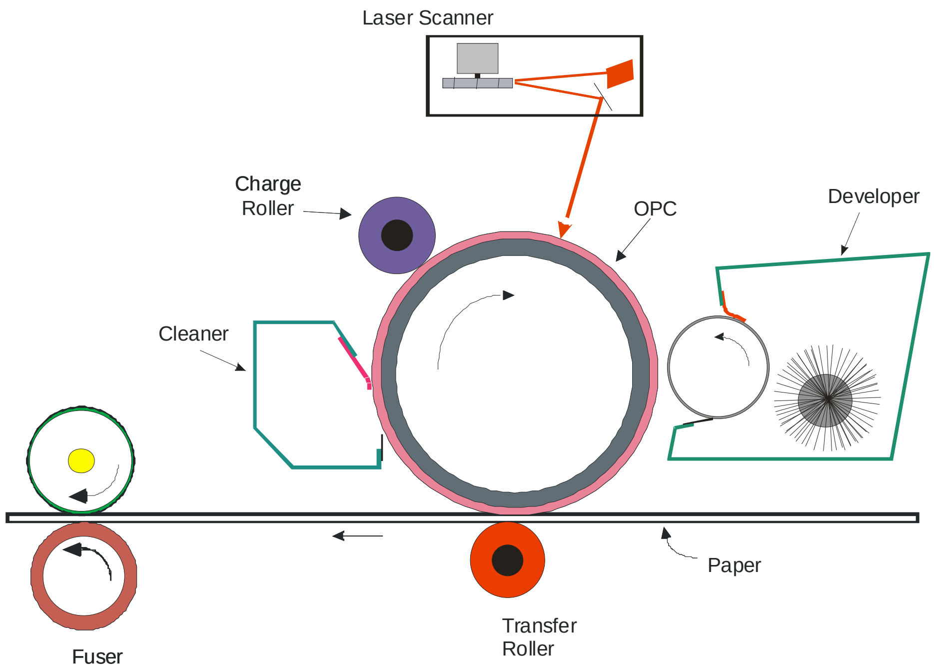

Figure 2 - Simplified EP Process, Side View

The mechanics of the laser printer are relatively simple in that the components shown above are held together in a frame of some kind and the rotating parts are driven through belts or gears by one or more small electric motors.

7 Photoreceptor or OPC

The photoreceptor is also known as the photoconductor. In the early days of EP, photoreceptors were made using various semiconductor alloys and salts. In modern printers almost all photoreceptors consist of a thin layer of an organic chemical coated onto a metal surface in the form of a tube or drum, or onto a plastic belt that has a metal surface on it. Therefore the photoreceptor is often referred to as the 'OPC', meaning Organic Photo Conductor. We shall use this term in the remainder of the report.

In the Figure, the OPC is in the form of a hollow tube or roll and we are looking at the end of the tube. The tube is metal and is connected to electrical ground. The tube can be rotated as indicated by the arrow inside. The OPC layer itself is of the order of one thousandth of an inch thick and must be made with very uniform thickness and no pinholes. Some of the processes in EP apply high electric fields between the OPC and other elements and if there is a pinhole in the OPC coating, there may be a spark or arc at the pinhole that can cause serious damage to the printer.

The material of the OPC and the process of coating the OPC are carefully chosen and controlled in order to guarantee uniformity and performance in the printer. The OPC must have the ability to accept and retain an electrostatic charge. It must also be an insulator in the dark and a conductor when light is shined upon it. If the area that is illuminated had a surface charge upon it, that charge must be dissipated by the light. This narrows the selection of material to a small group known as photosensitive semiconducting dielectrics. These materials are known to be able to conduct electricity under some conditions but to be insulators under other conditions.

The surface of the OPC is subject to wear due to the scraping action of the cleaner blade and the abrasiveness of paper that contacts the OPC surface. There is also the real possibility that some dust or other contaminant may get lodged under the blade and create a scratch in the OPC surface.

8 Charging

To start the EP process, an electrostatic charge must be placed on the surface of the OPC. In early EP, and in some larger, faster EP printers today, this is done using a device known as a corotron or scorotron. These devices are efficient at creating charge and do not have to touch the sensitive surface of the OPC. They are quite expensive however and almost all desktop and hallway printers today use a charge roller to place the charge on the OPC. The charge roller is shown at the upper left of the OPC in the Figure. Charge rollers are sometimes known as PCR's meaning Photoreceptor Conditioning Roller.

The charge roller usually has a metal rod at its center and the rod is coated with a relatively soft rubber material that is in contact with the OPC. The charge roll may further have a coating on the outside of the rubber part so that the coating is in contact with the OPC surface. The rubber material is conductive, but less so than the metal core.

In operation the charge roll is rotated so that the surface speed is the same as the OPC. A voltage is applied to the metal rod or core of the charge roll and since the OPC core is grounded or at zero volts, the charge roll voltage creates an electric field between the charge roll and the OPC. Typically the voltage that is applied has both AC and DC components. As the OPC surface moves with the transfer roll surface the field creates a charge on the surface of the OPC. It is possible to assume a negative or a positive voltage on the core, in our illustration we will assume that the voltage applied to the core is negative. If the overall voltage is negative, it will place a negative charge on the surface of the OPC. If we could easily measure the voltage of the charge on the OPC surface it would be in the 500 to 900 volt range with respect to ground.

The rubber on the charge roll is made conductive by having small particles of carbon or some other conductive material dispersed throughout the rubber, in a somewhat similar composition to that of a car tire. The uniformity of the dispersion is much more critical in a charge roll than it is in a car tire since this determines the uniformity of the charge on the surface of the OPC. The exact materials of the rubber and particularly the coating are difficult to formulate because of the conductivity, softness and uniformity requirements, and also because the physics of the contact point are complex. If the materials are not chosen correctly it is possible to get small electrical breakdowns or arcs at the input and output regions of the roller/OPC interface. This in turn can lead to immediate charge uniformity problems and possibly the creation of holes in the OPC surface which will create undesirable print defects and could damage the printer.

9 Exposure

The laser scanner selectively removes charge from the surface of the OPC. In Figure 2 we see a side view of the laser scanner. The scanner is contained in the rectangular box at the top of the Figure and the red lines are representing the path that the laser light takes to reach the OPC.

The grey component in the left end of the box is the actual scanner. The scanner consists of a disk that has equal size flat surfaces on its rim. That is, the disk is not exactly circular but is a polygon with each of the sides of the polygon polished to form a mirror surface. In the Figure we see four of these mirror surfaces. The polygon disk is mounted to the shaft of a motor shown above the disk.

To the right in the box there is a red area that represents a laser diode. A laser diode is a very tiny semiconductor laser that can be turned on and off in response to electrical signals. When it is turned on laser light is emitted. The laser diode light is shone onto the polygon through a series of lenses and mirrors. The light is reflected from the polygon mirror and shone through more lenses and mirrors so that it reaches the surface of the OPC. Most of the lenses and mirrors are not shown in the Figure in the interest of clarity. The complete optical system is arranged to produce a focus of the laser beam at the surface of the OPC. This focal point is referred to as the 'spot'.

When the laser light is shone at one end of a polygon mirror surface, the spot is reflected onto one end of the OPC drum. As the motor turns the mirror, the spot is moved across the surface of the OPC from the near end to the far end. The polygon mirror is so arranged that when the light reaches the end of the mirror facet on the polygon the spot also reaches the far end of the OPC. As the motor continues to turn, the light shines on the beginning of the next mirror of the polygon and is reflected back to near end of the OPC. This completion of movement of the spot all across the surface of one of the polygon mirrors then coincides with the completion of a line from one side of the OPC to the other. This is often referred to as a 'scan line'. The OPC is continually rotating and the speed of the rotation is synchronized with the rotation of the polygon so that if we looked down on the surface of the OPC and were able to see these scan lines, they would be parallel with each other and the axis of the drum and the scan lines would be touching each other.

During the operation of the printer the RIP has converted the image into an electronic representation of a series of dots. These dots are arranged into lines, just as they are on the computer display. Each line of dots is then sent to the laser diode and the laser diode turns on and off in response to the electrical signal. Obviously the 'line' imaged onto the OPC by the laser scanner now consists of a series of dots, some where the light is on and some where the light is off. Where the light is on the charge on the surface of the OPC is reduced or eliminated, where the light is off the charge remains.

If we could actually 'see' charge, and we looked at the surface of the OPC between the laser exposure and the developer unit in the Figure, we would be able to see a reverse picture of the page being printed. This charge picture is known as the 'latent image', and in our case, if we were able to completely discharge the surface where we shone the laser, the latent image would be zero charge and the rest of the surface would be negative charge. The areas where we shone the laser correspond to the image that we want to print. The remainder of the surface is known as the 'background' and corresponds to what we eventually want to see as the white color of the paper.

10 Toner

The print that comes out of a laser printer consists of the sheet of paper with some toner on it. In one sense, the whole job that the laser printer does is to place and fix toner in the right place on the sheet so that the visual appearance corresponds to the content of the image that was printed. The printer does this by bringing properly charged toner into contact with the latent image on the OPC surface.

Toner is a very fine powder, about the same size as flour particles and is mainly a plastic resin. Unlike flour, color toner particles are made up of several materials. Various plastic resins have been used to make toner, commonly polystyrenes and polyesters are used in modern toners. The toner resins are chosen for two primary qualities, their electrostatic charging property, known as triboelectric charge, and their thermal properties including melt temperature and ability to flow when semi-molten. All plastics have the ability to tribo charge, some charge positively and some negatively. The amount of charge on a particle and the ability of the particle to retain that charge are critical in developing electrophotographic images. Charge is related to the material that comprises the particle and to its mass, the measurable property is usually the ratio of charge to mass and this is popularly known as 'tribo'. Charge can be affected by surface conditions of the particle including shape and small additive particles that may cling to the surface. The other factor that can affect charge is humidity. Toner tends to charge to a higher level in dry environment and a lower level in moist environments.

The next most important ingredient in the toner is the colorant or pigment. Black toners use carbon as the color, and there are various pigments used for the other colors. Typically there is less than 10% of the colorant in the toner, so most of it is plastic. In monochrome printers, it is common to use magnetite, an iron oxide, as the pigment. Magnetite is both black and magnetic. The advantage is that the toner can be controlled and moved into the development zone using magnets. This facility cannot be used for color toners because there are no available color magnetic pigments.

Up until the advent of color EP, toner particles were made by a grinding and crushing process that does compare with grinding flour, although the equipment is very different and very much more sophisticated. After the particles are ground, they are sized. For electrostatic purposes, the larger particles will have a relatively low charge and the smaller particles will have a relatively high charge with respect to their mass. Low charge and high charge particles can create particular problems in development systems and can easily lead to print quality problems. For this reason, toner designers are at pains to make toner here all of the particles charge within a narrow range. This is a very difficult task.

An even worse problem is that some particles charge the wrong way. That is, if we want our toner to charge positively, it is impossible to guarantee that all particles will charge positively, some will in fact charge negatively and are called ‘wrong sign’ toner. The result of this can be toner where it is not wanted on a page, reduction in transfer efficiency leading to print quality problems and also machine contamination problems from what is known as ‘dusting’.

Therefore, manufacturers try to keep the range of sizes within narrow bounds. To do this a process known as classification is used, and this process removes the larger and smaller particles, leaving most particles in a narrow size range. Even with classification, some small number of particles that are outside the desirable size range find their way into the final product. Toner particles made this way are shaped like broken rocks as shown in Figure 3 below.

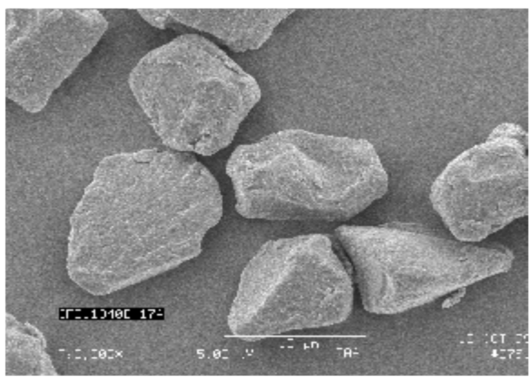

Figure 3 - Photomicrograph of Toner Particles made by Grinding

The color EP process is even more sensitive to toner particle size range than the monochrome process.   The first color printers used ground toner particles, but reliability and print quality problems in color systems are more difficult to manage than in monochrome. A different manufacturing process is most often used to make modern color toners. In this process, the particles are made from a liquid in what is a direct polymerization process that is a sort of chemical equivalent to the way that a pearl is made in an oyster shell. There are several variants of the process, but they all produce a narrower range of particle sizes than can be obtained from the grinding process and often do not need to be classified. The particle shapes are also different from the ground toner as shown in Figure 4 below.

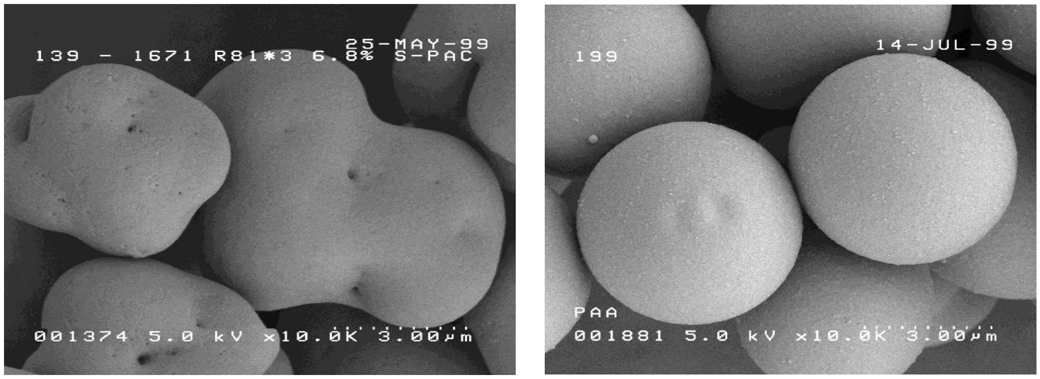

Figure 4 - 'Chemical' Toner Particles made by two different processes

As Figure 4 shows, one process makes potato shaped particles, the other is more spherical. Both can be made in a narrow range of sizes and toner made this way is much more controllable in the EP process than toner made by grinding. This process is less likely than the grinding process to create particles that are larger and smaller than desired. However it is not possible to completely eliminate these wrong sized particles, and, as in the grinding process, it is not possible to completely eliminate particles that charge the wrong way.

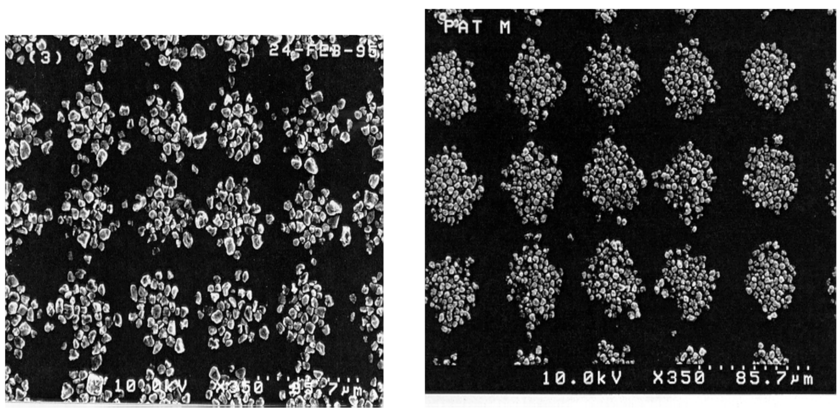

Figure 5 - Ground Toner and Chemical Toner Micrograph of the Same Image

Figure 5 shows the influence of toner particle shape on print quality. The ground toner image on the left obviously has a lot more particles scattered around the image than the chemical toner image on the right.

There are other advantages and disadvantages between the two toner particle shapes. The ground toner particles are actually easier to clean from the OPC surface than the more spherical particles. Spherical particles can have a tendency to roll under the tip of the cleaning blade and can then transfer onto the next print where they are not wanted. On the other hand, spherical particles are easier to transfer from the OPC onto the paper using the transfer roller.

So all of this means that the design and maintenance of the shape of the toner particles and the relative distribution of larger and smaller particles in the EP system is a critical design factor that has significant effects on print quality.

Another major factor in toner design is the use of toner additives. The surface of the toner particles shown in the micrographs above looks ‘clean’. Those particles were probably photographed before the final manufacturing step which is the blending of additives onto the surface of the toner particles. The appearance of the final toner particle is represented in the Figure below

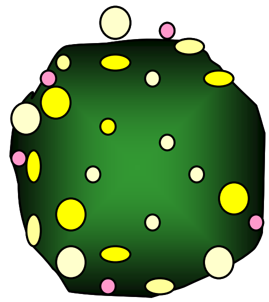

Figure 6 - Representation of a Toner Particle with Various Surface Additives

Surface additives are powders that have much smaller sizes than even the toner particles. The size relationship between the additive powders and the toner powder may be greater than 100:1. The first EP toners did not use additives. As various problems were encountered in the copiers and printers due to the characteristics of the toner powder, it was found that adding tiny amounts of these other powders could solve many problems in the printer. The first use of additives was probably to change the charging characteristics of the toner. It was found that good images need toner particles that are charged within a fairly narrow rang, and that particles that are charged outside this range can lead to print quality and machine contamination problems. Later, it was found that the toner particles have a tendency to cling to each other, especially in humid environments. Most toner reservoirs were gravity fed, and if the toner particles stuck to each other, the toner would not feed properly, instead it formed chunks or blocks of powder. This phenomenon is known as blocking and can be helped by flow control additives.

Additives are used for many reasons, including to control the triboelectric charge on the particles, to create a lubricating film on the OPC, to help stop the particles from sticking together, and to help stop the toner from sticking to the fuser roll. In order to accomplish all of these functions, it is customary that there are several additive powders blended with a given toner powder. As may be expected from this, the design and selection of surface additives is one of the most critical aspects of modern toner design.

11 Development

As the OPC surface rotates after the laser has exposed it, the invisible image made up of charge is completed. Now it must be made visible by the application of toner to the appropriate places. The development or developer system is the part of the printer that applies toner to the invisible latent image on the OPC.

In Figure 2 the developer unit is shown to the right of the OPC drum. Technically the developer unit has four primary functions. It must contain the toner, it must charge the toner, it must carry the toner to the surface of the OPC, and it must carry any unused toner away from the OPC.

The developer system is unquestionably the most complex part of a laser printer. During the evolution of EP, there have been many, many different types of developer system devised and used in commercial products. In this report we will confine ourselves to the most common form of developer in use in desktop laser printers.

One of the most common types of development in these printers is known as ‘single component, non-magnetic contact development’. This system is called single component because the powder that is used in the developer is toner powder only, some systems use a second powder and are known as two component or dual component systems. This system is called non-magnetic because many developers, especially monochrome systems use a magnetized toner powder or a second powder that is magnetic in order to move the toner into the development zone next to the OPC. This system is called ‘contact development’ because the developer roll that carries the toner contacts the OPC, there is no gap between the two and the toner is brought into direct contact with the OPC surface. A DC voltage is applied to the core of the developer roll and sets up an electric field between the developer and the OPC. This developer hardware is illustrated in Figure 7.

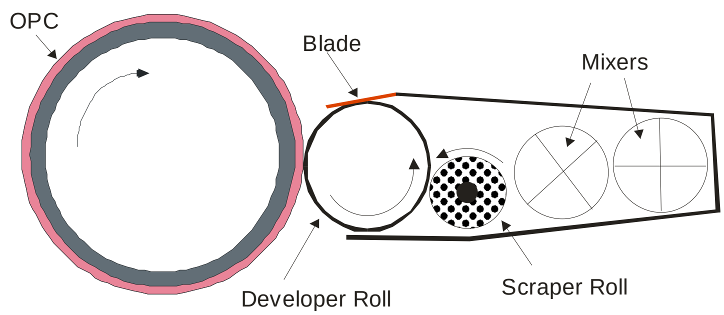

Figure 7 – Single Component Development System

As with previous Figures, Figure 7 is a representation and simplification of a generic system. As such it is not intended to depict an actual implementation. The OPC is shown, but other parts of the EP system are omitted for clarity. The ‘box’ shown enclosing the mixers and scraper roll also contains the toner powder (not shown).

Another system that was used extensively in the past is known as a ‘single component non-contact jumping development system’. The only physical difference between this and the developer outlined in Figure 7 is the gap between the OPC and developer roll in the Jumping Toner method. In addition to this physical difference, jumping development makes use of an AC field between the developer and OPC and contact development makes use of a simpler DC field.

In Figure 7 the black outline that encloses the developer roll, scraper and mixer is the toner reservoir and contains the loose toner powder. The OPC rotates clockwise and bears the latent image pattern in surface charge. In most configurations the developer roll is in contact with the OPC and rotates counter clockwise so that its outer surface is moving in the same direction and speed as the surface of the OPC. The blade is fixed in place and is in contact with the developer roll surface. The scraper roll is in contact with the developer roll and runs counter clockwise so that its surface is going in the opposite direction to the surface of the developer roll and there is a scraping contact between these rolls. The scraper is a softer roll than the developer and is usually made of an open cell sponge material. The mixer is a paddle wheel assembly and rotates to stir the toner in the reservoir and move it toward the developer roll. There may be more than one mixer.

The toner must be charged in order to make it work in the EP system. Ideally it must be charged within a fairly narrow range. That is, all the particles should have about the same amount of charge on them for best results. As noted, toner is charged by contact. There are three important places in the system where the toner may be charged by contact. First, the stirring action of the mixer brings the toner into contact with the surface of the mixer. Provided the material properties of the mixer are correctly chosen, the toner will charge here. Second, as the toner is thrown onto the developer roll and the roll turns, the toner will be carried under the blade. The materials of the blade and the surface of the developer roll are carefully chosen so that the toner will charge here; this is the most intentional charging location in the design. Finally, any toner that was not used for the image will stay on the surface of the developer roll as it rotates back into the reservoir. The scraper roll is provided to remove that toner and return it to the reservoir. The contact between the scraper roll and the developer roll is another opportunity for the toner to charge. In some instances the developer designer may want to limit toner charging to only one or two of these places. Materials can be carefully selected to reduce the charging probabilities on mixer and scraper.

With the surface of the developer roll now coated with charged toner, the roll rotates to bring that charged toner opposite to the image charged surface of the OPC. In contact development the power supply provides DC voltage setting up the required electric field between the developer roll and the OPC. The forces on the toner created by the field cause the toner particles to move between the developer roll and the OPC. If a toner particle moves onto a negatively charged area, it will not stick, because the toner particle is also negatively charged, and like charges repel. If however the particle moves to a positively charged (or discharged) area, then the particle will be attracted (unlike charges) and will stay on the OPC surface and become part of the image.

During the life of a development system there are a number of components that are subject to wear. First, the surface of the roll itself is in rubbing contact with a blade and a roll. The surface of a developer roll may be coated with a special material to help ‘carry’ the toner on it and/or to help generate the charge on the toner. If this surface wears the ability to consistently charge will be affected. This wear can be aggravated by contaminants that get into the toner reservoir. The most serious contaminant is paper dust from the sheets of paper being printed. This dust can be airborne or can be carried on the surface of the OPC. Paper dust accumulates in the developer housing over the life of the unit. Paper dust is much more abrasive than toner, and so as paper dust particles get on the developer roll and eventually come under the charging blade or on the scraper roll, they will begin to abrade the developer roll surface which will lead to non-uniform development and consequent print defects.

As the toner is depleted from the developer by being imaged onto the OPC, the particle size range of the remaining toner tends to change. This is likely to result in the average charge on the toner in the housing changing as the toner gets used up. Over time this means that the toner in the developer becomes less ideal and less likely to perform as designed.

Another factor affecting the toner life is the relative humidity of the environment where the printer is used. As noted above, high humidity will decrease average toner charge and low humidity will increase average toner charge. Toner that is charged in the ideal range is likely to produce the highest print quality and toner that is outside of the target charge range may lead to print problems. For example, toner outside the target range tends to develop on the white areas of the page causing what is known as 'background'. Very highly charged toner can be difficult to remove from a surface and may result in low levels of image density. Also, low charged or uncharged toner also may not be retained on the developer roll and may 'fall' from the roll and/or leak from the developer unit.

Finally, toner may 'block' in the developer unit under adverse environmental conditions. Blocking is the condition where the toner particles stick to each other so well that they form a lump or bridge in some part of the cartridge wall and will not drop away and become re-mixed.

12 Transfer

As the OPC continues to rotate during the print cycle, the next component that comes into play is the transfer roller. Just as some larger and faster printers use a scorotron or corotron for charging the OPC, so those same machines often use a scorotron or corotron for transfer. Most of the desktop and hallway printers use a transfer roller, sometimes known as a BTR for Bias Transfer Roller.

The transfer roll is very similar to the charge roll. It is a conductive rubber coating on a metal rod and a voltage is applied to the metal rod. In this case, the electrical connection is of the opposite sign to that used for the charge roller. For example, if the charge roll voltage is negative, then the transfer roll voltage will be positive. Since the OPC is connected to electrical ground or zero volts, and the transfer roll is connected to a power supply that provides a net positive voltage, there is an electric field between the OPC and the transfer roll. The voltage applied to the transfer roll is usually significantly higher than that applied to the charge roll.

At some point in the print cycle, well before the image on the OPC reaches the transfer roll, the print controller tells the printer to begin feeding a sheet of paper through the printer so that it can accept the printed image. The timing is set so that the first edge of the paper sheet is just past the transfer roller when the beginning of the image on the OPC reaches the transfer roller. This is to insure that there is always paper in the nip between the OPC and the transfer roller when there is toner to be transferred. This in turn is done to make sure that no toner gets on the surface of the transfer roller where it could contaminate the roll and create print defects.

Since the transfer roll voltage is positive and the toner on the surface of the OPC is negative, the toner will want to move under the influence of the electric field towards the transfer roll. The paper is between the OPC and the transfer roll, so the toner moves or transfers to the surface of the paper. The toner image is then transferred to the paper.

Just as the interface between the OPC and the charge roll can create problems, so can the interface between the OPC and the transfer roll. In the case of transfer, the problems are seen as defects on the print. Electric fields are not precisely contained, and as the surface of the OPC nears the transfer roll but is not yet in contact, a weak electric field is set up. The field gets stronger as the two rolls touch. Some toner particles that are not properly charged may move in this relatively weak field. When they do this, they will get to the paper in an area where they ought not to be and if enough of them move, they will be visible and a degraded print quality will result.

As the OPC rotates through the transfer area not all of the toner particles transfer to the paper. The amount of toner transferring divided by the total amount of toner available to transfer is known as the transfer efficiency. Toner may not transfer due to high charge level, strong adhesion forces between the particle and the OPC surface or other causes. It is common to have transfer efficiency between 90% and 97% in the EP process. As the two roll surfaces begin to separate some of the adhering particles that did not transfer may have lost some of their adhesion or charge and they begin to transfer late. This also gives rise to print defects due to toner in the wrong place on the paper.

13 Fusing

After the toner is transferred to the paper it is still loose. It is electrostatically held and will not fall off the paper, but if we were to remove the sheet from the printer after transfer we would be able to rub the toner off the paper with our finger. The toner must be fused to the paper in order to have an acceptable print that can be handled without being damaged or contaminating the user with toner.

The fusing process melts the toner onto the paper. Actually, the toner usually is not quite melted, but it is taken above a temperature that is known as the ‘glass transition temperature’ that is lower than the melting point of the resin. Fusing consists of applying heat to the print so that the toner fuses but the paper does not scorch or burn. Many different methods have been used to fuse toner images, beginning with radiant heaters, including chemical vapor fusers and high intensity light flash fusers. By far the most popular method of fusing is to pass the print through the nip made between two rollers, at least one of which is heated. A modern variation used in some desktop and workgroup printers uses a heated belt and a roll, but the principle is similar.

The principle of the roll fuser is fairly simple. Two rolls are aligned with their axes parallel. At the left side in Figure 2, we see the end of the two rolls. In our illustration the upper roll is the fuser roll and the lower roll is known as the ‘pressure roll’. The yellow disk in the center of the upper roll represents a heat lamp which is used to provide the heat for fusing. When the lamp is turned on the roll begins to heat. Sometimes if a laser printer has a digital display it may show ‘Warming Up’. This means that the heater has been turned on but the roll is not yet hot enough to melt the toner properly.

Fusing depends on getting the toner and the paper up to the right temperature in the time that the paper moves in contact with the rolls. This is a very short time. In order to make the time longer, more pressure is added so that the rolls are squeezed together and the softer pressure roll flattens a bit. Because pressure can only be applied at the ends of the roll, the center bends very slightly causing the flat area to be smaller than at the ends. This can be illustrated by taking a soft foam rubber roll and placing it on a sheet of glass. Look from the other side of the glass while pressing the ends of the roll onto the glass. You will see a ‘bowtie’ effect where the roll meets the glass. Since the rolls are pulling the paper through, this means that the paper will travel at different speeds at the ends versus in the center. This can cause wrinkles and can even tear paper. To overcome this problem, the rolls may have slightly offset axes, or may even be machined so that they are smaller diameter at the ends versus the diameter in the middle.

We have already noted that the bulk of a toner particle is a plastic resin of some kind. If you heat these kinds of plastic they first get soft and then become liquid and will flow. The toner plastic needs to be heated to somewhere between the soft and the liquid stage in order to make it stay acceptably on the paper for use as a print. In a hot roll fuser, the pressure between the rolls is used to squeeze the plastic into the paper when it is in this very soft, almost liquid state. Unfortunately, plastic in this state is also very sticky and behaves like glue. Unless something is done about it, the toner will transfer to the surface of the fuser roll and contaminate the roll leading to print defects. In the extreme, the toner will adhere to the fuser roll and take the paper with it, causing the paper to wrap around the fuser roll. This will create a jam and may lead to mechanical damage to the printer.

To overcome this problem it is customary to use a fuser roll with an extra smooth surface, such as Teflon. Even this is not sufficient in most cases. Early roll fuser systems all used a complex system to coat the fuser roll with oil, typically silicone oil. The oil was carefully metered onto the roll to enable release of the toner but to make sure that an unacceptable amount of oil did not transfer to the print. Some high speed systems still use this method.

Most smaller printer systems today use a different approach. They use a toner that is modified so that it will not be quite so much like glue. This is accomplished by incorporating a lower temperature wax into the toner formulation. In the fuser system the wax melts first and has two effects. The first is that some of the wax transfers to the surface of the fuser roll and creates a very slippery surface so that the toner resin will not stick. The second is that since the wax melts first, the ‘wet’ interface between the toner and the roll becomes the wax which forms a layer between the toner resin and the roll, also preventing transfer.

Whether the fuser uses an added release agent such as silicone oil, or wax in the toner, some very small amount of toner can transfer to the surface of the roll. Most fuser systems include a cleaner that is pressed against the surface of the roll to remove this stray toner so that it cannot get onto the print and cause a defect.

Following the fuser, the print is ejected into the output tray and is ready for the user.

14 Cleaning

As we mentioned in Section 3.12 above describing transfer, not all of the toner is transferred to the paper. This toner must be removed from the surface of the OPC before the surface is used for another print. This is known as the cleaning stage.

In Figure 2, the box shaped object on the left of the OPC represents the cleaner. Brushes, fabric rolls and vacuums have been used as cleaners in EP systems, but the most common cleaner is a blade as shown in the Figure.

The small pink line at the top right of the cleaner box is the cleaning blade or wiper. The cleaning blade is made of a rubbery material such as polyurethane and is pressed into contact with the OPC. The tip or edge of the blade may be used, but the function is that of scraping. As the OPC rotates, the blade scrapes toner from the surface and the toner falls into the box. This box may be known as a reservoir or hopper and it is used to collect this toner which is known as 'waste' toner. If the hopper is very small, there may also be a means of moving the waste toner to the side where it can be collected in another container.

Waste toner is never recirculated into the developer unit for use on prints. It may have been deformed, additives may have been transferred, and it almost certainly now contains paper dust. All of these items make it unusable for quality imaging.

Occasionally there are cleaner faults. Most commonly these are caused by toner particles jamming between the cleaner blade and the OPC surface. This can result in a 'tuck' or it can lift the blade away from the surface locally. When the blade is not in contact with the surface, waste toner can pass through and be deposited on the next print where it is not wanted and causes defects. Tucks can allow enough toner through to create streaks on the print.

15 Color Electrophotography

15.1 How colors are made in the printer

It is necessary to review how we see color in order to understand how color is created in laser printers. Most of us are familiar with a science experiment where we use a triangular piece of glass known as a prism to 'split' light into the colors of the rainbow. We may not remember that the light that we split was light that we would normally see as 'white' light such as sunlight. The experiment shows us that what the eye sees as white light is actually a combination of all of the colors of light that we can sense.

If we were able to reverse this experiment and had three different light sources, one of each major or primary color, red, green and blue, and we were able to combine these lights, the result would be that we would see white light. The Figure below is an illustration of how this happens.

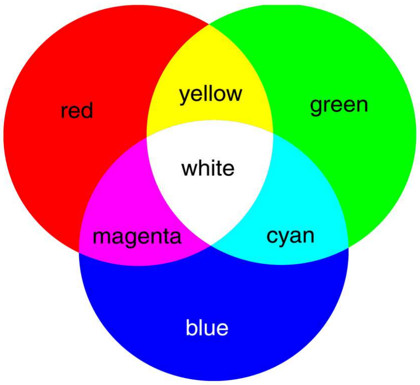

Figure 8 - Additive color primaries

Notice that as these primary additive colors overlap, they create cyan, magenta and yellow.

If we shine the white light onto a sheet of ordinary paper, we see white paper. This is because paper efficiently reflects all of the colors. If we then placed a sheet of yellow cellophane over the paper we see yellow paper. This is because the yellow cellophane absorbs all of the colors except yellow. The yellow part of the light passes through the cellophane, then reflects from the paper, passes back through the cellophane and we see it as yellow. It is said to 'subtract' all of the colors except yellow.

This is how color prints are made in color laser printers. The three subtractive primary colors are illustrated in the Figure below. In subtractive color theory we have three primary colors, but they are the colors of the cellophane, not of the light.

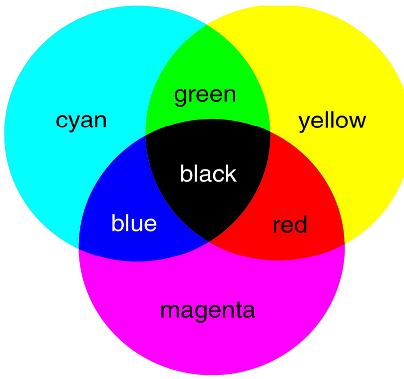

Figure 9 - Subtractive color primaries

Notice that the primary colors here are cyan, magenta and yellow, and as they overlap we can make the additive primaries of red, green and blue. Also notice that when all three subtractive primaries overlap they create black. So if we created three sheets of cellophane, one cyan, one magenta and one yellow, and placed them over our white sheet of paper, we would not be able to see the paper at all, it would look black.

In a color laser printer, we use the toner in place of the cellophane to make colors on a white sheet of paper. We must make the toners so that light can pass through them, or this will not work. So if we want a green patch on the paper, we place cyan and yellow toner there and they combine to make green. It is very hard to make a really good black from cyan, yellow and magenta toners, so most laser printers use a black toner instead.

Incidentally, if the paper for a laser print is other than white, the combination of cyan and yellow will not produce green because the light reflected back though the toner layers will have the color of the paper subtracted from it.

One of the design issues for a color laser printer is that of providing and maintaining color balance in the printed image. Color balance is simply having the right amount of each of the primary colors to produce the intended color on the print. So, if we want to print a light green, then yellow and cyan toner need to be placed on the page in the right proportions to get the right degree of 'lightness' in the green. In that case, there would be more yellow than cyan.

The amount of toner placed on the OPC in response to a given input image color can vary with humidity, and wear of the OPC, developer roll and toner. In order to maintain the correct balance, the printer needs to know just how much toner will be placed in response to the charge level. This was not much of a problem for monochrome EP printers but is a very serious challenge in color printers. The print engine usually incorporates a special system for checking itself in this respect. Sometimes the user can be aware that this system is operating because the printer may indicate '*Calibrating*', or '*Adjusting Print Quality*' before it prints. At that time, the printer prints a series of color patches, one for each primary color, on the OPC. The printer may use a small light such as an LED, and a sensor to measure the amount of toner that has been printed on the OPC, or it may use a capacitive sensor to determine the patch density. The printer may also transfer the patches to an intermediate drum or belt before making the measurement, but in any case, it then cleans the patch before making a print. The measurement is used to adjust either the charge setting on the OPC, or the bias voltage on the developer, using pre-set information stored in the printer. This procedure is used to make sure that color density always prints correctly.

15.2 Color EP architectures

To print in color a laser printer needs to be able to place at least the three primary colors of toner plus black toner onto the paper.

The computer application, the printer driver or the RIP in the printer first divides the image up into these four colors, in effect making four images from the one. One of the images will just have all of the cyan parts, another all of the magenta and so on. Each of these four images is printed separately in the printer and carefully re-combined onto the paper to make the print. Each image is printed using the EP process as described above. Doing this four times in a single printer and getting it onto the paper is not always done in the same way. The way that the major components of an EP system are arranged in an actual machine is often referred to as the 'architecture'. There are two major machine designs or architectures that use EP to make color images and we shall refer to them as 'four pass' and 'single pass'.

In a four pass color EP system there is only one OPC, one cleaner, one charger and only one laser exposure system, but there are four developer units, one for each color.

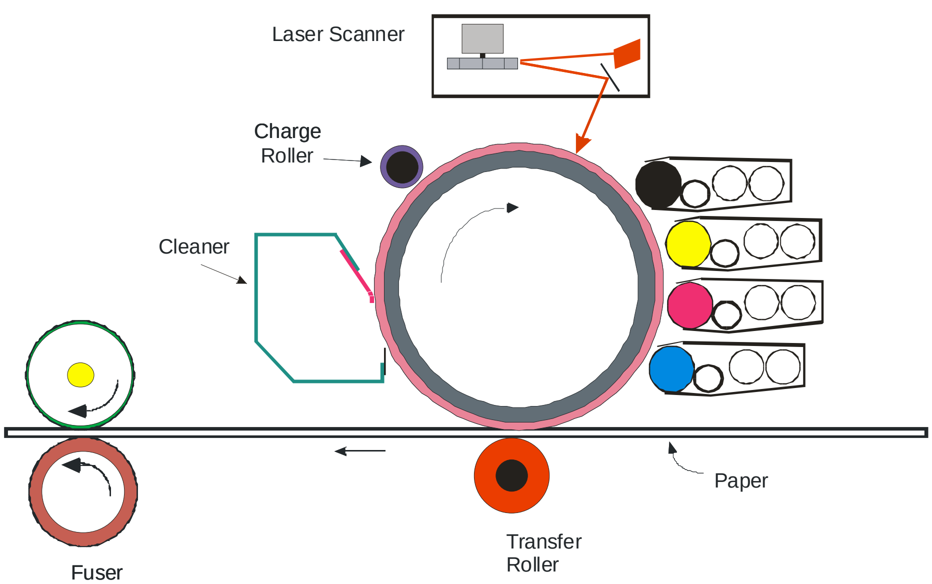

Figure 10 - Possible Architecture for 4 Pass Color EP

Figure 10 shows the simplest possible configuration for a four pass color EP system. This is a modification of Figure2 that was used at the beginning of this report. The system would first image the black layer of the image onto the drum, then turn the drum and put the next layer on, and so on until all four colors were imaged, then the image would be transferred to the paper and the cleaner would be used to remove excess toner before the next image. Unfortunately this color architecture is simple as an architecture but almost impossible to make work. Most of us will see that the cleaner blade would clean off the images between exposures. That is not the biggest problem however since the cleaner could be lifted out of place until needed. When there is an existing toner image on the surface of the OPC, it cannot be easily charged to exactly the same level as the bare parts of the OPC surface and also, the next developer will start to pull off some of that existing toner layer, contaminating itself in the process. Only one commercial implementation of this kind of EP has ever been successful and it is in a half million dollar machine. Most four pass systems use the architecture shown in Figure 11 below in order to solve the problem.

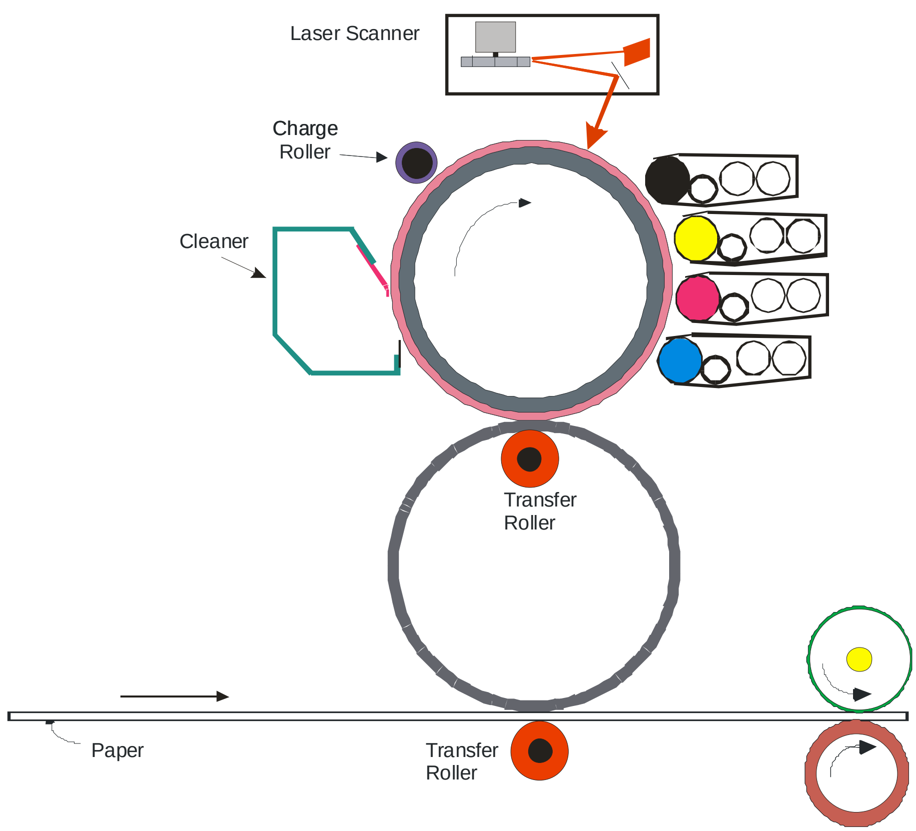

Figure 11 - Typical Four Pass EP Color Architecture

In this architecture there is another drum (it can be a belt) known as the 'intermediate drum' that has an outer coating that is an insulator and an inner coating or layer that is a conductor, similar to the OPC except that there is no need for the photo and charge retention properties of the OPC . The first image is made and transferred electrostatically onto this drum. Then the next image is made and transferred onto the drum in the same way. Toner images can be transferred easily on top of each other but cannot be developed easily on top of each other. After all of the images are accumulated onto the drum, the paper is brought up into the second transfer zone shown at the bottom of the intermediate drum, and all four color images are transferred at once onto the paper and then fused together. Even though the extra hardware of the intermediate drum is needed, the saving in OPCs, chargers, laser exposure systems etc makes the four pass system lower in cost that the single pass system.

Single pass color EP systems use four individual complete EP systems in parallel to create the color image.

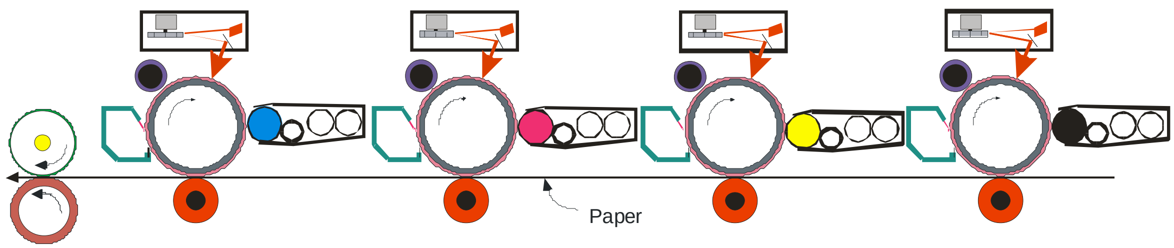

Figure 12 - Typical Single Pass Color EP Architecture

In Figure 12, each of the four color systems works as described in the general section of this report. Each has a different color toner in the developer unit. Each transfers the color image to the paper in sequence until the entire image is on the paper and the image is then fused. Many real single pass systems transfer the color images onto an intermediate belt and then transfer the complete image onto paper before fusing.

Single pass systems are more expensive to build than four pass systems. If the OPC speed is the same in a single pass system and a four pass system, then the single pass system will print about four times as fast as the four pass system. For these reasons, four pass systems are generally offered in low cost color EP printers and single pass systems are offered in higher speed more expensive printers.

Color printers have several print quality attributes that represent much higher challenges than monochrome. Two of the more significant requirements are for color registration and for color balance. The four colors of an EP color image are printed separately and combined on either an intermediate drum or belt, or on the paper. Any small mis-alignment between these images, even a few thousandths of an inch, can be detected by the human eye. The four pass architecture has a small advantage over the single pass architecture in this respect since the mechanical alignment of each color image is governed by the single OPC and single intermediates system. The designer of a single pass system must take great care to align each of the four systems mechanically so that these registration errors are minimized.

16 Color Electrophotographic Machine Design – Cartridges

16.1 Cartridge Design

As noted above, the color EP process is extremely complex. One of the most significant developments in the evolution of EP printers was the invention of the integrated supplies cartridge or EP cartridge. This took what had been perceived as an unreliable, somewhat dirty process and made it user friendly and easy to fix. It is not a stretch at all to say that without the cartridge concept, color EP could not be made possible in an acceptable product. It needs to be emphasized that the name 'toner cartridge' is misleading. The cartridge is actually a container that incorporates most or all of the sophisticated and complex components needed to make the EP process work, as well as the toner.

Before the EP cartridge, when the EP process failed, the user had to call for a service engineer to come and fix the problem or replace the failed part. Even toner replacement was liable to result in toner spillage, excessive airborne dust and other problems that are unacceptable in the home or office. The cartridge resolves all of these problems by packaging the unreliable parts and toner into a single component that can be easily and safely replaced by the printer owner. The integrated supplies cartridge must be very carefully designed and tested by the manufacturer so that there will be no component failures before the printer stops printing due to low or no toner. An early monochrome supplies cartridge is illustrated by the cutaway view of a relatively simple early Canon monochrome cartridge in Figure 13.

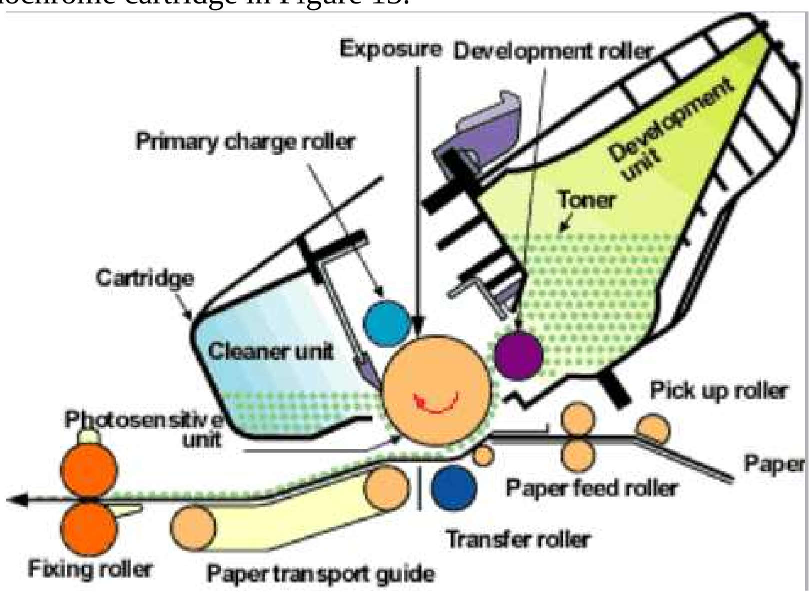

Figure 13 - Cutaway View of Early Design Canon Black Cartridge

As can be seen, all of the EP functions except exposure and transfer were incorporated into this cartridge. In this case, there were no mixers and gravity was used to feed toner onto the developer roll. Some toner could easily become lodged in the upper left area of the reservoir and this explains why the idea of shaking a cartridge when the print quality is poor is now part of user folklore. Shaking this cartridge would tend to dislodge toner in these areas.

The first cartridges were for monochrome copiers and laser printers. The printer usually included a density control that the user could set. The user could increase the density setting and get darker prints when the prints began to fade. The density setting often controlled the bias voltage on the developer roll. This often enabled the user to get a higher apparent yield from the cartridge than specified by the manufacturer. Finally, when this failed and the prints were unacceptably light, the user would be instructed to replace the cartridge. Even then, there would still be some toner left in the cartridge due to toner blocking, adhesion to the walls of the cartridge and 'dead spots' where the paddles could not reach.

In color EP systems there are two general kinds of cartridge that contain toner and they are related to the printer architecture. Four pass printers usually have a cartridge that contains the components depicted in Figure 7. That is, in addition to the toner, the cartridge includes the developer roll, blade, scavenger roll and mixer. Single pass systems often have a more complex cartridge that contains these components but also contains the OPC, cleaner, waste toner hopper and charger.

There is a price to be paid for the convenience and reliability that the integrated supplies cartridge brings. Since there are a number of sophisticated components in the cartridge, not just toner, these components are replaced together when the cartridge is replaced. All of these components, the OPC, cleaning blade, developer roll, charger roll will have wear and may be approaching failure. As noted before, the challenge of the cartridge designer is to insure that the most probable non-toner failure does not occur before the toner failure occurs. In this way, the customer perception is not that the printer is unreliable, but that the toner needs to be replaced.

16.2 Cartridge Toner Sensors

Often, especially if the user is to be warned that a cartridge needs replacing soon, the printer needs to have some knowledge of how much toner remains in the cartridge at any time, especially as the toner gets used up. There are two primary methods that manufacturers use to check toner availability. The first is to assess how much toner has been printed by measuring the actual size of images as they are printed. This is known as ‘counting bits’. The second method uses a sensor. The toner is constantly being stirred in the reservoir, so a level sensor will not work well. Instead, manufacturers use transparent panels or light pipes on the cartridge sides and shine a light through the reservoir. The amount of light passing through the reservoir is measured and is related to the amount of toner remaining.

Although there may be some variation between printer models, the general approach to toner sensing is as follows. With approximately 25 percent of the toner remaining in the cartridge, the sensor begins measuring and reporting the amount of toner remaining. Whereas a full cartridge will block all light, cartridges with below 25 percent toner remaining will not be sufficiently dense to do so, and as an ever-decreasing number of toner particles remain in the reservoir, the amount of light passing thought the reservoir increases. At some point, the amount of light will correspond to the point that the manufacturer has determined, through its testing, that the cartridge has reached its end of life due to toner depletion. The actual amount of toner remaining at this point will vary due to tolerances in the sensor and also the fact that the beginning amount of toner in the cartridge will vary based on the accuracy of the system used to fill the cartridge in the first place. That is some cartridges will be filled with a little more toner than others at manufacture.

16.3 Cartridge Yield

The number of prints that can be made from a cartridge is known as the cartridge life or cartridge yield. The cartridge is marketed as having the capability to print say 5,000 letter size pages, each page having a stated toner coverage such as 5%. This projection is based on extensive testing, usually to an industry accepted test protocol with defined images to be printed. The most often quoted standard for testing the yield of color EP cartridges is ISO 19798.

In general a cartridge that has a yield of 5,000 prints at 5% coverage would be expected to be able to provide 2,500 prints at 10% coverage, but not necessarily to be able to provide 10,000 prints at 2.5% coverage. This is because cartridge life is not the same as cartridge yield. This is important because users do print pages that have various amounts of toner on them. It is impossible for a manufacturer to predict the actual toner usage pattern for each printer. Some users may print mainly photos and use up toner from a ‘5,000 print cartridge’ in less than 1,000 pages. Some may print mainly labels and the toner in the cartridge could be enough for 10,000 of these pages.

16.4 Cartridge Life

As noted above, cartridge life is different from cartridge yield. Cartridge yield speaks only to the amount of usable toner in a cartridge. Cartridge life recognizes that the cartridge has other components that can fail and cause an end of the useful life of the cartridge.

We have described component wear issues in the sections describing OPC, charge roll, developer and so on. In addition to component wear, cartridges can leak toner. Leakage is the problem of containing all of the unused toner in the cartridge and making sure that it does not leak out and land where it is not wanted. For the developer unit that contains the toner the developer roll has end bearings that must be sealed to prevent toner from escaping. Sealing the developer unit completely is almost impossible, and the seals that are in use do wear and may eventually allow toner to leak into the printer. Toner also escapes from the developer where the roll is open to the OPC, especially as the roll returns toner to the reservoir. This area cannot be effectively sealed otherwise toner would be scraped from the roll and not returned to the reservoir. In larger more expensive laser printers, it is not unusual to have some form of vacuum applied to the interior of the developer in order to prevent toner from escaping from this gap.

Toner wear is an additional problem that the cartridge designer must take into account. The charge on toner particles is partially governed by the additives on the surface and by the humidity of the environment. As noted above, smaller particles have a lot of charge for their size and larger particles have less charge for their size. This means that the some particles will develop preferentially than others as they will move more easily in an electric field. Over time, this will affect the particle size distribution of the toner in the reservoir and if not compensated, will change image density.

As toner is developed, it is mechanically worked by the scraper roll, the charging blade and the mixers. This happens whether toner is developed or not, and is a function of how many prints are made. All of these actions can remove additives from the surface of the toner particles and therefore affect charge, also affecting image density. As noted above, the printer can compensate for image density by changing the bias on the developer roll, but there are limits to this compensation effect.

The median size particles that are correctly charged will tend to be developed first, and this means that as prints are made, the toner remaining in the reservoir is made up of less and less ideally sized particles and normal charge and more and more of the less than ideal. As the supplies cartridge is used to make prints, the net effect of all of these factors is that the ‘good’ or usable toner gets used to make prints and the proportion of ‘bad’ or unusable toner increases in the reservoir.

The testing done during the development of the printer is aimed at determining just how long the developer system can keep working properly before the printer loses the ability to compensate for wear. The results of this testing are used to make developer or cartridge life predictions that are usually passed on to the customer in terms of expectations.

Rather than ending the cartridge life when the toner runs out, the cartridge may be set to reach end of life using a “Hard Stop’. This is a more complex method to implement, and may be preceded by a warning to the user that the toner is low. The Hard Stop approach is used when the manufacturer wishes to provide consistent print quality for the complete life of the cartridge. This means that the end of life must be reached at the point where there is still sufficient toner in the reservoir to make the last print at the acceptable level of print quality set by the company. This in turn means that there must be a reliable toner sensor. Since print quality defects can be caused by wear on the developer system and the OPC drum, the manufacturer must decide how many prints can be made by the cartridge before any such failure will occur. Unlike running out of toner, this factor relates only to number of prints, and is not related to the toner coverage on those prints. The Hard Stop is invoked when either the toner sensor indicates that there is not enough toner in the reservoir to provide acceptable prints, or when the cartridge has completed a certain number of prints, whichever factor occurs first.