Electro-Photographic Monochrome Cartridge Yield Testing: Problems, Approaches, Suggestions

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Introduction

Measurement of toner cartridge yield has a number of uses in the marketplace:

- Use by customers for comparisons between products
- Measurement of design goals by manufacturers
- Calculation of Total Cost of Ownership (TCO) by purchasing departments
- Use in marketing specifications

In the past, several methods were used to measure cartridge life. The methods varied by manufacturer, consultant, reviewer and consumer. In each case the methodology fulfilled a specific need for that user. However, the variation in methods made direct comparisons impossible. This created a lot of confusion in the marketplace and in customers' minds. The establishment of a standardized methodology for the measurement of cartridge yield would clear up confusion in the marketplace. It would allow customers to focus on other aspects of the purchase decision, marketers to reliably represent their products, and manufacturers to set design goals to monitor their production. In short, an accurate and repeatable method for measuring cartridge yield would enable products to be manufactured, marketed and sold with a higher degree of confidence.

History

As previously stated, several methods have been developed for the measuring cartridge yield. Two of those methods and their associated issues will be discussed.

EPMI developed one of the earliest methods used to determine cartridge yield[1]. The test page used in this method was developed for ISO/IEC 10561[2] (aka Dr. Grauert), a standard written not to measure cartridge life, but to measure the throughput speed of printers. ISO/IEC 10561 was used as the starting point because it defined a page used as input into the printing system. This method suffers more from its age than anything else. The strategy of using a test file based on a business letter allows a consumer to relate to the type of pages used for measurement. This makes the measurement more significant to customers. However, the standard page file used was designed before the desktop publishing revolution, which facilitated more complex page description languages. As a result, the file used is rendered only in 11-point Courier font without any graphical content. This simple rendering is no longer standard even in the most basic of applications. Other issues include a loosely defined end-of-life criterion and how to deal with defective printers or cartridges.

The Standardized Test Methods Committee (STMC) has established another method for yield calculation[3]. This standard is based on ASTM F1856, Standard Practice for Determining Toner Usage for Printer Cartridges. As the title implies, the methodology calculates how much toner is deposited on a sheet of paper. This measurement is performed after calibrating the printer to provide a certain area coverage of toner on the page. Using this standard and measuring the mass of toner in the cartridge; an estimate can be made regarding the cartridge yield. However, the standard does not explicitly give a procedure for determining end-of-life, if toner is consumed non-uniformly throughout the cartridge life further approximations and more complex testing must be made. It is also assumed that all toner in the cartridge is used during printing. As before, the standard was not specifically designed to measure cartridge yield.

Additionally, the calibration of the test page for each printer and cartridge type does not permit accurate comparisons of the system performance in the field. For example, if printer "A" prints thicker characters relative to printer "B", the number of characters on a test page printed by "A" will be reduced in number compared to "B". Using ASTM

F1856-98 the test pages for both printers are modified such that page coverage is 5% ±0.5%, allowing page coverage to range as low as 4.5%. In the marketplace, the customer will not adjust the number of characters for a business letter when printing. The modification of the test sheet on a printer or cartridge basis makes comparison of intra-printer test results difficult.

Issues in Testing

In order to accurately and repeatedly measure and represent the expected yield of a cartridge, care must be taken in several areas. While not all inclusive, the following areas spotlight the major sources of error in yield measurement.

- Test page creation and printing
- Control of the printing environment
- Determination of end-of-life
- Sampling and statistical evaluation

Test Page Creation and Printing:

In support of its broad intended use, the test page should be designed and formatted to minimize potential device dependence. It should include font and graphic elements representative of current word processing technology. Fonts and gray scale should be specified as such, not forcing abnormal rendering and screening behavior on the printing device. Any increase in coverage of the toned image from the digital specification (spot growth, or dot gain) must also remain the normal behavior of the printing device. Starting with the general form of a business letter, the test page should include some specialized content in order to facilitate certain measurements and to assure it is being printed at the correct size. Its digital file format should be robust, independent of the computer, the operating system, and the installed fonts.

Control of the Printing Environment:

The electro-photographic (EP) process is sensitive to variations in environment. Comparison of yield tests results requires strict control over temperature and humidity. In a controlled test environment, all components under test should be allowed to acclimate before testing commences. Components needing acclimation include the printer, paper, and EP cartridges.

Determination of End-of-Life:

Determining a standardized condition for end-of-life is not as simple as one may assume. End-of-life may entail the onset of a fade following several cartridge shakes, activation of a Toner Low/Toner Out alarm or both. Fade appears as degraded print quality due to toner starvation. This is easy to recognize visually, yet hard to define quantitatively. A standard requires some quantifiable method to be used. The measurement itself should remain quick and simple to prevent disruption of testing. Though fade should be measurable anywhere on the printed sheet, features for detection must not overshadow the nature of the test page. A standard must also accommodate whether the cartridge is to be shaken at the first sign of fade and if the printer supports a toner out/toner low detector.

Sampling and Statistical Evaluation:

Due to manufacturing variations engines consume toner at different average rates. This results from varying laser power, spot size and development/charging biases. Due to manufacturing tolerances, cartridges will contain varying amounts of toner. All of these factors figure into providing an accurate assessment of cartridge yield. Use of single cartridges and engines has the potential to give a skewed answer for the average cartridge.

ISO Standard Development

For the past two years work has progressed on development of an international standard for the measurement of monochromatic cartridge yield. This work is being done under the auspices of ISO/IEC JTC1 SC28. SC28's charter is the creation of standards for office equipment. An IDC report served as the starting point and laid the groundwork for the future standard proposal. Development of the standard has gone through much iteration with comments from persons involved in every aspect of toner cartridge use. Touching on the issues previously described, the thought process and methodology for testing follows.

Philosophy:

The guiding principal in this standard was to create a methodology by which cartridge yield specifications would be comparable between designs. The committee decided to use a consumer type test page, as opposed to a fixed percent toner coverage page. This facilitates better understanding of published results by users. The committee took care to make the process as simple and cost effective as possible without sacrificing accuracy.

Test Page Creation And Printing:

In support of the objectives mentioned above, the test page is based upon a business letter format. It includes text and some graphics. Fonts and gray scale are specified as such, allowing the printing device to use its rendering and screening behavior as the consumer would see it. The text is specified in 10-point Times, with Arial used in the logo and 6- and 8-point Times (Bold Italic) used in the captions. The logo combines line art and text, and a small chart with bars in specified percentages of gray is included.

To facilitate certain measurements, four one-centimeter black squares are added near the corners. The centers of each contain half-centimeter reverse squares, reducing the coverage. The squares are offset from one another, both horizontally and vertically, to more evenly distribute the toner coverage, whether the test page is printed in portrait or landscape format. Lines of text, facilitating the observation of fade, connect the four squares; these lines are slanted to accommodate the offset. A black line marked "A" is attached to one of the squares and the side of another is marked "B" to act as a fiducial marks when confirming that the printed size is within specification. The margins of the test page are designed so that the test target can be used with either A4- or Letter-sized paper; note that even though the coverage percentage is changed, the same amount of toner will be used.

The test page is provided as a digital file in Portable Document File (PDF) format in order to maximize device independence. The file contains the required font information, and any font substitution should be turned off when printing. The file may be printed from a wide variety of computer types and operating systems by using Adobe's free Acrobat Reader. The latest versions of Acrobat Reader allow printing of the test page from multiple versions of Windows (95 through XP), Macintosh (OS 9.0.4 through OS X), and UNIX (Linux, Sun, IBM, DEC, HP, and SGI) operating systems. The most recent printer driver available from the manufacturer should be used. All image and print quality modifiers should be at their factory pre-set configuration for the printer and default install condition for the driver. If the printer and driver differ, then the driver defaults should be used. Any user selectable toner conservation modes should be disabled. Any scaling such as fit-to-page, must be disabled.

The test is run in continuous print mode simplex printing, with printed output occurring at or near rated printer speed. If testing two cartridge types in a printing system, the cartridges should be tested at the same time using printers and drivers set to the same settings and printing should be done on the same paper.

Control of Printing Environment:

As mentioned previously, the EP process has sensitivities to variation in the printing environment. For this reason, printing conditions have been carefully defined. The use of running averages reduces the amount of necessary environmental control hardware. Both temperature and humidity are controlled as follows:

Temperature: Testing room average 23.0C ±2C

Readings to be made with a running average of 1 hour with readings recorded at least every 15 minutes. All recorded temperatures are to be between 20.0C and 26.0C.

Relative Humidity: Testing room average 50% ±10% RH

Readings to be made with a running average of 1 hour with readings recorded at least every 15 minutes. All recorded humidities are to be between 35% and 65%.

Control of the running average tolerance as opposed to individual measurements allows larger excursions in the environment to occur. These excursions are usually the result of user interaction with the printer. The larger tolerance on individual measurements enables the use of less costly environmental controls.

Determination of End-of-Life:

The standard takes into account several types of printing systems. It defines the end-of-life for systems requiring shake of the cartridge, printers with Toner Low/Toner Out sensors and combinations of these. Determination of fade due to end-of-life posed a large challenge to standardization. Everyone recognizes fade on the printed sheet, yet measuring fade provides difficulties. Originally, densitometry was considered for judging fade. This added cost to the test equipment required and considerable time to the testing process. After much discussion, the committee defined fade as a visible break of 3mm on the text occurring at both the top and bottom of the sheet. This method, while not perfect, provides a common quantifiable point for determination of fade. A visual fade can occur sooner (Figure 1), but in practice, few additional pages are printed before the 3mm break condition is occurs (Figure 2).

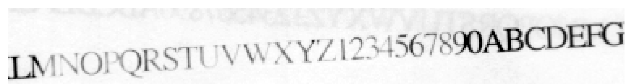

Figure 1. No fade

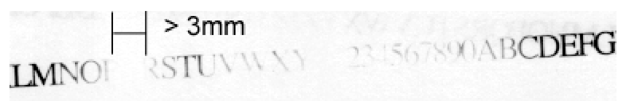

Figure 2. Fade has occurred

This methodology enables quick assessment of pages during testing without expensive equipment.

Sampling and Statistical Evaluation:

In a perfect world, the test population would fully reflect the range of engines and cartridges found in the field. Testing would entail a large number of engines with even more cartridges per engine. The first proposal employed four engines and four cartridges per engine. This would provide a set of 16 cartridges for statistical analysis. Unfortunately, this testing strategy requires significant time and money, excluding its use by smaller organizations. A concession reduced the engine quantity to three with three cartridges per engine. This provides a group of nine cartridges for analysis. The standard does acknowledge larger test populations as long as the number of cartridges tested is the same for each engine.

Data from testing are analyzed using standard confidence bound methods.

Sample Average,

$$\overline{X} = \sum_{i=1}^{n} \frac{x_i}{n}$$

Sample Standard Deviation,

$$s = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{(n-1)}}$$

With 90% confidence, the true average yield of the cartridges falls within the following bounds:

Lower Confidence Bound

$$LCB = \overline{X} - \left(t_{\alpha/2,n-1}\right) * \frac{s}{\sqrt{n}}$$

Upper confidence bound

$$UCB = \overline{X} + \left(t_{\alpha/2,n-1}\right) * \frac{s}{\sqrt{n}}$$

where

n Is the sample size. For testing n shall be ≥ 9

$t_{\alpha/2,n-1}$ Can be found on a Students' t-Distribution Table with n -1 degrees of freedom (df or 'ν') and an α of 0.1. (in this example, n –1 = 16-1 = 15) This provides a 2-tailed confidence interval with 90% confidence. This specific t-statistic for 15 degrees of freedom, and 90% confidence is tα/2,n-1 = 1.753. This can be used in the above calculation, only. A different sample size and/or different confidence interval will yield a different tα/2,n-1.

From these calculations, the average cartridge yield is reported as the *LCB*. Use of this method allows a manufacturer to test a larger number of cartridges, potentially increasing the stated yield by reducing the uncertainty reflected in the confidence interval.

Conclusions

The previous discussions cover key issues surrounding the creation of a yield standard for monochrome EP toner cartridges. A developing standard within ISO/IEC JTC1 SC28 address solutions to these issues. It is intended that development of this standard will enable consumers, manufacturers and marketers to better understand and represent one aspect of the performance of an EP cartridge. Work on this standard and others within SC28 is open to all interested parties. Please contact your national representative for more information on participation.

References

1. EPMI – Guidelines on Evaluation of Printer Cost of Ownership, Part 2 – Dye Carrier Print Volume, First Edition 1995.
2. ISO/IEC 10561 – Information technology – Office equipment – Printing devices – Method for measuring throughput – Class 1 and Class 2 printers, 1991.
3. http://www.i-itc.org/STMGuide.htm – Section 9.

Biographies

Paul Jeran joined Hewlett-Packard in 1992. During that time he has been involved in the development of new printing technologies, print quality measurement and printer reliability. Currently he is a member of the Advanced Technology Section working to establish print quality metrics for LaserJet printers. He is an active member in ISO/IEC JTC1 SC28 standards committee. Mr. Jeran received his BS and MS degrees in Mechanical Engineering from the Rochester Institute of Technology.

David Spencer founded Spencer & Associates in 1989, having previously been founder and chairman of Data Recording Systems, creators of the first 1000 dpi laser printer; group executive of Muirhead North America, the graphic arts equipment developer; president of Datalog, the printer division of Litton Industries; and head of graphics engineering at EG&G, developer of the Unifax II NewsPicture receiver. Currently he consults on color print quality and manages the *SpencerLab* Digital Color Laboratory, which performs independent testing of print quality and throughput performance as well as cartridge yield/cost-per-print. He is an active member in ISO/IEC JTC1 SC28 standards committee. Mr. Spencer received his BS and MS degrees in Electrical Engineering from the Massachusetts Institute of Technology.