An Instrumented Cartridge Method for Quality Control of Photoconductors

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Abstract

For economic and ecological reasons, original equipment manufacturers and recycled EP cartridge suppliers alike are under intense market and social pressure to recycle every component as many times as possible. As a result, the demands on recycled components are being stretched, often beyond the life expectancy designed into them by their manufacturers, and this can result in appreciable degradation of performance. Substandard product performance threatens the commercial viability of recycled products in the marketplace. Confronting this problem, recyclers of EP cartridges must work extra hard to ascertain the quality of recycled components, using the quality control methods available. Unfortunately, these are generally of limited usefulness. The most common methods are visual inspection and print testing, neither of which is capable of delivering objective, quantitative measurements or dependable predictions of remaining life. Better alternatives are clearly needed. This paper discusses a method of evaluating recycled and new aftermarket photoconductors using instrumented cartridges to measure performance. The design of a practical test system based on this method is described, and the efficacy of the system is demonstrated with laboratory and field test data.

Introduction

The essential challenge for toner cartridge recyclers is to determine whether a component can be reused or whether it should be reconditioned or simply discarded. In the early days of the toner cartridge recycling industry, recyclers routinely replaced used photoconductors – typically organic photoconductors (OPCs) – with new aftermarket OPCs, because they lacked confidence in the quality of the recycled components. This attitude persists today. As the industry grows in response to both economic and environmental opportunities, it also becomes more competitive, and market pressures to reduce price and costs increase. In an effort to meet market demand and control costs, many recyclers are now reassessing their reluctance to reuse recycled OPCs. Since the OPC is the most expensive component in a cartridge, multiple reuse of this component makes very good economic sense as long as high performance quality can be maintained.

While a few recyclers have developed or invested in systems for tracking OPCs, many have neither tracking systems nor any means of maintaining historical information on used OPCs. In the absence of such information, assessing reusability is difficult, if not impossible. Most recyclers today continue to rely on the traditional methods of visual inspection and print testing as their primary screening tools. Unfortunately, these tools are neither quantitative nor predictive, and a more precise method is therefore needed to realize the goal of recycling OPCs with assurance of continued high-quality performance.

A method of assessing recycled OPCs for reuse by means of a specialized scanner was introduced by Tse et al.[1] in an earlier paper in which the authors demonstrated that charge acceptance, discharge sensitivity and dark decay measurements can be correlated with the usage history and residual life of a used OPC. This method is now available commercially and has been successfully implemented in both manufacturing and remanufacturing applications.[2]

While the scanner-based method is well established and growing, the cost of these systems is relatively high and often beyond the reach of recyclers, and a lower-cost alternative is needed to serve a broader remanufacturing base. This paper introduces an instrumented cartridge method of OPC evaluation for product development, quality control, and drum life assessment in toner cartridge remanufacturing.[3] Tse et al. have previously demonstrated the use of instrumented cartridges for evaluating charge rollers.[4] Thus, the idea of using instrumented cartridges for component testing is not new, but applying the concept and the underlying methodology to the problem of assessing used OPCs for continued reuse does appear to be novel.

The authors are not aware of any prior publications describing such an application.

One advantage of the instrumented cartridge method is that the printer is effectively used as a scanner, thereby eliminating the cost of a special scanning mechanism and lowering the overall cost of the system. Another advantage is that tests are performed in a printer, and the test environment therefore simulates the actual operating environment. On the other hand, the instrumented cartridge method requires a different cartridge for every printer and cartridge type tested, in contrast to a general-purpose OPC scanner, which offers the flexibility of testing a wide range of OPC types and sizes with the same equipment. In addition, the sensitivity of the instrumented cartridge method is limited by the design of the printer, and the test system designer therefore has less latitude for optimizing measurements, particularly where any modifications to the printer are concerned.

Design of an Instrumented Cartridge

In its simplest configuration, an instrumented cartridge for OPC evaluation is a modified toner cartridge with an electrostatic probe installed to monitor OPC voltages during the printing process. Typically, the toner and the development roller are removed, and the electrostatic probe is mounted in place of the development roller. The cartridge is also modified to facilitate the loading and unloading of OPCs. Extreme care in planning and executing these modifications is essential to avoid any degradation of cartridge performance. Figure 1 shows a schematic diagram of a configuration in which a charge roller is used for charging, although the instrumented cartridge method applies equally well to corona-type charging. Figure 1 shows one electrostatic probe, but a multiple-probe arrangement, or even a scanning mechanism, is clearly feasible if the additional information obtainable warrants the added cost of the additional instrumentation.

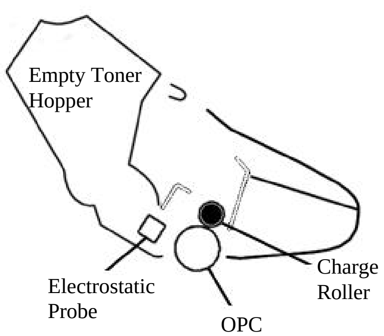

Figure 1: Schematic Diagram of an Instrumented Cartridge

Overview of the Test System

A basic instrumented cartridge system consists of an instrumented cartridge, an electrostatic voltmeter, a computer, and the software for controlling the test sequence and acquiring and analyzing the data (Figure 2).

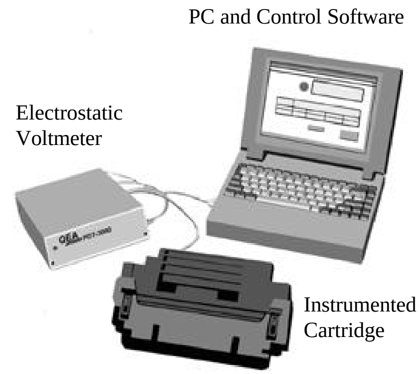

Figure 2: A Basic Instrumented Cartridge Test System

A Typical Test Sequence

To perform a test, the operator inserts the OPC into the empty test cartridge and loads the cartridge into the printer. The operator initiates the test with the control software. A test pattern is sent to the printer, a latent image is applied to the OPC, and the voltage on the OPC is monitored by the electrostatic probe. Generally, charge and discharge areas corresponding to solid white, black and in-between gray levels on the printed page are used in various arrangements to bring out the OPC characteristics of interest. For example, a solid white reveals the charging characteristics of the OPC and a solid black area reveals discharge sensitivity. Charging and discharge are the two fundamental measures that determine OPC performance and hence the quality of the printed page. In our experience, designing the test pattern properly is the most critical first step in applying the instrumented cartridge method.

Optimization of the Test Cartridge

The ideal test system for evaluating used OPCs will be able to detect any of the conditions that can render OPCs unsuitable for further use. A used OPC is deemed unusable for another cycle if: 1) it shows physical damage on its surface – pinholes, scratches or contamination – that will produce obvious print defects; 2) it is "aged" to a point where its charging and discharge characteristics can no longer provide acceptable print quality, producing for example obvious background or light print density; or 3) the thickness of the coating has been worn to a point where the additional wear from another cycle of use would lead to observable print quality problems. To maximize measurement sensitivity despite the inherent limitations imposed by printer design, the proper selection and placement of the sensor and various components in the test cartridge is essential. It should be stressed that optimizing the performance of an instrumented cartridge test system requires a thorough understanding of both the toner cartridge and the printer. Practical requirements of such a measurement system are robustness under heavy use in a production environment combined with a high degree of user friendliness and maintainability.

Feasibility Study

To evaluate the instrumented cartridge system, a series of tests was conducted on used OPCs. The primary objectives of these tests were:

1. To identify parameters that correlate to the condition of a used OPC for predicting residual life – the instrumented cartridge method should be able to measure these parameters with ease;
2. To determine the sensitivity of the parameters identified and demonstrate the reliability of the instrumented test method for residual life prediction; and
3. To establish the practical utility of the test equipment by testing a large number of samples and evaluating many drum types.

Test Procedure and Method of Data Analysis

OPCs with one or two cycles of previous use were tested. Although a large variety of cartridge types has been instrumented and tested successfully, the results reported here are for EX OPCs used in Hewlett Packard's Laserjet 4® and Laserjet 5® series printers. The EX OPC is among the highest-volume photoreceptors recycled today. The test samples used for this study were all aftermarket OPCs (often marketed as "long-life" OPCs).

In preparation for testing, each OPC was wiped gently with a soft cloth to remove any loose toner. No other cleaning method was used. The samples were then tested in the instrumented cartridge, a process in which loading and unloading each OPC typically takes no more than a few seconds when performed by a trained operator. Most of the time required for the test cycle is attributable to printer speed and the time it takes the printer to produce one or more test pages. For the Laserjet 4 and Laserjet 5 series printers, typical test duration ranges from 40 to 80 seconds.

With the instrumented cartridge method, the test patterns used typically include both solid areas of black (discharge) and white (charge). The data are acquired and analyzed automatically by control software running on a PC. A reference sample, usually a brand new OPC of the type to be tested is scanned first, and the scan statistics are stored to provide a benchmark for production scanning. The software allows the user to specify pass/fail criteria, configuring the system for automatic go/no go decisions in production use. Pass/fail indicators during testing are accompanied by messages characterizing any problem detected – "pinhole detected," "moderate wear detected," and the like. The ability to run the system in pass/fail mode eliminates operator subjectivity from OPC evaluation and enhances reliability and speed.

In addition, the system has an automatic data logging capability, which is invaluable for OPC tracking and for archiving scan statistics for ongoing study. The system also provides raw scan data in the form of a voltage-vs.-time graph. With the built-in data analysis tools the system provides, the user can examine scan statistics and graph data to gain a very detailed understanding of OPC condition and performance over time.

Charge Voltage and Statistical Distributions

In the tests conducted, 80 one-cycle and 50 two-cycle OPCs were evaluated. The charge voltages measured for the one- and two-cycle OPC samples are shown in Figures 3 and 4, respectively.

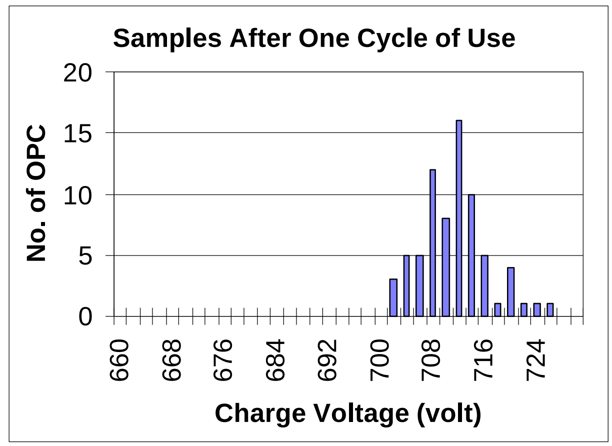

Figure 3: Charge Voltage Distribution for One-Cycle Used OPCs

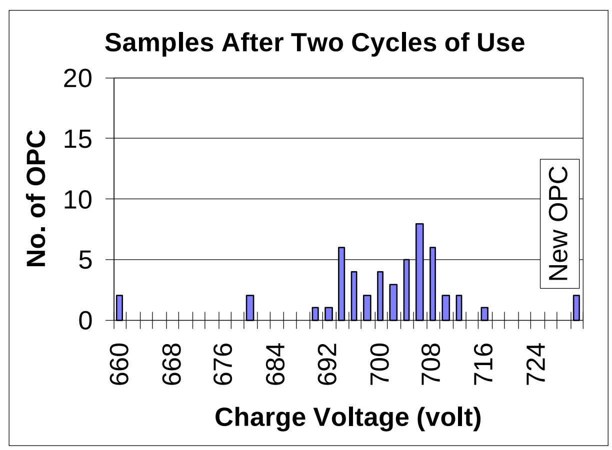

Figure 4: Charge Voltage Distribution for Two-Cycle Used OPCs

As these figures show, the condition of recycled OPCs within each category varies significantly. For example, the charge voltages on the one-cycle drums varied from 698 to 727 volts; similarly, the charge voltages on the two-cycle drums varied from 665 to 717 volts. The average for the one-cycle group was 711 volts, while that for the two-cycle group was 702 volts. These observations highlight two points: 1) the condition of recycled OPCs being statistically distributed, the objective in reusability assessment is to differentiate between reusable and non-reusable OPCs; and 2) charge voltage appears to be a clear differentiator.

Charge Voltage and Other OPC Characteristics

Looking more closely at the same OPCs, the coating thickness of the samples was measured with a coating thickness gauge.[5] The correlation between charge voltage and coating thickness for the two-cycle OPC samples is shown in Figure 5.

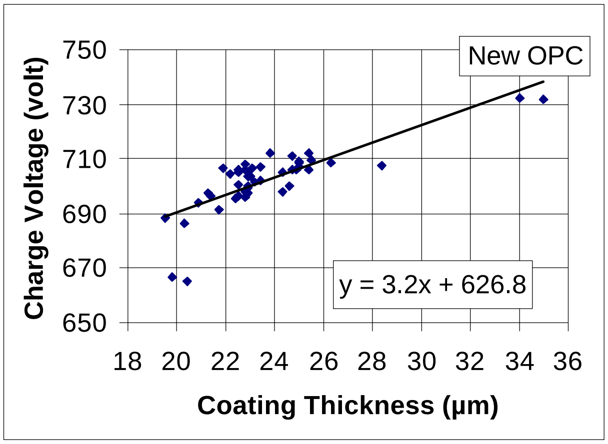

Figure 5: Correlation Between Charge Voltage and Coating Thickness for the Two-Cycle Used OPC Samples

Although the correlation between charge voltage and coating thickness is clear, it is also clear from this data that there is considerable scatter in the correlation, suggesting that charge voltage may depend not on thickness alone but also on other variables in the OPC, such as aging, fatigue, and other factors. Thus, we can conclude that, while coating thickness is a good indicator of physical wear, it is not a good indicator of other electrophotographic conditions, and is therefore not a reliable tool for predicting residual OPC life if used by itself. In contrast, the charge voltage measurements performed by the instrumented cartridge system provide information on both thickness (i.e. wear) and aging, thus affording more comprehensive information on OPC condition.

In instrumented cartridge testing, the discharge voltage is usually measured in the same test cycle as the charge voltage. Figure 6 shows that in the batch of OPC samples tested, there appears to be a strong correlation between the charge and discharge voltages, and this suggests that no independent information can be gleaned from the discharge voltage data. They do, however, confirm the charge voltage results.

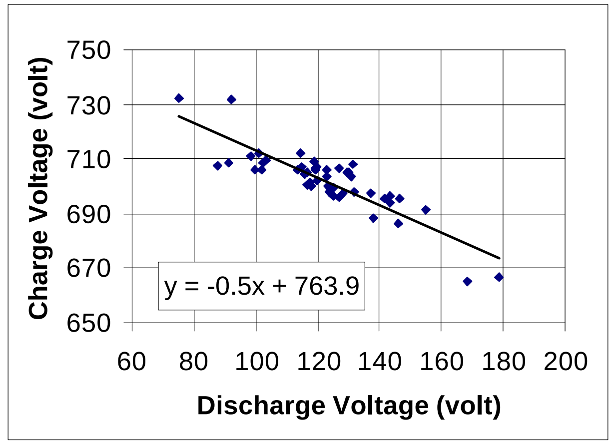

Figure 6: Correlation Between Charge Voltage and Discharge Voltage for the Two-Cycle Used OPC Samples

With the instrumented cartridge method, there is no convenient way to measure dark decay. In this study, to understand the dark decay characteristics of the OPCs being tested, dark decay was measured by turning off the printer to interrupt the print cycle. Using this technique, dark decay data was obtained, and results for the two-cycle OPCs are shown in Figure 7.

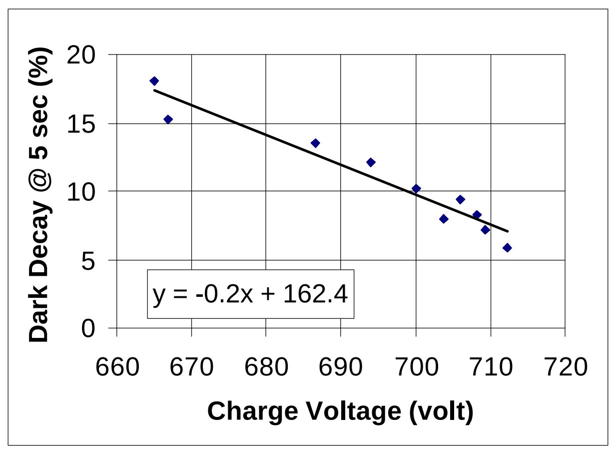

Figure 7: Correlation Between Charge Voltage and Dark Decay for the Two-Cycle Used OPC Samples

Figure 7 shows that there is a strong correlation between charge voltage and dark decay in the used OPCs. This observation is consistent with results obtained by the authors using an OPC scanner.[1] The correlation suggests that if dark decay is a good indicator of aging, then charge voltage is also a useful measure of aging.

Print Quality Measurements

The OPC samples tested by the instrumented cartridge method were also print tested to corroborate the instrumented test findings. Background and print density were measured with an automated image analysis system.[6] The results for the two-cycle samples are shown in Figures 8 and 9.

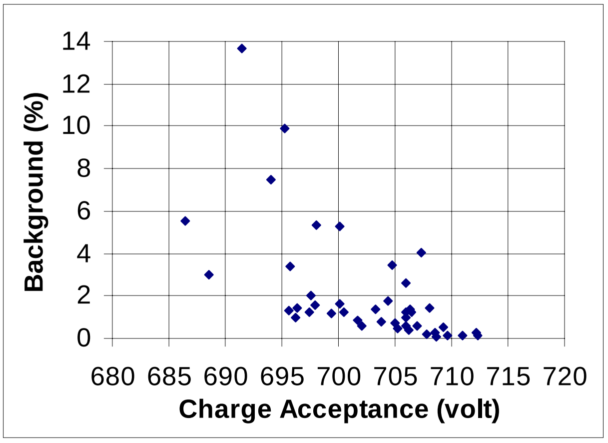

Figure 8: Correlation Between Charge and Background in Print Tests of the Two-Cycle Used OPC Samples

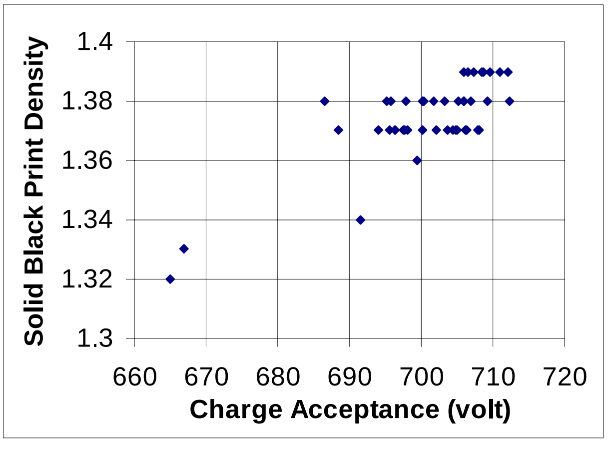

Figure 9: Correlation Between Charge Voltage Print Density for the Two-Cycle Used OPC Samples

Both Figures 8 and 9 suggest that charge voltage can be correlated to print quality in terms of print background and density. In assessing background, a reading above 5-6% in the scale of the image analysis system used was found to be quite noticeable upon visual inspection. Based on this finding, we conclude that a charge voltage below 700 volts may produce visually objectionable print background. As for print density, a charge voltage above 700 volts produces a print density of 1.36, which is sufficiently black for most applications.

Confirmation Study

Our print quality measurements suggest that observable degradation can be expected when the charge voltage is below approximately 700 volts for the OPC tested. As a test of the effectiveness of the instrumented cartridge method for residual OPC life prediction, several drums from the two-cycle OPC batch were selected for further testing. OPCs selected had charge voltages of approximately 710 volts. These drums were then print tested to determine their viability for another complete cycle without any observable print quality degradation. A complete cycle of use is considered to be 6000 printed pages at 5% coverage for this cartridge type. During the print tests, the print quality was monitored, and the charge voltage on the drum was measured every 500 pages. Representative test results from one of these OPCs are shown in Figure 10.

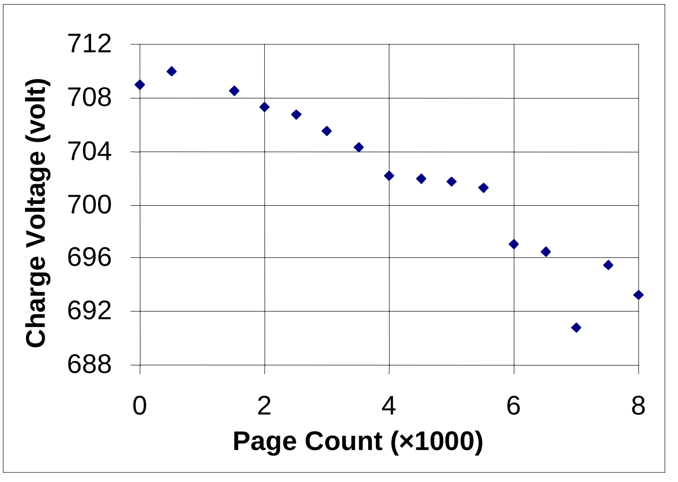

Figure 10: Confirmation Experiment

The data in Figure 10 show a continuous decrease in charge voltage as the page count increases. The print quality remained good throughout 8000 pages of printing, and the print test was stopped at this point since this far exceeded the expected 6000-page cycle. In other words, the chosen OPC successfully survived another complete cycle (thus completing 3 cycles of use), confirming the predictions of the instrumented test system. It should be noted that the same instrumented test results that predicted a successful third cycle also suggest that this OPC would not survive a fourth cycle.

Applications

Results confirming those above have been obtained in both the authors' laboratory and by a growing number of recyclers in the field using the instrumented cartridge method. The reliability of the test method is very high if the user follows the recommended test practices and exercises reasonable judgment in the selection of the accept/reject criteria. For example, with an accept/reject criterion of 705 volts, approximately 86% of the one-cycle and 39% of the two-cycle OPCs would be passed for another cycle of reuse. Based on our test results, as confirmed by full-cycle print testing, the field success rate with this accept/reject limit would be very high. On the other hand, if the user is more aggressive and sets lower accept/reject criteria, more OPCs will be accepted for reuse, but the field failure rate will likely increase. Thus, the user must recognize the trade-offs inherent in the use of the instrumented test method and base reasonable criteria on business objectives, economics, and other considerations that may be relevant.

With a properly designed instrumented cartridge, many types of defects including pinholes and severe localized wear can be detected. However, experience has shown that, since the variety of factors that can degrade print quality is very large and complex, even instrumented methods may occasionally miss certain types of defects. Therefore, to achieve the highest level of confidence in reusing recyled OPCs, the user may wish to post-test finished cartridges as a routine manufacturing QC procedure. This entails no significant increase in cost or time since post-testing is already an integral step in most cartridge manufacturing and remanufacturing operations.

Conclusions

1. A novel instrumented cartridge method for assessing the reusability of recycled OPC is described.

2. The design requirements for a computerized test system based on this method have been identified.

3. The efficacy of this method is demonstrated using one- and two-cycle used OPC samples.

4. Among several readily measurable parameters, charge voltage is found to be most useful for the purpose of predicting remaining OPC life.

5. Discharge voltage and dark decay can also be used as indicators of the condition of used OPCs; however, they do not appear to be independent measures.

6. Accept/reject criteria can be set based on the correlation between print quality characteristics (such as background and print density) and charge voltage.

7. The validity of the instrumented cartridge method is confirmed by print testing.

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