机器周期时间历来作为产量的关键指标。但对模版印刷机来说，这只是真正衡量生产率的因素之一。对两台印刷机的对比评价使用了完全相同的电路板和产品生产过程序参数。两台机器具有公布的相同使用周期时间，所以如果其它条件保持不变，使用周期时间可作为一种手段，假定两台机器每小时生产的电路板数量相同。虽然基本的机器周期时间相同，平均印刷量时间有5%的差异。此外，本文也列出影响产量的其它变量。

Throughput vs. Cycle Time in Evaluating Paste Printing

Joe Belmonte and Bob Boyes

Is the best indicator of performance machine cycle time, or first-pass yield?

Electronics manufacturers often use the terms "cycle time" and "throughput" interchangeably. In fact, they are specific and distinct factors in measuring performance. Cycle time is the speed at which the basic functions of a machine can complete the task of board handling and alignment. The actual movement of a board in and out of a machine, alignment of the board to some known target (stencil fiducial mark), movement of the board to its required position and its transport to the downstream process are typical cycle-time specifications. The actual completion of the primary function of that machine – in this case, the printing of solder paste – is generally additive to the accepted elements that define machine cycle time.

The printer supplier will often define cycle time as the period during which a circuit board travels in and out of the machine and alignment of the board to a known target. Generally, the actual print stroke is not included in the printer supplier's cycle-time equipment specification. The print stroke is tied to the particular solder paste used and the size of the substrate produced. Most printers today can move a squeegee much faster than even the fastest-printing pastes. Many companies use pastes that must be printed slowly by today's standards and often are the major time factor in printing cycle time. Given the impact of variables driven by materials, equipment manufacturers have scaled back the cycle-time definition to items under their control.

We should also consider a broader definition of machine cycle time to better understand machine throughput and equipment utilization. The broader definition would include all the functions described above plus the overhead functions the machine can perform. Overhead functions are those that the machine can perform that are not directly involved in the actual operation of transporting and printing paste onto the board. Most modern printers can perform a number of overhead functions, such as: stencil cleaning, 2-D post-print inspection and material dispense onto the stencil. Some advanced systems offer 3-D post-print inspection of the paste deposit, slow snap-off, installation of support pins, SPC collection and other management and quality data as additional capabilities to improve machine yield. Comparing printers is difficult when considering this expanded definition of machine cycle time, since these items displace manual or offline functions the manufacturer conducts to ensure process quality. True assessment of machine performance requires a full understanding of how each specific overhead function performs its tasks. The speed at which the machine can perform the overhead task is certainly one major consideration. However, so is how accurately and repeatably the machine performs the overhead operation.

One recent printer innovation is the capability to perform some overhead functions in parallel, resulting in no actual throughput penalty for the additional capability. The machine that performs two or more overhead functions in parallel and still provides best-in-class accuracy and repeatability will likely show the fastest machine cycle time, using this expanded definition.

Throughput is a measure of how many "good" board assemblies can be produced in a given time period. While machine cycle time is an important initial indicator of a machine's performance, it is critical to understand overall throughput as the key metric in evaluating process equipment. One important metric for any electronics manufacturing operation is, how many boards were built today that can be shipped to customers? A good assembly is a unit that passes all board and functional tests on the first try (first-pass yield), without touch-up or repair. To the extent that a printer exceeds the throughput requirements for a line, other utilities such as increasing stencil-wiping frequency, reducing snap-off speed or increasing critical component inspection, can be used to favorably impact yield performance. Manufacturers make money on building good boards, not on owning fast machines. When we consider throughput we must consider many more factors then just base machine cycle time.

A side-by-side evaluation was run between two printers using identical boards and product process parameters. Both machines had identical published specifications for cycle time, so if all other things remained equal, using cycle time as the measure could suggest that the two machines would deliver equal boards per hour. As **Figures 1 and 2** show, while the base machine cycle times were equal, there was a 5% difference in average printing throughput time. Further, use of overhead functions such as stencil cleaning or 2-D post-print sample inspection options within the printer can result in a difference of more than 25% (**Figure 3**). Given equivalent yield performance, printer A in this study clearly provides a much greater throughput in terms of boards/panels per hour. The machine that can perform overhead functions faster permits additional process control and monitoring, effectively increases yield – the true definition of throughput.

Throughput Variables

To effectively evaluate the actual throughput of a printer the following variables must be taken into account:

• ***Cycle time***, measured as board transport into the machine, alignment, delivery to the print height, return to transport height and exit from the machine (not including the print stroke).

• ***Print stroke parameters.*** These consist of applied force, squeegee travel and speed parameters. These are affected by board size, component density, component pitch and paste composition (a notable variable because different rheology typically means different speeds).

Optimizing solder paste printing cycle time requires the use of fast-printing paste. The larger the board, the more critical the actual print stroke is in contributing to cycle time. If a 12" board is being processed with a paste that can be printed at only 2" per second, then the print stroke is 6 sec. The print stroke can be shortened to 1.5 sec. if a solder paste that can be printed at 8" per sec. is used.

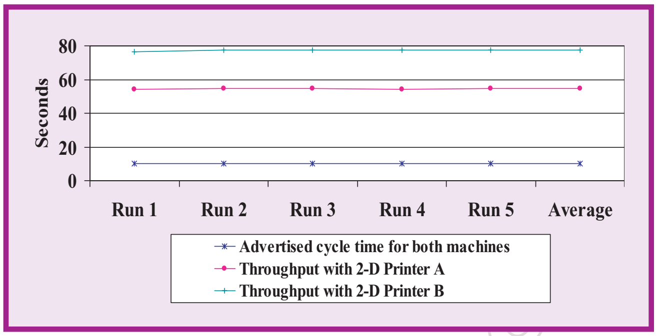

FIGURE 1: Throughput vs. cycle time with 2-D post-print inspection.

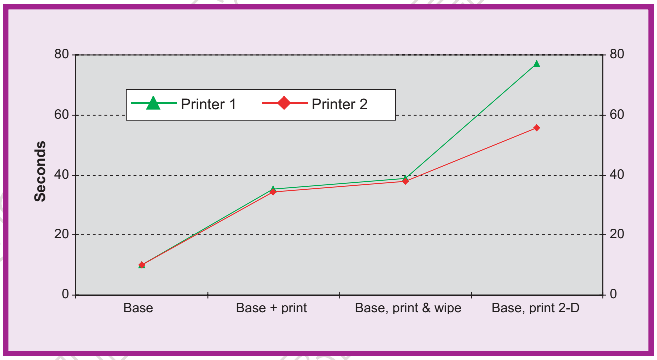

FIGURE 2: Cycle time and throughput for two printers.

• ***Whether squeegees or an enclosed print head are used.*** Enclosed print heads eliminate the time required to replenish solder paste on the stencil. Even if an automatic paste dispensing system is used, the machine must take some time to deposit new paste onto the stencil. The enclosed print head offers a unique advantage when changing over the printing requirement from one product to another. All the solder paste is now in the enclosed print head. Very little paste has to be scraped off the stencil prior to cleaning it. Less solder paste is wasted because the paste for the next product is already in the enclosed print head.

• ***Paste application.*** If squeegees are used, how is the paste delivered to the stencil? Some factors include the method (manual or automated dispenser), the aperture density and size of the PCB, as this will determine the frequency of replenishment required.

• ***Operating software ease of use.*** The software must be simple for an operator to use. All functions that an operator can control must be easily understood and accessible. Should be as intuitive and simple to use as possible. This facilitates setup, changeover and operation of the machine, which contribute to the long-term production output of the system.

• ***Stencil cleaning frequency and method.*** All solder paste printing processes require the stencil to be cleaned at some frequency. How often a stencil requires wiping is a function of several variables including stencil design, board final finish and board support during printing. Since stencil cleaning is a must for even the best-designed printing process, we must evaluate how a particular machine performs this function. All modern solder paste printing equipment offers stencil cleaning capability. How the stencil cleaning function is performed must be understood; for example, were a vacuum and solvent employed to assist the cleaning?

• ***Stencil-to-board snap-off distance and speed.*** All systems do not operate the same, and due to higher densities, some PCBs require slower separation speeds to improve paste deposit separation from the stencil.

• ***Post-print inspection.*** Most printers offer 2-D post-print inspection, and some offer 3-D post-print inspection of paste deposits of critical devices. 2-D and 3-D post-print inspection systems do not operate in the same way, and understanding what variables can be measured, the method and how the resultant data are used is essential to assessing the value of this additional operation.

• ***Setup and changeover solutions, including the associated MTTA.*** The majority of paste printing operations require product changeovers. Many operations change several times in one day. How quickly your equipment can be changed from one product to the next must be understood. What product changeover variables can a particular machine optimize?

• ***Process control.*** As discussed, throughput is a measurement of how many good assemblies can be produced in a particular time period. The quality of what we are building is critical to achieving maximum throughput. We must understand how our process is operating in as close to real time as possible. We cannot optimize throughput by finding defects at the end of a product run. We must have a proactive manufacturing culture that will prevent defects, not a reactive manufacturing culture designed to find defects. The key to a proactive manufacturing culture is a well-designed and well-executed statistical process control (SPC) program. What features of solder paste printing equipment can assist in the implementation of a SPC program?

• ***Operator training and discipline.*** A well-trained, disciplined, conscientious operator will be a major contributor to paste printing process performance. Operator training must go beyond basic machine operation. The operator must understand each factor that contributes to process performance and how it impacts all processes in manufacturing, including final product quality. Training is vital, but process discipline is just as important. Operators must perform their jobs the same way all the time, on every shift. Supervisors and support personnel must help operators understand and follow procedures.

• ***Process optimization*** (stencil design, operating parameter optimization, etc.). Process optimization is the means by which engineers and operators understand, identify and quantify all variables that influence the performance of the actual printing of solder paste, and use that knowledge to improve the process. Operating parameters such as squeegee speed, applied force, down stop and print stroke length must be quantified and optimized using formal statistically valid studies such as design of experiments (DoE). Other factors to consider are stencil design, board design and finish, board support and solder paste selection. The print process is often identified as a major defect source in the line; however, the hardware itself is only one portion of the equation. Even the best hardware can be overcome if the process is not optimized or incoming materials are not suitable.

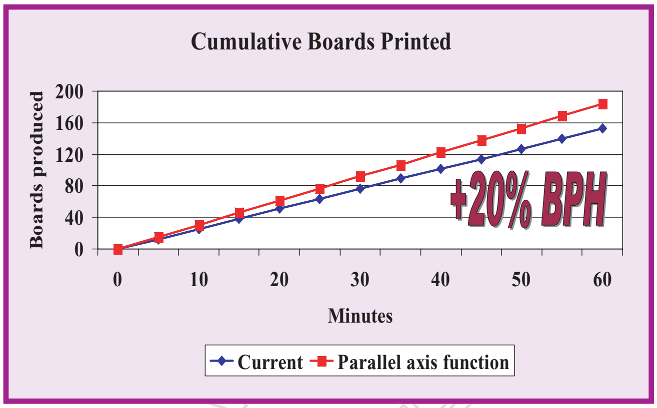

FIGURE 3: Printer throughput in terms of serial vs. parallel axis function.

• ***Equipment maintenance.*** One important aspect of throughput is machine uptime (or downtime). Fast cycle time is of little value if the machine requires a great deal of attention to keep it operational. Obtaining the best possible results requires a strict preventative maintenance (PM) program. Maintenance must be scheduled at regular intervals, as required. This is one of the most neglected areas. Users should develop a clearly documented PM schedule and equipment should be accessible. Completion of the required preventative maintenance should never be compromised. The equipment owner should monitor the data on the performance of their entire process to identify any additions or subtractions from the PM schedule. Some adjustments to the supplier's recommended PM program may be required by a particular process or for a particular PCB design.

While machine cycle-time specifications are usually available, documenting throughput is more difficult as many of the variables are not controlled directly by the printer. It is important to work with the supplier to isolate key attributes and optimize equipment parameters.

Optimizing process throughput starts with printing equipment that provides features that maximize the variables that the equipment can control. The combination of all these variables drives printer throughput. When evaluating printers, look beyond machine cycle time and understand each throughput variable that the equipment (and supplier) can help optimize. ■

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