自动光学检验（AOI）系统可以很昂贵，实现这种技术既要求管理部门、质量管理部门和生产部门的积极参与，也要求有熟练的操作人员和程序员。此外，还需要持续提供培训。同时，投资回报可能很快，不仅在节省人工检验的直接成本上，而且在防止次品向最终用户发货方面。高混/低产量的制造商考虑从人工检验转为AOI时，第一步就是要衡量其优缺点。

AOI in a High-Mix/Low-Volume Environment

Matthew Holzmann

The cost savings when using AOI can pay for the system on one job under the right circumstances.

With the greater flexibility and reduced time to market in the electronics manufacturing industry, the technical demands for automatic optical inspection (AOI) have fundamentally shifted for many manufacturers. Instead of 1,000 or 10,000 parts per production run, new product introduction (NPI), first article inspection and engineering change orders (ECOs) do not allow for long set up times and lengthy machine calibration as production runs are much shorter. End users demand rapid response in this environment, and product turnaround times can be from 24 hours to a week, which leaves little margin for error.

AOI systems can be very expensive, and implementation of this technology requires a firm commitment from management, quality control and production to succeed. The nature of the technology requires skilled operators and, depending upon the vendor selected, programmers. In addition, management must be committed to ongoing training, as both board designs and production demands change rapidly and many vendors regularly upgrade hardware and software to meet these new requirements.

At the same time, the return on investment (ROI) for AOI can be very rapid, both in direct cost savings vs. manual inspection and, more importantly, in preventing defective product from being shipped to the end user. Repair costs escalate dramatically at each stage of the value added process. As one example, the cost to repair a defect found at functional test can be 10 to 20 times the cost of that same defect found immediately after placement. One manufacturer estimates that his cost for repair after shipment to the end user can be up to five times his selling price per assembly because of value added penalties in purchasing agreements. Thus, both practically and theoretically, the cost savings when using AOI can effectively pay for the system on one job under the right circumstances.

As many high-mix/low-volume manufacturers are considering moving toward AOI from manual inspection, the first step is to consider the advantages and disadvantages from this standpoint. Ergonomic studies performed in Europe and the U.S. in the 1950s found that, in the inspection of fine features, quality control technicians typically lost visual acuity after between 10 and 15 minutes of work. Focus would be regained after a few minutes break but then would deteriorate rapidly thereafter.

As the features in electronics assembly inspection have become finer and finer, the use of illuminated magnifiers, optical comparators and projection microscopes have become more widespread and have helped enhance the inspection process. However, simple defects still escape, and, as density and the demand for greater reliability increases, we have as an industry reached the limits of yield improvement using manual inspection techniques. The issue of *nonconforming but acceptable*

vs. *fatal* defects must also be carefully considered, and, in addition, some nonconforming anomalies are allowed by some customers but not by others. All of these factors make the inspection process, and AOI, a very dynamic environment.

For some years, the largest market for AOI has been Asia. With volume production of high-density consumer electronics such as watches, cameras, video camcorders and notebook computers, the demand for both automation and improved yields spurred rapid growth in AOI implementation. The greater bulk of installations globally has been in Japan, Taiwan, Malaysia and China because of their focus on these product types.

A rough estimate is that approximately 2,000 inline systems and over 3,500 bench-top systems are in use in those markets. The greater utilization of bench-top systems resulted from the higher degree of flexibility and cost performance offered. Bench-top systems have been typically less expensive and offer a high degree of functionality. In addition, these systems lend themselves well to operations where inspection, repair and verification are all done at the same time. As volumes increase, inline systems with attendant offline verification/repair, networking and data transfer become more cost effective.

Manual Inspection	
Inspection time per assembly	8-10 minutes
Assemblies inspected per shift	42/7 Hours
Assemblies inspected per month (20 working days)	840
Employee cost/month (hourly wages only)	$1,800.00
Inspection cost per assembly	$2.14/each
AOI	
Inspection time per assembly	45 seconds
Assemblies inspected per shift (incl. 2 hour programming time)	400/5 hours
Assemblies inspected per month (20 working days)	8,000
Leasing cost for equipment: Bench top ($60K)	$1,400.00/month
Employee cost/month	$1,800.00
Inspection cost per assembly	$0.40/each

TABLE 1: The cost differential of AOI vs. manual inspection.

Basic Economics

In implementation of AOI in a high-mix/low-volume manufacturing operation, a significant consideration is the ROI. In addition to improved product quality, a reasonably simple economic analysis can highlight the cost differential of AOI vs. manual inspection. Table 1 shows analysis based upon a single inspector working an eight-hour shift with one hour for breaks and lunch.

Based upon a manufacturing capacity of 400 assemblies/day, the ROI can be quite substantial on the basis of productivity alone. However, many other factors contribute to the success or failure of AOI.

Programming

Most high-mix/low-volume manufacturers do not have extensive engineering resources to devote to programming. In many cases, the same engineer or technician can be responsible for programming pick and place, electrical test and AOI. In addition, time to market is critical, and profit margins can be based upon delivery time. Thus, ease of programming, speed and accuracy are critical to success.

Programming time on most AOI systems can run from one hour for a simple component inspection program to days when inspecting for solder defects in high-volume, high-accuracy applications. Inspection in high-mix manufacturing demands a decision analysis in programming, which will both ensure the highest defect capture rate while minimizing both false alarms and the time necessary for job setup.

Tolerancing is critical to minimize false calls. Component offset; minor differences in color, text/images or position; and, in the case of solder inspection, variations in reflectivity all require simple, easy-to-use data entry and image adjustment. They also require acceptance of multiple image masters to enable processing of common components from different vendors or variations in color/image density.

Many systems will accept various forms of download from computer automated manufacturing (CAM) software, including centroid data, Gerber data and package geometries. Golden board programming using a first article is also an option but will typically take longer and must be verified against either data or a known good image. A mix of CAM download and captured images from a golden board offers verification of both placement accuracy and color/image variations. Remember, proper prior programming prevents poor performance.

Offline programming is an option that will free the AOI system for production use. Typically, a combination of computer automated design (CAD) data and a scanned image of the substrate can be used on a remote PC to program jobs, with a brief online verification of the program prior to production. Speed and ease of use are critical.

Other related factors that must be considered for high-mix manufacturing are program size and job storage. Flexibility and rapid turnover are critical to profitability in time-to-market-based manufacturing. Thus, rather than running a few jobs in a single day as done in volume manufacturing, the high-mix manufacturer in many cases runs multiple jobs in parallel with only occasional repetitive part numbers. Thus, AOI, like pick-and-place systems, must be able to either store many jobs internally or be able to rapidly access programs offline through a network server. Verification of job number and revision number can be critical, and in these cases components from multiple suppliers are more likely and programs must be able to accept a library of acceptable images.

Processing

With the relatively high cost of AOI, many users expect the systems to run themselves, which, unfortunately, is not the case. Our experience indicates that approximately 20% of the AOI systems purchased in North America to date are gathering dust because of unmet expec-

tations or a lack of attention to processing issues.

The pressures of high-mix manufacturing demand flexibility, speed and accuracy. Scan times on most AOI systems will meet throughput gates on most pick-and-place systems, so scan speed is typically not an issue. Defect capture with a low false call rate is the issue.

Most AOI in this application is expected to capture shorts/bridging, misaligned components, opens, poor solder quality, missing/wrong components and reversed polarity. Some users will also want solder paste inspection after printing or post-reflow solder inspection. However, significant tradeoffs occur when inspecting solder, primarily in programming time, higher alarm rates and missed defects. The advantages of color vs. gray-scale imaging should also be considered. True color systems are better at capturing defects on through-hole components such as those related to bands on resistors, capacitor values or LED color values, while gray-scale systems will often perform better in solder inspection applications. Illumination and image processing are also critical. The computer cannot process what it cannot see, which is especially critical when inspecting laser-marked components, small components such as 0201s and polarity marks.

Optical character recognition (OCR) or optical character verification (OCV) is also useful for identifying text or other markings on components. OCR represents the ability to read text into software, while OCV utilizes pattern matching algorithms for the same purpose. While OCR is more exact, OCV is to date more reliable. Both accomplish the same job functionally.

Verification and Repair

The purpose of inspection is to ensure product quality and strive for the lowest cost per repair. Typically, even in first article manufacturing, yields are high, but, when considering a substrate with 500 components, over 2,500 inspection points can easily exist. Thus, a 99% first-pass yield could still generate up to 25 alarms per substrate. False alarms and non conforming but acceptable variations typically represent the bulk of these alarms. Various studies have found that the higher the number of alarms, the greater is the risk of fatal defects being passed over in the verification process. Reducing these calls to a minimum is critical.

Verification when using inline AOI systems is problematic. These technologies typically do not allow for an ergonomic method of comparison between the programmed image and production results, and most inline system manufacturers today offer offline verification options for this reason.

Many bench-top and inline systems offer image comparison or split screen images, where the production substrate can be compared to the master image.

This is a clear, graphic comparison between the known good and nonconforming image fields, and quality can be rapidly verified. Many bench-top systems have a strong advantage in being able to be used to repair the substrate in place. Many of these systems can be configured as inspection-verification-repair work cells where all three functions can be performed efficiently by the operator. In Asia, many large-volume manufacturers will place bench-top AOI systems on the production line in this manner, typically prior to reflow soldering, to ensure the earliest possible repair or rework of the substrate. Offline verification/repair stations offer the ability to link to multiple AOI systems and, in many cases, higher functionality in the ability to repair a wider range of defects.

Meaningful data collection and analysis in high-mix/low-volume applications are very difficult. While most AOI systems include statistical process control software, the sample size in this application is by definition limited, thus reducing the available database to a point where results lose statistical relevance. Long-term trends can be observed, but, with repeated setup and tear down of pick-and-place equipment for new jobs, tracking data such as placement accuracy or engaging in process measurement is difficult.

Operator Training

AOI is a moving target, and demands regularly vary both between jobs and as technology advances. More importantly, AOI operators and verification/repair technicians must understand both the hardware and software as well as quality control parameters. In addition, a constant theme at many companies is the loss of trained personnel. Despite the simplicity of many systems, issues arise on a regular basis that require an understanding of both applications and programming. The same job that can take one user 90 minutes to program and run can take another six hours due to poor training, and many AOI systems sit idle because of the loss of properly trained personnel. Management must commit to the long-term success of the process not only when acquiring equipment but through an ongoing commitment to operator education.

Summary

The implementation of AOI in high-mix/low-volume applications has become a significant trend in recent years with over 20 vendors in North America alone. However, significant differences do exist in system technology, ergonomics and operation that will substantially affect performance of AOI in different applications. Understanding these limitations during the decision-making process is critical. ■

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