

**Figure 1.** After processing, a tiny particle of mercury or iron may produce an artifact much larger than itself.



Figure 2. Managing the airflow on the "air highway" controls particle movement.

# Air Flow in

ou've set up your cleanroom strictly according to specifications. A particle counter verifies that the facility is a Class 10 or Class 100 or Class 1000 cleanroom. Yet your product is contaminated. How can that be? When is a cleanroom not a cleanroom?

A clean manufacturing environment has three essential components: the facility (the cleanroom), the process occurring inside the cleanroom, and the personnel who use the equipment and materials. These factors are usually considered independent, but are actually interdependent. This trap snares cleanroom users whose facilities are built by companies with very impressive construction credentialsbut little or no expertise in operating a cleanroom. The process's self-contamination potential and the problems caused by people who work in the cleanroom are often underestimated during cleanroom design and construction.

#### EMPHASIZE AIR FLOW MANAGEMENT

Normal contamination problems multiply when applied to film. A particle of mercury or iron almost too small to measure may have a chemical reaction with a film product, producing an artifact several orders of magnitude larger than its original size. The processed film may then be projected to produce a final print many times larger than the original film. A 1.O-micron spot may appear as a **1-mm** spot on the finished product (Figure 1).

For years PCBs had line widths no finer than 8 roils or about 200 microns. For this width, some form of cleanroom environment was desirable, but the final product was tolerant of lapses in cleanroom protocol.

## Management Cleanrooms

However, more sophisticated manufacturers are now working with line widths of 2 or 3 roils and in some cases even smaller. This trend is redefining



**Figure** 3. Scan testing verifies the integrity of the filters and the seal between the holding frame and filter.



Figure 4. Comparison of washout and recirculation of clean benches.

the need for cleanroom environments. With resistive circuits, an artifact amounting to about 10% of the line width can cause a degradation in performance. For a 2-mil (50-micron) line, for example, a 5-micron dust particle can cause problems. Suddenly, cleanroom environments have taken on a whole new meaning for phototool fabricators.

A new line of Kodak AccuMax films was developed specifically for high-precision applications, To ensure these products' integrity, a Class 100 manufacturing environment was needed. In this case, going by the book was not enough. Past experience had shown that measurements conforming to Federal Standard 209D definitions of cleanrooms won't identify problem areas. A cleanroom may have fewer than the requisite number of particles of a certain size and, thus, qualify as a Class 10 or Class 100 room overall. Yet there may be concentrated eddies of damaging particles in critical product areas. In other words, having a Class 100 room won't help if air flow within the room moves particles directly to your product.

No manufacturing process of this sort can be made totally free from particulate contamination. Air is the highway particles use to travel from their source to critical product surfaces. To control particle movement in terms of film manufacturing—it is necessary to control the air highway by managing air flow (Figure 2).

Good designs can be compromised by poor air flow. For example, an operator can be stationed between the source of clean air and the process, so that the contamination generated by the operator is drawn into the process. Rearranging the process equipment and personnel interface so particles are drawn to the air return without passing the process equipment can solve the problem.

#### LAMINAR AIR FLOW

Laminar air flow is a key tool for managing the particulate air highway. In a laminar flow, the entire body of air within a confined area moves with uniform velocity along parallel lines. This flow delivers a uniform supply of clean air to specific locations.

A laminar air flow also isolates two operations with an effective barrier. Contamination generated by one process is swept away before it can contaminate the process next to it. Finally, and possibly most important, laminar air flow can remove contamination as soon as it is generated.

The first step in creating a laminar air flow system is to provide a clean air source. High-efficiency particulate air (HEPA) filters or ultra-low penetration air (ULPA) filters, which are placed in the ceiling of a cleanroom or tunnel, are usually used to provide the clean laminar flow of air. HEPA and ULPA filters are also used in clean benches and in laminar air flow modules, which are suspended over an operation to provide a localized supply of clean air.

The filters' integrity and the seal between the filter and holding frame must be verified. Otherwise, the air supply may be a source of contamination. Airborne particle counts may not reveal defects in the filters, unless the particle counter itself happens to be stationed under a leak. Even a tiny pin hole in a filter or gap in the seal can result in a stream of contaminating particles. The only method that is foolproof is to scan test the entire face of the filter and its seal (Figure 3),

Next, you must consider how much contamination enters the air from the time it leaves the filter until it reaches the process. During the manufacturing process for AccuMax films, moving parts generate particles that get into the air flow. Kodak contains these particles with enclosures under negative pressure whenever possible.

Even if particles don't move, obstructions can create eddy currents. Such obstructions may harbor particles for long periods of time because they cannot be removed by the laminar air flow.

The solution is to avoid eddies by

using designs that eliminate obstructions. If eliminating obstructions is difficult, however, the laminar air flow source should be placed as close to the process as possible and downstream of the obstruction. In some cases, the air might have to be supplied in a horizontal direction to provide a barrier between obstruction and product. Eddy currents can also be reduced by placing air foils around obstructions. Computer models can help you study air flow and design the correct air foil configurations.

Another method for reducing eddy currents is to use localized exhaust or return air to remove air and contamination from the eddy current area while pulling clean air in.

#### **AIR BALANCE**

Which is a more effective tool for removing particles: a vacuum cleaner or an air blower? Pulling the air always directs the particulate to a place where they can be collected and removed, while pushing tends to scatter dirt in unwanted ways.

Therefore, the air supply (push) and return (pull) should be designed to provide a balanced flow. In a cleanroom with a raised floor, the air return system can be designed in a straightforward manner. When raised floors aren't practical, you'll need to give special consideration to the number and location of air returns.

Some cleanroom designs specify only floor-level, side-wall returns to reduce costs. Often this placement of returns can result in cross-contamination of operations if the air flow patterns are not considered when placing equipment in the area. You should do a final check of air flow after all equipment is in place.

In some situations, the air return is raised to the work level. One example is when a base or wet station is used in a laminar flow cleanroom.

When any localized exhaust or air return is used, the environment surrounding the exhaust must be supplied with clean air in a quantity greater than the air that is being removed. Otherwise, contamination can be drawn into the critical area.

Whenever a laminar air flow supply is provided by a module placed over a process, it is necessary to confine the air with physical barriers to realize the full benefit. If the air is not confined, particles from the surrounding area will be carried into the clean air. The resulting clean air space will essentially be reduced to an inverted pyramid whose altitude is equal to the width of the air supply module.

It is critical that these barriers be sealed to the air supply module to prevent the aspiration of particles into the air stream through leaks between the barrier shield and module.

The benefits of a push-pull air flow over a push-only air flow can be found by comparing washout and recirculation vertical laminar flow clean benches. The washout design uses a three-sided enclosure with an open front and a work surface that is generally solid (Figure 4).

Air enters the enclosure through the filter located in the top of the bench. It is then pushed out through the front opening, In general, the enclosure is purged, and contamination from outside the bench is kept out. However, the air flow along the back portion of the work area is turbulent and may take hours to clean if it becomes contaminated. Product placed in that back portion of the bench may become contaminated,

In the recirculating bench, the air is pushed down through the filter and pulled through perforations located at the front and rear of the work surface. This push-pull action provides a uniform flow of air from the filter to the bench work surface without creating areas of turbulence. As a result, any contamination generated by activities in the bench is removed as soon as it is generated. The pull action actually draws a layer of air over the objects on the work surface, which creates a barrier layer that particles have difficulty penetrating. method of using air flow management to protect a process, particularly at an operator interface. However, to be effective, air flow management must be push-pull. Just using push will cause turbulence and allow migration of contamination through the curtain. Use of air curtains does allow unrestricted access to the operation and effective control of contamination.

### AIR FLOW AND PERSONNEL MANAGEMENT

It is often stated that personnel are responsible for 80% of contamination in the air. Training is crucial. It is vital that personnel be taught to recognize the great importance of maintaining a cleanroom environment. Thus, a potential liability can be turned into an asset. A properly trained employee can help provide valuable feedback on how to spot and solve contamination problems.

Management of air flow can help minimize contamination by making

sure the air highway doesn't pass from personnel directly to critical manufacturing or packaging sites. Another important step is to encapsulate personnel to prevent contamination from being emitted into the air. Garments that are properly designed, sized, cleaned, and worn are requisites for a cleanroom environment.

After they are manufactured, AccuMax films are placed in plastic trays that have been manufactured in a clean environment. The bags are removed from their boxes by customers in the anterooms of their own cleanrooms, wiped off, and carried in. Films and trays are sealed inside clean plastic bags. Up until the time the film is processed, it has spent its entire life in a clean and uncontaminated environment.

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Air curtains are also an effective