***A properly designed and implemented automation system directly impacts cleaning efficiency while maximizing overall manufacturing objectives.***

# Making the Move Toward Automation of Open-Top Cleaning Lines

BY JONATHAN ARIES

The argument for automation is simple: efficiency. Good automation maximizes throughput and utilization of human and material resources. The most successful automated cleaning operations also consider overall plant operations before and after product cleaning.

Vapor degreasers were traditionally considered isolated islands removed from the production environment. Degreasers utilizing traditional halogenated solvents were automated where worker exposure to noxious fumes were a concern. As the cost of CFCs increased, automation was justified for the conservation of resources.

The current broad spectrum of cleaning chemistries present increasing processing complexities which even further rely on the merits of automation. No longer incidental to production, cleaning is now often a production bottleneck.

Most new cleaning requirements involve more steps with longer times at each station, concerns for dilution of chemistry and attenuating waste treatment costs, potential damage to parts from over-exposure, concerns for efficient drying, and special handling of parts to ensure penetration of process steps in small spaces.

The objectives of a successful automation system can be grouped into two categories:

- Those directly related to cleaning efficiency - quality control, throughput, process control/abilities; and
- Those maximizing overall manufacturing objectives - integration of the cleaning operation with production, worker safety, and conservation of cleaning materials.

## Quality Control

Obviously, for any chemistry to be effective, cleaning regimes must be followed to avoid rejection of parts due to inadequate cleaning. inadequate drying, or from over -exposure to aggressive chemistries.

One advantage of sophisticated automation is that it affords greater flexibility in processing various parts with the same equipment. Plus, depending on manufacturing packaging, throughput can be impressive even in relation to inline systems.

## Throughput

As the number of cleaning stations are consolidated due to the cost of equipment changeover and integration of cleaning operations into total production environments, throughput - described in terms of payloads per hour or minutes per payload - is becoming increasingly important.

Beyond the quality control concern for over- or undertreating parts, wasting time is no longer tolerable. The objective is to maximize throughput by eliminating bottlenecks; i.e., minimize the delta between processing time and automation cycle time. Improving throughput is a function of controlling distance and speed.

Obviously, tanklines should be as compact as practical for both length and height. After establishing the physical envelope, look to how well speed can be controlled and if breaking up the travel distance provides significant advantage.

Throughput strategies are best explored in terms of the three levels of processing sophistication: serial, parallel, and automatic prioritization.

## Serial Throughput

With a serial approach, one payload is processed at a time according to its recipe - the specific order of processing from loading into the system through unloading, including the sequence of tanks with dwell time in each and accompanying drain-off time.

During this progression of steps, additional input or output (I/O) instructions may be called out, such as turning on air knives during withdrawal from a certain tank, waiting for confirmation that the unload station is clear, etc.

*Throughputfor each payload = cumulative dwell and drain-off times + automation cycle time.* The only way to affect throughput is to decrease cycle time. Since serial applications are typically for low production rates, very short tanklines, or other special conditions, the best approach to marginally improve performance is to increase operating speeds.

## Parallel Throughput

A parallel approach allows for simultaneous processing of payloads according to the longest delay within a recipe. This is most easily conceptualized as a tank line with load and unload stations at opposite ends and all stations between being full. When the payload at the final station unloads, the automation works its way "upstream" until a new payload loads into the system and the cycle repeats.

Also considered here are hybrid serial/parallel recipes where a station with aggressive chemistry (or oxidation of parts) requires critical removal and placement of a payload in an adjoining. rinse tank. These multiple steps are described as a "serial segment" within a parallel process.

Throughput for each payload = longest dwell and drain-off time (serial segment) for any payload in the system + marginal automation cycle time.

While a considerable improvement over serial processing, simple parallel processing presents two limitations. The most significant is that throughput is limited by the longest dwell time for any payload in the system.

The best operations with parallel processing group together payloads having identical recipes. When switching from one recipe to another having significantly different dwell limes, it may be best to simply clear the line before proceeding with the next group. With some applications having dissimilar recipes this can result in several hours of lost productivity.

A second uncommon limitation of simple parallel processing is that all recipes must be sequential - the progression of tank steps is a one-way street. This is occasionally a concern with re-work or when the tankline requirements are uncertain.

Depending on the application, throughput can be enhanced either by increasing operating speeds, through use of a "walking beam" or gang future on a single head which will move more than one payload at a time, or with multiple heads moving with varying degrees of independence.

### Automatic Prioritization

Also referred to as "dynamic" or "random" loading in the plating industry, automatic prioritization allows for simultaneous processing of payloads regardless of recipe requirements. Tank stations are defined as to the criticalness of over -exposure or delay between any two stations.

Each payload is processed with maximum efficiency, respecting the priority of payloads previously placed into the system. While it may appear that the system is merely in parallel processing, it is a significant advantage to the user who is switching between recipes regularly, even with each payload.

This type of processing permits "leapfrogging" of one payload ahead of another when possible, as well as non-sequential recipes. Throughputfor each payload = automation cycle time + marginal dwell and drain-off time.

To take full advantage of the flexibility of this more sophisticated processing, automatic prioritization typically utilizes one or more heads carrying single payloads. Higher operating speeds will have a dramatic improvement on cycle times, particularly if horizontal speeds increase when the automation is not carrying a payload. Multiple heads are advantageous under two conditions:

l When overall travel length (for either axis) creates long travel distances where the head carries no payload. Multiple heads "break up" operating zones, and each head performs efficiently.

. When a particular processing step requires time that is disproportionate to the rest of "a balanced tankline." This can occur where a slow-pull operation requires a head to extract a payload at a fraction of its speed rating or where a "serial segment" bottlenecks the system.

While there should be no limit to the number of heads along a tankline, first consider increasing speeds within safe operating tolerances. An additional head will not significantly improve throughput where the limitation is the automation cycle time for reloading the same station.

### Process Control/Abilities

Automation in its simplest forms (serial processing) allows for the simplest control, continuously progressing payloads through a series of positions while turning on and off switches for sonics air knives, etc.

Automation with a moderate level of sophistication (parallel processing with some speed control) approaches the advantages of an experienced operator making adjustments in speeds.

Even more powerful automation (full speed control and automatic prioritization) can do much more than should be attempted with human labor: for example, simultaneous processing of divergent recipes, slow-pull drying or coating operations, and multi-axis manipulation of complex parts or process steps.

### Integration with Tank Lines

The wide variety in cleaning tank systems corresponds to the broad range of chemical approaches to cleaning precision parts. Each approach calls for a change in automation requirements.

As described in "Components of Automation," pages 20-21, automation systems are composed of three main components: mechanical superstructure, drive system, and control package all of which must work well with each cleaning equipment approach.

For vapor tanks - chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), perfluorinated hydrocarbon (PFC), and alcohol-based systems - the mechanical automation superstructure must accommodate the deep sumps resulting from the freeboard over the vapor zones.

Where ceiling heights do not allow clearance approximately equal to the height of the tanks, an "I-beam or cable" mechanical system or motion multiplier may be appropriate. Though they're made to entirely avoid self-shedding, these instruments remain a consideration with cleanroom applications.

Aqueous, semi-aqueous, and water-miscible systems typically require longer cycle times for payload recipes (though not necessarily impacting throughput), more horizontal travel, and increased interaction with discrete tank functions. Both alcohol and semi-aqueous systems require spark suppression; all require tank monitoring and interaction with the automation.

Automation systems traditionally activated only process-dependent I/O and perhaps conveyors at either end of the tankline. There is no reason, however, to limit the control package. With unlimited potential to expand the automation's I/O capability, anything with a sensor can be integrated: tank heaters and pumps, fill pumps and drains, tanks additives (such as those monitored by pH), etc.

In addition, automation is increasingly needed to interact with its own discrete features such as full-barrel rotation both in and above tanks, specific manipulation of parts such as tubing with multiple bends, or re-orientation of parts for tunnel dryers. All of these interaction forms can be accomplished in the control package software and associated hardware.

### Conservation of Resources

As cleaning operations have become more expensive, maximizing utilization of resources and minimizing associated waste treatment expenses take on greater importance. With most vapor degreasers, the objective is to disturb

# Components of Automation

### Mechanical Superstructure

The concept for horizontal and vertical travel can vary greatly. Objectives should be for a clean design with minimal moving parts, *especially* over the tankline.

The automation needs to be rigid, durable, adaptable to available envelope, and compatible with the chemistry in use. Possible concerns include overhead clearance and accessibility of the tankline to operators.

Basic approaches include the following:

*Conveyors*

Overhead conveyors (Figure 1) incorporate a chain pulley mounted above the centerline of the tanks. Tank lengths are typically exaggerated to accommodate the transitions for vertical travel, and there is high contamination potential associated with moving parts above the payload.

Additionally, there is no flexibility in altering processing, and the only variability in throughput involves altering conveyor speed. These systems typically are not used in precision cleaning applications.

Tank-level powered rollers (Figure 2) move payloads between stations; vertical movement occurs via lifts in each tank. Although this approach can be efficient in terms of automation, processing flexibility is limited, tanks are significantly oversized, and it may not be appropriate for delicate parts.

*Walking Beam*

Typically a top-mounted (but can be side-mounted) fixture, a walking beam (Figure 3) advances payloads simultaneously, one station at a time. The approach can be advantageous in single-recipe, high-volume applications.

Limitations in flexibility and throughput are comparable to those described above, and contamination potential applies to the top-mounted systems. Additionally, these systems limit tank design in that all stations must be the same distance apart, with identical process times for each.

*I-Beam or Cable*

This configuration (Figure 4) employs suspended independent head(s) which travel over the centerline of the tanks. The only advantage of these systems is where ceiling clearances are an issue. By design, the moving parts of the head create potential for particulate generation and thus payload contamination.

Alternatives for low-ceiling applications include motion multipliers for telescoping cantilevered designs or a slotted cantilevered design. While typically better than an I-beam or cable, even these approaches require caution in high-grade cleanrooms.

*Cantilevered*

For a cantilever setup (Figure 5), a horizontal frame is mounted behind the tankline along which one or more heads travel and execute vertical movement. Properly designed, this concept is considered optimal for general applications since it creates the least contamination, uses the smallest footprint, and affords unimpeded operator access to the tankline.

Use of multiple heads which overlap one station can be an efficient way to increase throughput. Increasing speeds works, too, especially during "dead travel" with no payload. With use of a "gang fixture," any head can lift more than one payload at a time for simple high-throughput applications. But, as with a walking beam, the distance and processing time between stations must be equal.

*Gantry*

A gantry design (Figure 6) makes use of two horizontal frames, one along each long axis of the tankline. From here the system can essentially be two I-beam setups with associated contamination concerns, or mated cantilevered heads sharing weight distribution of the payload. The main disadvantage of gantry operation is limited access to the front of the tankline.

### Control Package

Automation control mechanisms can be as simple as electrical relays with timers, but more typically involve a Programmable Logic Controller (PLC) or pre-programmed embedded PC. "Embedded" signifies that industrially rated computer boards are used in combination with ancillary devices — not to im-

Figure 1
Overhead Conveyor

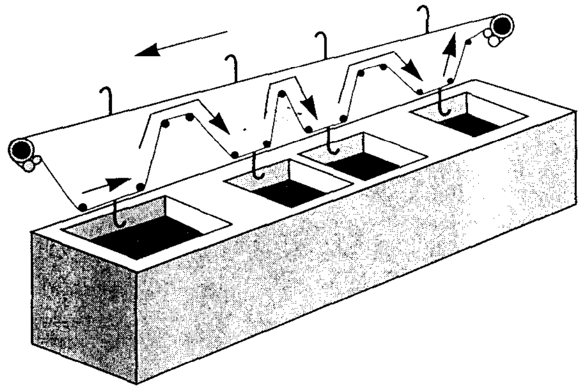


Figure 2
Powered Rollers

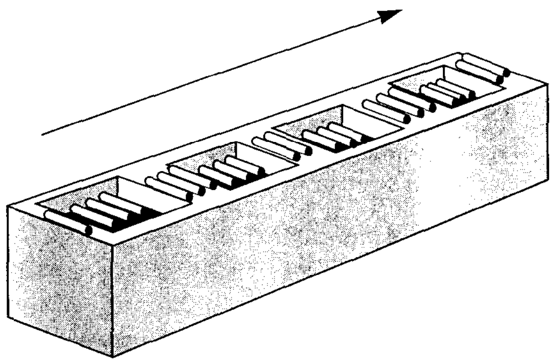


Figure 3
Walking Beam

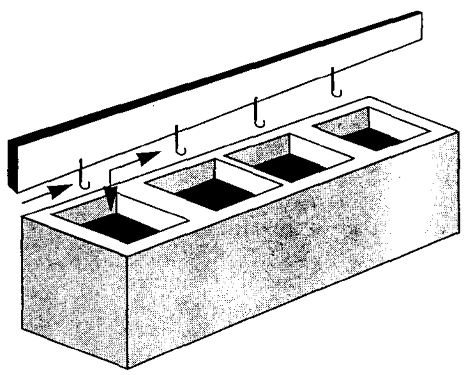


Figure 4
I-Beam or Cable

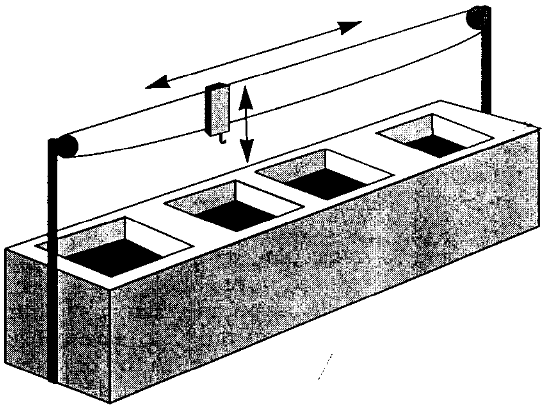


Figure 5
Cantilevered

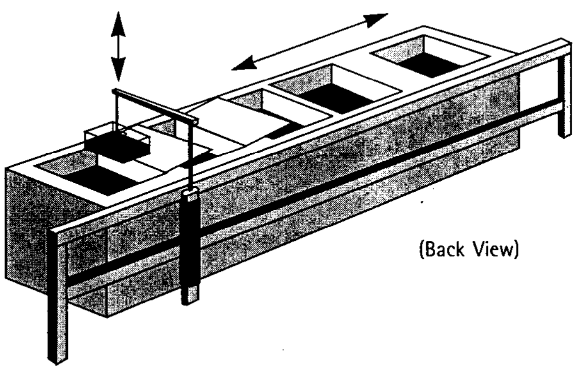
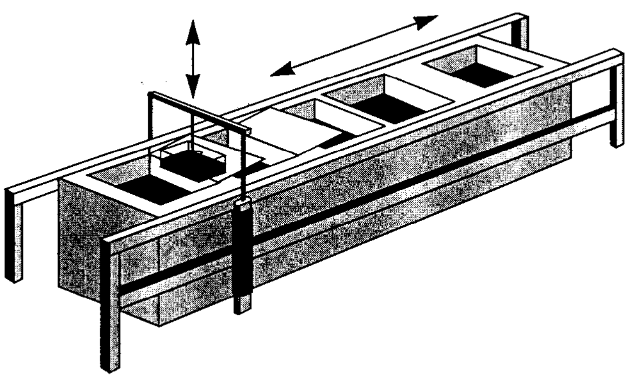



Figure 6
Gantry



ply a typical office or home personal computer. The type of control package is related fundamentally to the level of control needed:

*Simple closed-loop systems* direct motion between any two discrete sensors (targets). There is no data on the automation when it is not at a target. Positioning accuracy is low because of unreliable stopping accuracy of the automation past a target, especially when the automation is trying to hit a target from either of two directions and may have a full payload or be empty.

Although there are ways to overcome this limitation, none provide the control of an *advanced closed-loop system* or high-quality stepper motor (*open-loop system*), which have real-time knowledge of where the automation is at any point in time.

Some PLCs with stepper motors or regenerative motor drivers can provide acceleration/deceleration ramps, but typically use multiple targets at the same location to "zero in" on a target position.

Advanced closed-loop operation provides full speed control at any point. Not only does this allow more sophisticated processes, it also affords an additional safety feature in that if the automation does not move as projected, an error is generated and the automation can be stopped.

Generally, PLCs are easier to program and are acceptable for use with stepper motors and simple closed-loop systems. A pre-programmed embeded PC is considerably easier to adapt to various I/O requirements, sophisticated processes, speed control features, as well as positioning and recipe modifications.

### System Interface

Whatever type of control package is selected, the manner in which outside functions are interfaced needs attention. Obviously, having enough I/O points available for current and projected needs is important. The ability to efficiently deal with various voltages of input sensors and output features is a convenience. Optically isolated interfaces are generally available and are a standard feature of some PLCs.

One feature of control systems often overlooked is the operator interface. Emergency stop buttons (E-STOPs) should be located at all locations where the operator is likely to interact with controls, and at additional locations as dictated by the automation setup. The E-STOP circuit should allow any number of additional E-STOPS to be wired in series.

The balance of controls can vary from a start button, to LCD/keypad interface, to typical full PC interface, to touch-screen Operator Interface Terminals (OITs).

Add-on features can include provisions for bar-code interfaces, and control pendants which travel the length of the line. The latter can be limited to manual operation only or provide different levels of access to recipes.

Determining appropriate interface type depends on the level of access the operator is to be afforded to enter recipes and turn on or off I/Os when manually processing a basket, as well as both how and where process changes can be made.

It is important to match the interface to the facility environment. With low-variability settings, the interface can be quite simple. The most desired interface is simple to operate and gives slightly more information than the floor manager feels will be needed.

### Drive Systems

These may be defined as any combination of motion devices and interface to a control package. Most automation systems employ motors in combination with screws (lead or ball), belts, rack & pinion, or a combination or these methods.

Hydraulics and pneumatics are typically not considered acceptable for main axis movement due to travel limitations, positioning accuracy, and cleanliness. They are appropriate, however, for flammable applications and as ancillary axis devices to manipulate payloads at process step locations.

The type of motor employed is a function of sophistication and cost. Full servo-motors or motors with kit encoders are preferred for positioning accuracy and speed control. Stepper motors are appropriate where speed control and positioning are issues, but are typically very expensive where relatively moderate speeds or power are required.

Simple motors, typically DC for safety and cost, are adequate for simple closed-loop systems.

the vapor blanket as little as possible.

This is an ideal application for automation in that controlling the speed of penetration and removal of payloads from the vapor blanket, along with sealing the tank system to the maximum degree possible, will minimize losses. Fully enclosed systems are typically automated, though some vacuum batch systems are not designed for automation.

For aqueous and semi-aqueous systems, the objective is not so much keeping the chemistry from escaping the tank system, but minimizing dilution of chemistry as the payload moves from one tank to the next. Automation cycles should be balanced to move payloads as quickly as possible for increased throughput, but still provide adequate time allowances for drain-off above each wet station.

The savings in waste treatment from minimizing dilution may justify slightly reduced throughput. This is also particularly important where a slight increase in drain-off time can save considerable energy and delay at the dryer, which is often the bottleneck in throughput.

## Overall Plant Integration

One of the advantages of current cleaning equipment changeovers is that the process is now being incorporated with overall plant operations.

Some facilities are standardized with

## Pointers for Automation Planning

The most important consideration in choosing an automation system is anticipating current and future needs. Some designs are modular and can be expanded if the tankline configuration changes. Based on anticipated uses, choose the type of mechanical superstructure, drive system, control package, and operator interface that will best meet facility needs.

Some tips for designing any cleaning system for automation:

✔ Locate the load and unload stations at opposite ends of the tankline when possible. This will reduce the amount of "dead time" in parallel processing. Consider multiple heads, walking beams, or increased operating speeds where long traverses will significantly decrease throughput.

✔ Ensure that baskets and fixtures are rigid so that pick-up points will not become misaligned from operator handling. Closed-loop automation should operate within a range of 0.05" to 0.25" repeatability, far in excess of typical needs.

If the deflections in the mating of fixtures to end-effectors is out of tolerance due to the fixtures becoming bent out of shape, system accuracy becomes irrelevant. Whenever possible, design for a level three- or four-point handling design with tight registration to the end-effector connected to the automation.

A defined plane will improve registration, reduce deflection caused by the payload, and eliminate fixture swing from unevenly loaded baskets. Heavy or unevenly loaded baskets might also warrant nesting the payloads, typically with angled tubing at the bottom of each tank.

✔ Look for ways to improve safety in the operation, both in the automation system itself and with worker encounters. Depending on the environment, these measures may include light curtains, barriers, warning beacons, horns, etc. With tanklines over 10 feet in length, consider a remote pendant.

✔ When designing service to the tankline, consider the impact of vented hoods and plumbing fixtures, to avoid conflicts when servicing the tanks or installing the automation.