Integrated Motion Control

IN PACKAGING MACHINES DELIVERS VALUE

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Introduction

For some time now, packaging has been a key source of competitive differentiation for many companies, offering everything from food products, office products and consumer products, all of which require packaging. Packaging has developed from being merely a way to deliver a product to being part of the product itself. Ideas such as the "fridge-door-fit" ketchup bottles to milk cartons that stack better for decreased shipping costs have changed the way we view packaging.

The explosion of new products and increasing customer expectations require OEMs to provide better flexibility, openness and performance for their manufacturing and production customers.

Maximizing machine productivity and performance is imperative to success and is driving OEMs to adopt and invest in the latest technologies that can meet their customers' challenges.

At the forefront of these performance-driven technologies is an integrated control system—or programmable automation controller (PAC)—and latest-generation motion solutions. PACs provide easy integration for multi-domain functionality such as motion control, process control, logic control and HMI (human-machine interface), enabling the operational excellence that allows companies to become more productive and more efficient. PACs with integrated motion control can especially benefit applications in the packaging industry that require high-performance, multi-axis motion control.

This article discusses the background and recent trends that have led to the need for integrated motion control in packaging machines and how they deliver value in their applications.

The Packaging Industry Drives Innovation in Automation

Consumer desire can be a fickle target to satisfy, so companies rely on an endless variety of new product introductions of manufactured goods and multiple line extensions to fuel interest and remain competitive. Strolling through a typical supermarket presents this reality, for example, with six different versions of the same brand of cheese on the shelf—one-kilo block, one-half kilo block, shredded, cubed and a two-flavor mix.

Likewise, there may be five different sizes for the same flavor of pretzels—school snack pack, 100-calorie pack, 20-ounce, 32-ounce and family-size packaging. Shelf life is much shorter as products come in and out of vogue, and stores are continually restocking their shelves to meet consumers' demands for new offerings. This explosion of SKUs requires packaging machinery manufacturers to have more flexibility, speed and innovation in their machines to stay apace.

OEMs and end-users are driving a major shift in automation solutions to adapt to these trends. In the past, end-users would choose to standardize on a given automation platform and specify to OEMs what control platform they should use, even if it did not allow the level of performance, openness and flexibility to maximize productivity. The primary reason was to reduce the learning curve for their engineers and to leverage their existing expertise and intellectual property on a particular system.

However, to keep pace with the growing demand for increased productivity and product variability, more end-users are allowing OEMs to select a control platform that maximizes productivity by leveraging the highest degree of innovation and latest technology. To maximize asset utilization, end-users must have the ability to run more products on the same line and at increasing production speeds. This flexibility to handle frequent line changes and increase machine or line throughput is raising the bar on performance for new machine designs.

Packaging machines represent the largest application of general motion control systems; greater than 20% of general motion control systems go into some sort of packaging application, with form/fill/seal equipment most widely used, and labeling and coding machines (e.g., thermal transfer bar code printers) recording the highest growth in recent years. OEMs of packaging equipment are leading with performance-driven solutions that enable a higher level of flexibility, accuracy and speed. And they continue seeking to deliver automation systems that can handle faster product turnover, greater variability and shorter production runs—all while delivering increased product quality—thus driving much of the innovation in automation for all industries.

The Marketplace Move to PACs and Integrated Motion Control

Since productivity and time-to-market have become more critical—indeed, essential—to end-users, integrating disparate plant floor packaging and production equipment—and networking them to operations and enterprise-level systems as a way to improve productivity—have led to greater demand for integrated control systems such as PACs along with ever-greater motion control performance and flexibility. Furthermore, the successful integration of systems such as HMI/SCADA, process data collection and overall enterprise data connectivity is becoming critical for end-users in our information-driven world.

While a PAC's form factor can be similar to that of a traditional PLC, the PAC's capabilities are far more comprehensive. PACs are multifunctional controller platforms that encompass various technologies and products that users can implement as needed. PACs include motion control, process control, logic control and HMI—enabling true convergence (Fig. 1). Since their introduction in 2003, PACs have become attractive to end-users because they can greatly reduce the total cost of ownership.

***Key PAC features include*:**

- A single-integrated, multi-discipline development environment
- Common tag names and a single-tag database for access by all functions
- Open architecture for interoperability with other suppliers' solutions based on interface standards such as TCP/IP,

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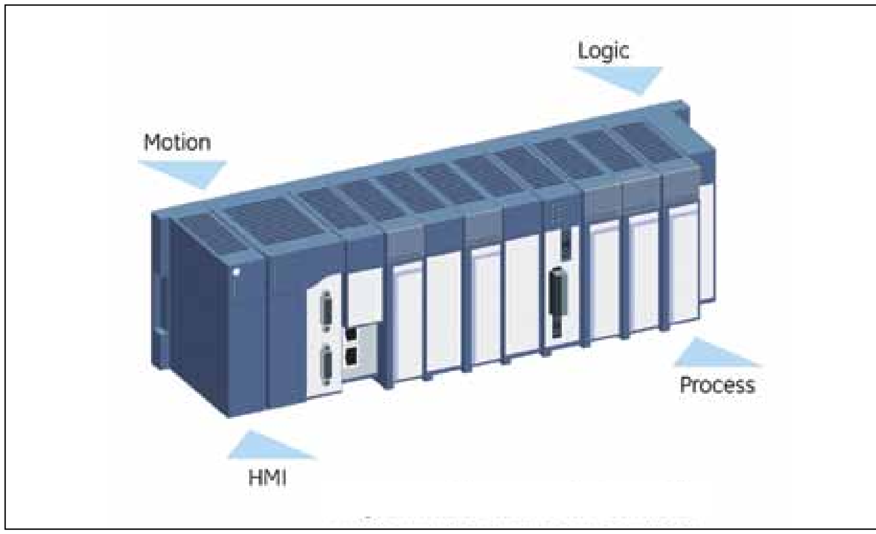

Figure 1—Programmable automation controller (PAC)—Easy integration of multi-domain functionality in one controller.

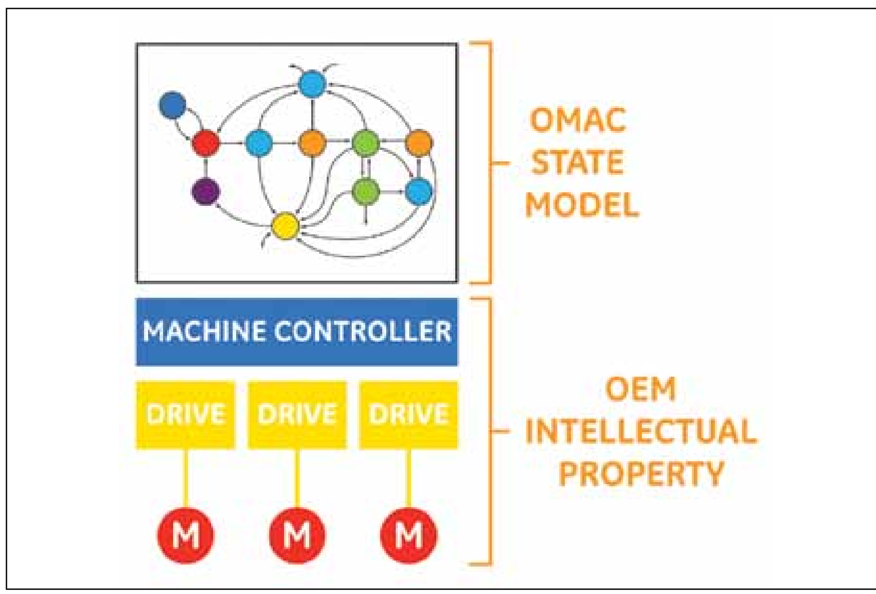

Figure 2—A noteworthy trend affecting engineering efficiency is a shift toward open standards that reduce engineering development effort.

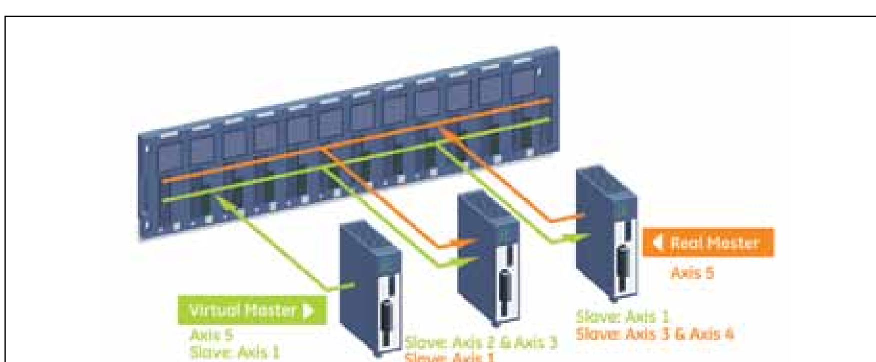

Figure 3—Being integrated directly into the PAC provides the flexibility to tightly synchronize all axes in the system by passing master axes over the backplane, and any axis can be a master or a slave to any other axis in the system without any additional wiring.

OPC and XML, and open-communication standards such as Ethernet/IP, Profibus and CAN

Motion control is easily integrated into a comprehensive PAC package. The latest generation of motion control—tightly coupled with a PAC controller, such as GE Intelligent Platforms' PACMotion and PACSystems RX3i,—can provide significant customer benefits, including:

- Improved machine productivity
- Increased engineering efficiency
- Enhanced machine flexibility and modularity

Improved Machine Productivity

In a recent study done by Chicago-based DDR Direct Response Communications, the single-greatest decision criteria cited by end-users for purchasing packaging machines was high productivity—for which they were willing to pay an up-charge—followed by greater throughput.

There are three major ways to increase productivity:

- Increase throughput
- Improve production yield (reduce scrap)
- Increase machine availability

Increasing throughput. Accelerating the control systems of a machine is dependent upon the ability to process the many inputs and outputs more efficiently. PACs integrated with motion controllers use a very high-speed backplane and real-time data exchange techniques to provide tighter synchronization of multi-axis motion, and between motion and logic events. GE's PACMotion, for example, employs a demand-driven data exchange model with the PAC CPU, which reduces scan time impact and ensures the most recent motion data is readily available to the application program.

While in traditional architectures that include a PLC and a standalone motion unit, you have to pass motion data (for example, axis actual position) at specific times within each CPU scan; an integrated motion control module in a backplane passes instance data to the program motion function blocks asynchronously as soon as new data is available—thus providing access to the motion data without waiting for the next CPU scan. This level of data synchronization is critical for accurate control of high-speed machines such as labelers, as a scan delay can cause phase errors to occur because the data may be stale by the next CPU scan.

Improving production yield. Production output also increases machine productivity, as more good parts are made using the same amount of resources. In some products using a non-integrated architecture—or even an integrated architecture that is not optimized—the main host controller CPU is also used to execute motion path planning for each axis. Motion-path planning is computationally intensive; with this additional processor load, therefore, the time between position-loop updates must increase as more axes are added.

In some cases, the servo position loop for each axis is also closed by the main CPU, resulting in even further reduction in motion update rates. This means that the motor's actual position and commanded position are compared less frequently—resulting in larger position errors. The reduced update rate may force a reduction of machine cycle rate (throughput), and larger position errors can have a direct impact on product quality.

For example, imagine a home that is trying to maintain a set temperature (the *command*). If the thermostat checks the temperature once every hour (the *feedback*), there can be large swings in the actual temperature over that hour (the *error*).

On the next update cycle, the tem-

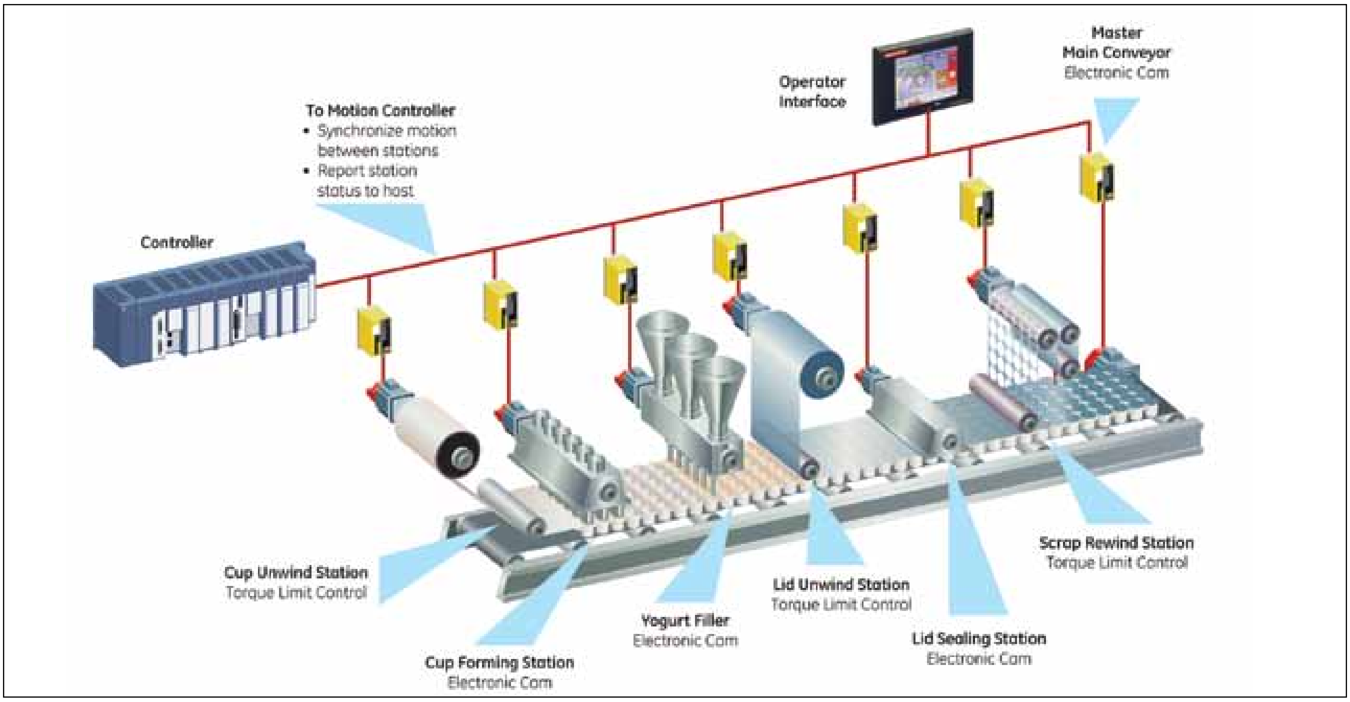

Figure 4—This electronic synchronization not only simplifies the wiring and reduces I/O; it enables instant line conversion at any time. For example, in a line used to manufacture, fill and seal plastic yogurt cups, each operation must be synchronized to the main conveyor that is moving through the line.

perature is checked against the set point, and the thermostat detects the temperature error and activates the air conditioner in an attempt to return the temperature to the desired level. However, an A/C system can quickly cool a house, and over the next one-hour cycle of the thermostat the temperature drops well below the desired temperature set point—again resulting in significant error in the desired temperature. The same thermostat, if checked once every five minutes, would maintain a much more constant temperature in the house.

Servo position loops work in much the same way. The more frequently they are checked, the more accurately they will control axis motion on the machine. Timely position-loop updates keep position deviation small when torque disturbances are encountered that can arise from machine binding, excessive friction, impact loads, etc. The faster the servo recognizes the disturbance, the more quickly a root cause is identified and corrective action initiated.

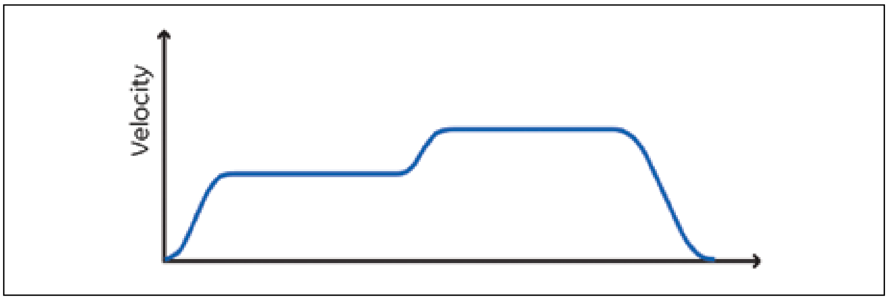

Figure 5—100% jerk control requires exactly twice the acceleration torque from the motor compared to linear acceleration in the same amount of time.

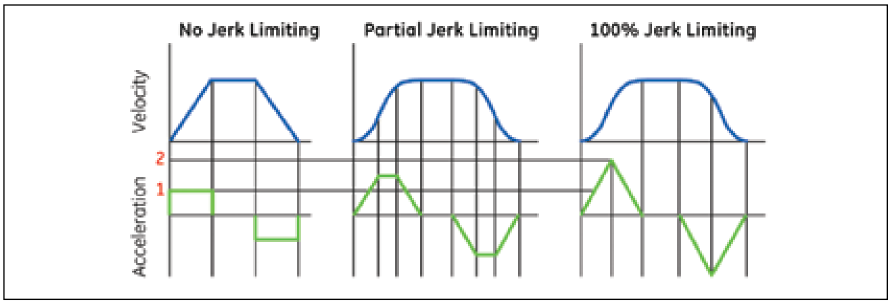

Figure 6—The same concept of blending jerk-limited profiles at non-zero velocity can be used to change the speed of a moving web without tearing or stretching the material, resulting in higher product quality and reduced downtime.

A rotary cut/seal machine cuts and heat-seals a continuously moving web of material at defined lengths; there is a high cycle rate on the knife axis for productivity and high-speed registration inputs to detect printed registration cut marks. The knife speed must match material speed during the cut to prevent tearing or bunching, as well as size accuracy with the material being cut. If the machine encounters a phase error due to asynchronous position updates or long servo updated loop times, it could, for example, introduce a 1-ms phase error. If the machine is throughputting product at 1-meter-per-second, a variation in cut length of up to 1 mm could occur—causing scrap or rework.

Increasing machine availability. Packaging equipment has also become more important as product life cycles have drastically shrunk; long gone are the days of putting one product on one line and letting it run for days. Manufacturing today requires rapid line changeovers in order to run different products and virtually no downtime during those changeovers. Companies are adopting new tactics to achieve these goals by increasing the automation of their machines—most of which have gone from a mechanical line shaft to an electronic line shaft—and have increased the integration of servos.

In evaluating integrated motion control systems, OEMs have come to realize that the reliability of all system components is critical and in acknowledging that it only takes one part of the system to "crash" the entire machine. The servo systems orchestrating these parts undergo more physical stress than any other part of the system; too, these application programs tend to be some of the most complex programs running on the system.

With that said, the evaluation criteria of a motion control system for reliability should include low-mean-time-to-repair (MTTR) for fast recovery and reduced downtime. Manufacturers should publish mean-time-to-failure based on historical information that helps you gage component reliability in real-world applications. For example, GE's PACMotion controller uses the highly reliable FANUC servos that boast a mean-time-before-failure (MTBF) measured in *decades*. The FANUC amplifiers have no stored configuration or tuning parameters that need loading when replaced, so they are easily swapped out in the rare case of failure. This type of design in any motion control system can directly impact the reliability of the entire machine.

Increased engineering efficiency. As time-to-market is critical for success in today's competitive packaging marketplace, integrating motion into one common environment with HMI, logic and process control substantially increases engineering efficiency. With a common open standard programming language, tag database and function blocks, engineers can spend less time and effort learning new programming environments and synchronizing different programs. The result is faster program development, quicker time to market, and faster machine commissioning.

Machine builders that have used standalone motion products have had the added burden of having to use and learn different programming software environments for the host controller, motion and servo configuration. Each piece of the system requires its own individual application program(s), and the additional programming required

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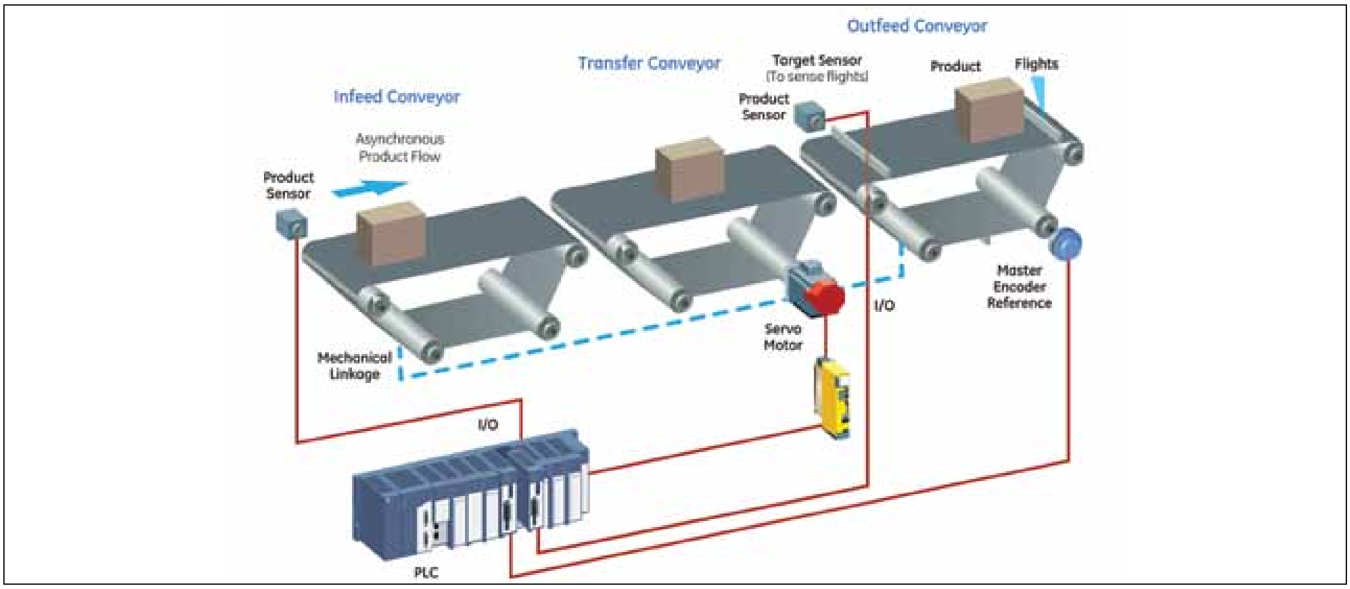

Figure 7—As OEMs increasingly adopt and invest in the latest technologies to meet their customers' challenges, integrated motion with a programmable automation controller provides value by maximizing machine productivity, engineering productivity and machine flexibility.

to synchronize the main machine control (logic) program and the motion program(s) can be significant. As a result, system performance is compromised because of the processor burden to run additional synchronization logic, the timing constraints for asynchronous handshaking between programs, as well as the bandwidth of the motion interface.

The coordination of passing information between the multiple programs forces trade-offs between quantity of data and speed, and also introduces another layer of complexity where errors and bugs may occur. This added program complexity can also impact timely commissioning of new machine designs, leading to longer development cycles.

However, the integrated programming environment of a PAC should not be confused with a "simple" programming environment, as most integrated control programming packages allow users to program in many of the standard IEC languages such as Structured Text, Ladder Logic, C and others. For example, GE's PACSystems features a control engine that is portable to multiple platforms and allows users to choose the hardware and programming language that best suits each particular application. When integrating motion control, the system provides a universal engineering development environment for rapid development, implementation and migration.

A noteworthy trend affecting engineering efficiency is a shift toward open standards that reduce engineering development effort. The Organization for Machine Automation (OMAC) provides many packaging industry standards such as PackTags and PackML, and adoption of OMAC standards can lower multi-machine integration and coordination costs, standardize program structure, increase machine features and reduce the cost of maintenance and training. A library of re-usable OMAC standard machine application code greatly reduces the development cycle.

Motion-specific programming has also followed this paradigm shift away from proprietary languages toward open (PLCopen) standards. PLCopen has developed an open standard motion language that integrates with IEC languages. Open standard programming significantly increases programmer productivity and protects investment in intellectual property by providing portability to different hardware platforms.

Products such as GE's PACMotion support over 50 motion functions—in both Structured Text and ladder diagram function block—and its programming has been developed in compliance with PLCopen standards. Any quality vendor of integrated machine control should provide standards-based programming to reduce engineering development effort.

Enhanced machine flexibility and modularity. As stated, because production runs are routinely turned over multiple times per day, today's production lines require an incredible level of flexibility. In addition to providing the scalability to handle machines with varying levels of performance and different numbers of axes, automation and motion control solutions must also facilitate instant, push-of-a-button line reconfiguration, as a single line might fill 16-ounce, 20-ounce and 2-liter bottles in successive daily production runs.

To realize this capability, current-generation machines utilize electronic line shafts (ELS) to synchronize all axes of motion on a machine or line. An electronic line shaft-synchronized system uses independent axis control at each station, which in turn is synchronized to a master source—either an encoder or time-based profile, i.e.—virtual master.

Typically, a single master axis acts as the pacer for all other axes—or slaves. This master can be a real axis (motor), an external encoder mounted on the machine or a time-based virtual master. For example, each PACMotion motion module includes a master axis that can be configured as a real master tied to an encoder or as a virtual master with full motion programming support. Being integrated directly into the PAC provides the flexibility to tightly synchronize all axes in the system by passing master axes over the backplane, and any axis can be a master or a slave to any other axis in the system without any additional wiring. More importantly, these master/slave relationships can be redefined in process by the applications program (Fig. 3).

This electronic synchronization not only simplifies the wiring and reduces I/O; it also enables instant line conversion at any time. For example, in a line used to manufacture, fill and seal plastic yogurt cups, each operation must be synchronized to the main conveyor that is moving through the line. The cup-forming press, filling and sealing stations use electronic cam profiles that can be changed or scaled in-line to reintegrate for different cup volume sizes or shapes.

The wind/unwind stations use torque control to control tension in the plastic film used to make the cups and the foil used to form the lid. These torque limits can be quickly and easily changed to conform to the requirements of different materials used across the range of yogurt cups made on this line.

Furthermore, tight integration with the PAC controller leverages flexible system configuration, whereby both centralized- and hybrid-distributed architectures are supported. Hybrid solutions merge the benefits of centralized programming and control with the reduced wiring by distributing the amplifiers and motors. Distributing the amplifiers and motors also facilitates modular machine designs such as wrapping, cartoning and case-packing with multiple stations (Fig. 4).

Advanced features in motion control with PACs. The sweet spot for PACs integrated with motion may be the more complex, higher-speed packaging applications requiring higher cycle rates and tight coordination of multiple axes. Many of these high-end applications benefit from the advanced motion features available in high-performance PACs such as variable jerk control and the blending of jerk-limited profiles.

Jerk control can be advantageous in certain applications such as transporting liquids without spillage, tearing or stretching when pulling paper or plastic film, or in preventing boxes from toppling or slipping on a conveyor belt. Additionally, proper application of variable jerk control can minimize machine wear while optimizing servo motor sizing. However, be advised that there exists a trade-off in using jerk control—greater torque (acceleration) capability from the motor.

As Figure 5 illustrates, 100% jerk control requires exactly twice the acceleration torque from the motor, compared to linear acceleration in the same amount of time. However, variable jerk control can tap the motor reserve torque to minimize machine wear without increasing motor size and cost. Minimizing jerk reduces the repetitive impact loads on mechanical components such as lead screws, gearboxes and couplings that can cause premature failure. And yet, some motion path planners only support linear and/or 100% jerk control, so select a motion control solution that will meet all of your application requirements while reducing maintenance cost and maximizing machine life.

The blending of jerk-limited profiles can provide much tighter control in applications where velocity changes are required during the move. For example, a packaging line transfer conveyor (also known as a "smart belt" or "random in-feed") equalizes the random spacing of products coming off an in-feed conveyor, thus affording their seamless transfer to an out-feed conveyor for wrapping or packaging.

As the product is transferred from the in-feed conveyor to the transfer conveyor, the speeds of the two belts must match. Once the transfer is complete, the transfer conveyor will accelerate or decelerate, based on sensor inputs, to equalize the spacing as it is transferred to the out-feed conveyor. During the transfer conveyor's speed changes, it is critical that product not slip on the belt, which would in turn jumble the product spacing. In this case, it is important to blend two jerk-limited profiles (Fig. 6).

Conclusion

The packaging machinery industry continues evolving and adapting to demanding customer needs through the use of more complex automation. As OEMs increasingly adopt and invest in the latest technologies to meet their customers' challenges, integrated motion with a programmable automation controller provides value by maximizing machine productivity, engineering productivity and machine flexibility.

Companies in high-performance packaging that require multi-axis motion control for mid-to- high-end applications may especially benefit from integrated control systems that help maximize machine productivity for a competitive, sustainable advantage.

For more information:

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