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The Drive & Control Company

Bosch Group
Machine building has seen an disruptive shift in how equipment is built and how it operates. From software and robotics to virtualization, simulation and the Industrial Internet of Things, the manufacturing landscape is shifting faster than Sarahan sand dunes. But, despite all of the changes, motors and drives continue to play a major role in making machinery move.

A February 2016 survey of Control Design readers identified usage and application trends in motion, drives and motor technology, reinforcing that, the more machines change, the more their motion requirements stay relatively unchanged.

More than two-thirds of respondents reported using servo motors, while almost half are using standard motors, and almost one-third are using stepper motors. Regarding efficiency motors, almost half are using high-efficiency, and one-fourth are using premium-efficiency motors.

The vast majority (86%) of respondents who use servo motors said they’re mostly digital-drive technology, with only 14% using analog. And almost 40% of respondents using stepper motors use open-loop steppers, with the remainder using closed-loop.

For performance characteristics of their drive systems, 67% of respondents said position control was most important, while 42% identified speed control, and 27% indicated it was torque control.

Respondents using a digital bus indicated use of EtherNet/IP (42%), followed by CAN/CANopen, SERCOS/SERCOS III, EtherCAT and Profinet, all hovering in the 9-to-13% range. Powerlink, DeviceNet and CC-Link all showed up at 5% or lower.

This State of Technology Report explores in greater detail the trends that have shaped motors, drives and motion control, the fundamentals of the technology, and real-life examples of implementation that have proven successful. Drawn from the most recent articles published in Control Design, this special report includes articles on emerging developments, basic primers and motion-control examples illustrating the latest technology in action. We hope that you find it useful.

—Mike Bacidore, editor in chief
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MEET THE PEOPLE THAT ARE MAKING IT BETTER AT BIMBA
Applications that will benefit from collaborative robot innovations

Panel of industry experts discusses the impact of robotics on manufacturing and how technology keeps affecting robots.

By Mike Bacidore, editor in chief

Collaborative robots are all the rage. But, why and how will these mechanical marvels benefit manufacturing applications? With robotics playing such a pivotal role in the future of discrete manufacturing, we asked a seasoned panel of industry for their insights and predictions on the role of robots. Get to know the panel and see what questions we asked at www.controldesign.com/robotics-expert-panel.

Q: Collaborative robots eliminate the barrier between the working human and the robot, but what kinds of applications will actually benefit from collaborative robots?

Craig Souser: They need to be applications where the robot motion is relatively slow and not much mass is moving. Light-duty assembly and fixturing of a part for a human to interface to are good uses.

Carole Franklin: Collaborative robots may be best described as collaborative robot systems, rather than any particular type of robot. Collaborative robot systems are ones in which the robot and human worker have overlapping workspaces. However, it is probably not realistic to assume that all safeguarding barriers will go away tomorrow. For now, the collaborative workspace will most likely be a small defined space with familiar fencing or other safeguards surrounding the rest of the robot.
Melanie Cavalieri: There are a lot of traditional applications that come to mind when considering industrial applications, which are repetitive and physically demanding, such as assembly, loading/unloading, packaging, sorting, dispensing, sanding and polishing. These types of applications will continue to benefit as the adoption rates increase across a range of business sizes. Robots are no longer only for the large industrial manufacturers, and these businesses will see a wide range of benefits.

A large number of applications see a return on investment (ROI) in less than one year with today’s collaborative technology. In addition to the reduction of labor costs and the increase in productivity, these robots allow facilities to reduce assembly line sizes because they don’t require separate stand-alone, caged areas. Robots can be co-located to work directly next to their human counterparts, which means fewer barriers to work around and less lost time for people.

Finally, robots can work in the complex human environment without large installations of external sensors and barriers. This allows facilities to deploy robots, remove robots or deploy humans as required in the current working environment. This enables flexibility that is required by a lot of high-mix, low-volume manufacturing facilities.

A collaborative, complex sensing robot not only allows a robot to work next to a human counterpart, but it also allows it to work in complex and dangerous applications that still would be difficult to deploy a traditional robot. Applications like painting or removing paint from large ships traditionally expose a person to dangers including chemicals and height. Now robots can be deployed to do this work without the overly complex task of installing guides, tracks or sensors.

Applications where we’ve seen automated equipment being used in large organizations can now be used with smaller organizations, with smarter and more accessible collaborative robots. Warehousing and logistics have been using AGVs for a number of years but traditionally require a large facility investment to allow these vehicles to operate. Mobile robots combined with articulated robots present an exciting new opportunity to have robots handle movement around a facility, as well as select and pack products, all while working in a human environment.

Finally, collaborative robots are providing an exciting opportunity in remote security and monitoring. This application combines a variety of technology including mobile robotics, sensing and video monitoring. Opportunities for these robots include country and state borders and other large, sprawling areas such as agricultural farms, solar farms, warehouses, airport parking lots or military bases.
David Arens: Collaborative robots by their name indicate that they will be working in a human environment. They are not eliminating the barrier between the working robot and the human; they are just changing the barrier between human and robot to be the surface of the robot and any manipulators or attachments.

This being said, the robots can assist humans in steadying the motion, for example, in surgery and or lab operations to prevent the human jerkiness and fine motor skills from causing unwanted motion. In addition, there are limitations of the human-like strength, temperature and other environmental tolerance that, should the human not be able to continue the work, the robot can maintain the operation and or sustain the system while the human recovers the ability to work in the environment. Applications include blast furnaces and steel mills, blast freezers and genetic clean room labs—these should not have a human involved since their own DNA can contaminate a sample.

Shishir Rege: Robotics has come full circle with the advent of collaborative robots. Initially, robots were introduced in manufacturing to replace humans from repetitive or hazardous jobs. Robots were caged-in so they could work fast without interruption or accidents with operators. Then, the purpose of manufacturing plants that employed these robots was purely efficiency of operation for that machine or system.

Now, with collaborative robots on the rise, robots are becoming aware of their surroundings to tailor the activities in response to the environmental changes. The purpose of manufacturing is not only efficiency of one machine or system, but improving efficiency of the overall plant. Previously, prior to the collaborative robots, a lot of space was consumed with single robot installation, primarily for guarding purposes to avoid run-away conditions of the robot arm. Also, if someone wanted to enter the robot workspace, even if the robot was on the other side of the zone, the operator would need to stop the robot before entering the zone.

With smarts added to the robot software and intelligence in the peripheral sensor technology, the robot is much more aware of what is happening in its work zone. So, if an operator enters in one area of the work zone, when the robot is in another area of the zone, the robot can lower its speed and continue to operate until it does not need to share the area where the operator is. This makes many more operations in the factory automation setting possible with smart robots. Collaborative robots allow manufacturers to increase productivity in the plant with added space by removing barriers around the robots.

Roberta Nelson Shea: Collaborative robot systems do not eliminate barriers. A collaborative application is where a person or people and a robot system, including the
end effector or tooling on the robot, share the same workspace for their respective tasks. Most applications can benefit, except in the case of hazards that require barriers for personnel protection, such as weld robots. The benefits can be as simple as reduced floor space and improved ergonomics. This can be achieved using safety-rated, monitored stop capability and loading directly to a robot end effector, rather than a fixture.

An increasing number of applications will be collaborative, but these applications will contain features that provide protection to people. That protection will include protective devices such as light curtains, safety-related functions and passive means to reduce risks, such as padding to lessen forces and spread over a greater area.

In these applications where power and force are limited, the robot system will not likely cause pain or injury because it is limited in its forces and speeds. The new ISO TS 15066 includes an annex developed from a study of the forces on multiple body regions where pain onsets. For these robot applications, it is possible that no guards or protective devices would be needed. However, a power- and force-limited collaborative robot that has an end effector with sharp edges or pinching potential is not a collaborative application.

**Allan Hottovy:** In the near term, I think the biggest growth will be in helping people manage heavy, repetitive loads and to increase precision in manufacturing at higher volumes. Currently, the mechanical power, computer intelligence and precision of the robots couple well with the imagination and flexibility we humans currently provide. In the long term, with the rapid increase in the abilities of AI-based control systems, it's hard to predict the role humans will play in future highly automated, AI-controlled manufacturing systems.

**Alex Bonaire:** Applications that most benefit from collaborative robots are applications where a user or operator needs to directly interact with the robot and/or the work piece at the same time that the robot is. For example, a work cell with a large work piece that is difficult to maneuver by hand or via a power-assisted device could benefit, as a robot could be programmed to re-orient the work piece while the operator is working on the part.

Assembly applications that combine both easy and repetitive work along with more complex assembly processes are also good applications for collaborative robot implementation. For example, a product may have many screws on one side of the product that can be inserted by a robot while the operator assembles a more complicated assembly on the opposite side, not interfering with the same area that the robot is applying the screws.
“Examples of applications that would benefit from collaborative robots include light assembly, packaging and machine tending.”

Corey Ryan: Adaptive assembly and applications requiring people and robots to be constantly in the same working area will benefit the most. From a market perspective, consumer electronics is the fastest-growing segment for collaborative robots. During the assembly of tablets, smartphones and other electronic devices requiring robots to carry very low payloads, it is much easier to allow for safe human-robot collaboration (HRC) since the payloads are very light. Entertainment and medical applications, where the main goal is having the robot and human interact, can use the safety of the new collaborative robots to explore new markets without having to add sensors or develop new technologies.

Scott Mabie: It really runs the gamut; any imaginable application that features a repeated task with a payload less than 22 lb could potentially benefit from our cobots. The machining sector continues to be a big demand driver, but now we’re seeing new markets open up and unexpected applications appear.

Our robots are in applications that receive a 3D laser scan of people’s feet and cut out customized flip flops; the robots are being tested in agriculture, spraying iodine on cow udders before milking; they assemble thermal cups, work as camera men, increasingly handle injection-molding machines and feed CNC machines milling dental crowns and medical devices. We’re also seeing a lot of interest from the electronics manufacturing sector where our cobots perform tasks such as lifecycle testing and epoxy filling in circuit boards. Our new tabletop robot is now experiencing a high demand from the electronics assembly market.

Garrett Place: A good portion of today’s collaborative robots are limited in both speed and carrying capacity. This means that we should be looking for applications that aren’t impacted by these two factors. Examples of applications that would benefit from collaborative robots include light assembly, packaging and machine tending.

John Keinath: In typical robot applications, the operator loads parts to a fixture, conveyor or turntable. Then the operator leaves the work space, and the robot does its work. With collaborative robots, the operator can give the part directly to the robot and never has to leave the work space. This reduces production time, investment cost and floor space.
### MEET THE PANEL

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<th>Photo</th>
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<tr>
<td><img src="image" alt="David Arens" /></td>
<td>David Arens is senior automation instructor, certified TUV functional safety engineer, at Bosch Rexroth Drives and Controls Division.</td>
<td>Bosch Rexroth Drives and Controls Division.</td>
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<tr>
<td><img src="image" alt="Henry Menke" /></td>
<td>Henry Menke is marketing manager, object detection and position sensing, at Balluff.</td>
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<tr>
<td><img src="image" alt="Alex Bonaire" /></td>
<td>Alex Bonaire is robot product manager at Mitsubishi Electric Automation.</td>
<td>Mitsubishi Electric Automation.</td>
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<td><img src="image" alt="Roberta Nelson Shea" /></td>
<td>Roberta Nelson Shea is global marketing manager for safety components at Rockwell Automation.</td>
<td>Rockwell Automation.</td>
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<td><img src="image" alt="Melanie Cavalieri" /></td>
<td>Melanie Cavalieri is product manager at Kollmorgen.</td>
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<td><img src="image" alt="Garrett Place" /></td>
<td>Garrett Place is product manager, imaging technologies, at ifm efector.</td>
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<td><img src="image" alt="Carole Franklin" /></td>
<td>Carole Franklin is director of standards development at Robotic Industries Association.</td>
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<td><img src="image" alt="Shishir Rege" /></td>
<td>Shishir Rege is marketing manager, industrial networking, at Balluff.</td>
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<td><img src="image" alt="Mike Hannah" /></td>
<td>Mike Hannah is market development lead for The Connected Enterprise at Rockwell Automation.</td>
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<td><img src="image" alt="Corey Ryan" /></td>
<td>Corey Ryan is manager—medical robotics, North America, at KUKA Robotics.</td>
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<td><img src="image" alt="Allan Hottovy" /></td>
<td>Allan Hottovy is business development manager at Telemecanique Sensors.</td>
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<td><img src="image" alt="Scott Mabie" /></td>
<td>Scott Mabie is general manager, Americas Division, at Universal Robots.</td>
<td>Universal Robots.</td>
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<tr>
<td><img src="image" alt="Craig Souser" /></td>
<td>Craig Souser is president of JLS Automation, a robotic packaging company in York, Pennsylvania.</td>
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Motion control joins the efficiency revolution

Smart machine builders are using innovative designs, components, software and production methods to save energy, materials and expenses.

By Jim Montague, executive editor

Intelligence is just like a Swiss Army knife or other multi-purpose tool that you can apply in different situations to solve many types of problems.

What’s different now is that some machines and their controls are being endowed with more of the analytical capabilities of their human counterparts, so they can make better operating decisions and save power and other expenses more quickly and easily. These skills may be rooted in combinations of more powerful microprocessors, better software, more sophisticated robotics, more pervasive networks or cloud-based data processing, but, whatever their source, they’re enabling new levels of efficiency for machine builders and their end users.

SAVINGS START WITH MOTION

In recent years, probably the most popular way to make machines more energy efficient has been moving from less-flexible induction motors and drives, which are typically on at full power or off, and implementing variable-frequency drives (VFDs) and servo motors, which allow much wider ranges of speeds and power levels and can save a lot power doing the same jobs.

For instance, BW Container Systems, in Lynchburg, Virginia, recently developed its latest AdaptA Series mini-buffering (MB) and multi-lane (ML) conveyor systems for preventing
traditional slips, gaps, bumping, pressure, damage and other line inefficiencies among containers running between close-coupled machines. AdaptAMB runs containers around a u-turn wheel that automatically extends or retracts to lengthen or shorten the containers’ single-file path, which helps with queuing and feeding to reduce damage (Figure 1). This buffering also helps AdaptA ML, which employs pressureless infeeding to accumulate containers in a transfer station with four to 24 lanes.

“The real estate between machines is at a premium, but this means conveyors often run inefficiently, and so containers need buffering,” says Tom Spangenberg, business unit director at BW Container Systems, which includes Barry-Wehmiller’s Fleetwood, CBI-Fleetwood, Goldco-Wyard and Ambec divisions. “There’s a wide variety of buffering approaches, but users also want easy access and the ability to handle many different products and containers with stability.”

To achieve optimal efficiency, simplify control and minimize energy use, AdaptAMB is driven by a 2-hp Nord motor with VFD and a switch chain, while AdaptA ML uses two servo motors and a ControlLogix PLC. Meanwhile, AdaptAMB’s wheel uses two motors and two VFDs, and the transfer station relies on three servos. “AdaptA is controlled like a symphony,” says Spangenberg. “Mini-buffer’s u-turn grows or shrinks as needed, and so users don’t have to worry about manually moving devices or handoffs, which used to be very complex.”

So far, AdaptA has been implemented by about a dozen food, beverage and consumer product manufacturers, and Spangenberg reports it’s achieving 5-20% efficiency gains. “One customer said they saved about $200,000 in damage to their food containers,” adds Spangenberg. “However, AdaptA is also transforming us beyond being a machine provider to doing data acquisition for our customers and also delivering higher-
Likewise, Komo Machine in Lakewood, New Jersey, recently needed to build a new, more affordable version of its Mach One GT MTX open-bed, gantry-style router for milling wood, plastics, composites and sheet metal at about 80 sheets per day (Figure 2). Consequently, Komo decided to control its x and y gantry axes and z spindle axis by integrating an IndraMotion MTX micro CNC system and IndraDyn S MSK 60 servo motors from Bosch Rexroth.

MTX micro includes high-capacity CNC controls, integrated PLC compliant with IEC 61131-C programming standards, integrated HMI and a 32-bit processor that supports up to six CNC motion axes with control of up to four interpolated axes of motion at any time. Optimized for milling applications, MTX micro supports 2.5D and 3D milling and free positioning of the workpiece coordinate system in space, and it includes many NC capabilities in a compact platform, such as 1,000 NC blocks with look-ahead functions, axis-specific jerk limitations and control of interpolated milling sequences down to the nanometer level.

“These look-ahead capabilities will allow milling shops to run the machine faster but maintain accurate control of the axes,” says Jeff Erickson, Komo’s vice president. “Mach One GT MTX supports a high feed rate of 1,500 in/min, but, as it comes to a corner, it will ramp down to precisely cut a sharp corner without rounding it and then quickly ramp back up to 1,500 in/min, while maintaining control of all the axes. This will enable it to sustain a higher rate of throughput without sacrificing milling quality, enhancing the return on investment for Komo’s customers.”

Besides reducing milling time, Komo Engineering Manager Steve Ostermann reports that Mach One and MTX micro CNC also save energy by supplying power to all four level line efficiencies and overall system improvements.”
axes through one interface, rather than separately to each drive. “MTX micro features enough I/O interfaces to support the Mach One’s requirements, and the fully integrated HMI is easier to configure than a separate HMI package,” explains Ostermann.

**PRECISE CONTROL, DUH**

Of course, one of the primary paths to efficiency and power savings has always been tighter control and running machines and applications closer to required specifications.

For example, founded in 1926, Gehring Technologies in Ostfildern, Germany, invented and continues to build high-accuracy honing machines for making sure cylinders used in engines, hydraulics, pumps, landing gear and connecting rods are as close to critical tolerances as possible, so all the equipment they go into can optimize the fuel and power they consume and use less lubricating oil. Honing is usually the last step in machining cylinders.

The Gehring form-honing process uses tooling with eight to 12 diamond stones and carbide guides, runs at 400 rpm and specializes in creating “negative forms of deformation” to ensure that cylinders will be even closer to perfectly cylindrical when running at high temperatures. Unlike typical honing machines that use a fixed spindle and one- or two-axis table, Gehring’s Lifehone line and its year-old Hexahone and Octohone models employ a two-axis spindle and three-axis table in six- or eight-sided inner columns to perform up to 16 tasks in one machine, including pre- and post-gauging (Figure 3).

“Our machines automatically compensate for the form and shape of bores to increase accuracy and make them perfectly straight, which takes some burden off their operators,” says Thorsten Botzenhardt, Gehring’s key account manager. “We also invented a piezo-based feed head that independently extends each of the abrasive stones on the honing tool, which is better than the tradi-
tional feed heads that extend all the honing tool fins at once.”

These complex components and processes are controlled by Gehring’s proprietary Honing Control software and then coordinated by a Siemens Simatic S7 320 DP safety-integrated PLC, which can also interact with users’ support robots for loading and unloading the machining center. In-process air gauging provides results to the control and feedback systems, which manages speed, feeds, force control and pressure better than regular numerical controls, according to Botzenhardt. In addition, Lifehone uses Festo’s pneumatic safety brakes on guide rails for air-sizing and handling tasks, Lumberg’s distribution blocks for proximity switches and minimizing cabling and Profinet protocol for network communications, including remote monitoring and diagnostics.

“Integrating all these functions, such as our safety PLC and regular controls, enables our machines to work faster and more efficiently,” adds Botzenhardt.

ROBOTS TO THE RESCUE
Along with saving energy while gaining productivity, many builders report that users also want greater flexibility and machines that can adapt and produce more varied types and sizes of products with less changeover than in the past. One way to simultaneously save power and gain flexibility is to use robots for tasks that formerly required multiple integrated components.

For instance, Sugino in Itasca, Illinois, and Toyama, Japan, builds mainly drilling, tapping, machining and high-pressure water deburring equipment, and it recently improved its solutions by implementing robotic functions in some of them. The company’s JCC-Wide high-pressure washer runs at up to 7,000 psi, but it was recently updated with robot-type CNC software and renamed JCC-Robo. This upgrade allows Sugino to go beyond the usual x, y and z axes and articulate at horizontal and vertical turning axes, as well, which enable users to wash any area of parts at any desired angle (Figure 4).
“We can get to anywhere on a part with CNC programming, and wash it with 6.4 mega-Pascals, which is almost 1,000 psi,” says David Becker, Sugino’s sales manager. “Beyond this robotic flexibility, a couple of customers are even simulating putting a standard drill unit, such as an ES2 air/electric, on the end of a Fanuc M710iC robot, so it can also achieve more flexible positioning and work on much larger aircraft, composite or other oversized parts without comparably larger operating or energy costs.”

John Kalkowski, marketing director at Delkor Systems in St. Paul, Minnesota, reports his packaging clients have been demanding similar levels of flexibility and increased productivity. As a result, Delkor also opted for robotic solutions to achieve these goals, merged previously separate operations, and reduced material and energy costs at the same time.

“For example, MSP-200 uses a Fanuc M-2iA 3SL delta-style, vision-guided robot to align and set up pouches for pick-and-place, and then a Fanuc M-710iC 50H robot puts them in their cases. Both are coordinated by Fanuc’s R-30iB controller and can load up to 150 pouches per minute. “This design allows MSP-200 to work with the corrugated, paperboard and other cartons and cases we form, fill and close, and it also enables it to update individual functions in its production line or add new pieces as needed.”

**PC-BASED SMARTS SHOW OFF**

Given the intense and growing emphasis on machine intelligence, it was inevitable that PC-based control would arrive to help improve machine and production line efficiency and save energy.

For example, Fabri-Kal in Kalamazoo, Michigan, designs and builds plastic processing and thermoforming equipment for making plastic cups and packaging for yogurt, smoothies, milk shakes and other food products. However, like every machine builder tasked with doing more with less, Fabri-Kal also needed to improve throughput and speed, while reducing energy consumption.

Fabri-Kal uses extruders to form deep-drawing plastic sheets of precisely defined thickness, which are then shaped in a separate deep-drawing machine. In the extruder, PC-based control technology regulates the temperature and pressure, as well as the...
setpoint for the frequency inverter. Consequently, Fabri-Kal implemented CX2030 and CX1020 embedded PCs from Beckhoff Automation to serve as the control hardware for Fabri-Kal’s machines. In the deep-drawing machine, the PC control platform with Beckhoff’s TwinCATNC regulates the drawing unit, along with the composition and separation of the end product. In addition, the PC-based automation technology monitors and documents the factory’s entire production process.

“What we were aiming for was a dynamic control system with flexible connectivity solutions for linking to the other equipment in the factory, plus the option of capturing and centrally managing large amounts of data in an SQL database,” says Dale Michaels, Fabri-Kal’s electrical engineer. “Thanks to TwinCAT’s open architecture, we were able to achieve just that. CX2030 is equipped with a 1.5 GHz Intel Core i7 dual-core CPU, which offers high performance in a compact design. Besides handling the PLC and motion control, the embedded PCs also govern the temperature and pressure throughout the production process.”

Fabri-Kal also uses EtherCAT for fieldbus networking, which enables communication speeds in the microsecond range.

“EtherCAT significantly improves the performance of our machines,” adds Michaels. “For motion control as well, we’re increasingly using AX5000 series EtherCAT servo drives that offer us both high speed and precision.”

Additionally, the I/O stations and drives interspersed along the line of machines are connected via EKI1100 EtherCAT couplers. Precise temperature control and performance monitoring ensure efficient use of energy. Precise temperature control plays a key role in the extrusion of high-quality plastics, affecting both resource consumption and product quality.

“No now that we have an integrated PC-based control platform with EtherCAT thermocouple I/O modules, we can precisely maintain the desired temperature on the basis of process data that is captured in real time,” adds Michaels. “Integrating PC-based control hardware and software has given us a flexible way to upgrade our machines without coming into conflict with existing control systems as we migrate technologies.”
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Encoders and resolvers—giving you a sense of where things are

Whether it is rotational angle, speed feedback or actuator position, rotary encoders and resolvers can give you a sense of where things are.

By Tom Stevic, contributing editor

When it is required to measure the rotational angle or get speed feedback of a motor or shaft, the two most common methods used are rotary resolver or a rotary encoder.

Resolvers have been around for more than 50 years and are robust and reliable rotary position sensors. The resolver consists of a rotor and a stator, similar to an electric motor. Inside the resolver housing, the arrangement of the windings are such that one coil, effectively a rotating transformer, induces a voltage in the rotor. This voltage in turn induces voltages in two additional windings that are physically arranged 90° apart from each other. As the rotor turns, the induced voltages of the additional windings are 90° out of phase with each other in a sine/cosine relationship.

The raw outputs of the resolver are analog signals that are converted into digital values in modern devices. Since the windings are fixed in position, no matter the angle of rotation of the rotor, its position can be immediately determined by measuring the phase relationship between sine and cosine windings. Even if the rotor is turned during a power-off of the system, upon reapplication of power to the controls, the electronics can recalculate the rotor’s position.

Adding more pairs of secondary windings increases the accuracy of the resolver. For
scientific resolvers, one rotation can be measured within minutes, or 1/60 of a degree, or even seconds, 1/3,600 of a degree. This accuracy is achieved using a device with 128 or more pole sets.

Resolvers are restricted in the speeds in which they can operate because of the inductive time lag, RL, and the input excitation frequency. Resolvers are very rugged, rather simple electromechanical devices that usually have their electronics detached from the resolver itself. However, the analog wiring leading from the resolver to the interface converter may be susceptible to electrical noise. Proper wire shielding techniques must be followed.

When used in a motion control system, the controller may have inputs to connect the raw output of the resolver. The output of the resolver may also be connected to a signal conditioner module that converts the angle of rotation into a digital binary value similar to encoder outputs. This signal may then be connected to most any digital control device.

Rotary encoders typically use magnetic flux sensors—Hall-effect or magnetoresistive—or an optical light source such as an LED or laser. The magnetic style uses a magnetized gear-like rotor passing in front of the sensors. An optical rotary encoder uses a rotor made from etched glass, plastic or precision-machined metal to interrupt the light source from striking a photo detector producing a shutter effect.

The most basic encoders are incremental. A single-channel encoder has a single output that changes from an on to an off state multiple times as the rotor moves. The rotational angle is calculated by counting the pulses and dividing them by the total number of pulses in one complete rotation. If an inductive proximity sensor is used to count the teeth of a chain sprocket, this could be considered a single-channel incremental encoder.

A disadvantage of a single output encoder is that rotational direction cannot be determined with a single pulse. Also, if the rotor of a single channel encoder is positioned very close to the on/off switching point, vibration can possibly cause an error in counting. If those disadvantages are unacceptable in the design, a two-channel, or quadrature, encoder is used.

An incremental encoder typically has three output channels, A, B and Z. The A and B typically form the two-channel quadrature, square-wave outputs. Depending on which channel turns on first, the attached control device can determine if the encoder shaft is turning clockwise or counterclockwise. In one direction, Channel A turns on, Channel B turns on, Chan-
nel A turns off, Channel B turns off. In the other direction Channel B leads.

Some quadrature encoders have an additional channel, Z. The Z output turns on only once every revolution. This allows the control device to measure over multiple turns of the encoder.

When an incremental encoder is used and a power outage occurs, upon reapplying power to the system, the actual rotational position of the encoder is unknown. Some method of moving the encoder, motor or mechanical actuator to a known “home” position is required. For example, homing to a sensor and then resetting a position variable to some known value is common. The position is set to a position relative to the home switch.

A second type of encoder is an absolute encoder. The advantage of an absolute encoder over an incremental encoder is that, any time the system is powered on, the angle of rotation is determined immediately; it does not lose position information when power is lost. The encoder position signal is provided either by discrete parallel outputs or serial output.

From a parallel output standpoint, instead of having only two or three channels, an absolute encoder can have four, eight, 12 or another number of channels, depending on the pulses-per-revolution (ppr) resolution. As the encoder turns, a binary count output is produced. However, some absolute encoders do not produce the standard binary output pattern; instead, they produce a coding system called Gray code, or reflected binary code (RBC). Gray code differs from standard hexadecimal or octal by producing signals that only change the state of one signal line at each count interval allowing error detection if one of the signal outputs or connection wires is damaged.

The control system used to receive the absolute encoder position data must be able to decode the data. More electronics are needed in the encoder and more wires and inputs are needed to process the device’s output. The encoder output can also be encoded and output in serial form. Again, the device used to receive the signal must be specified to match the encoder output. Hardware requirements must be carefully met, as an open bidirectional/serial/synchronous (BiSS) interface protocol may not work with a synchronous serial interface (SSI) protocol. Carefully consider transmission speed and wire connections.

General industrial buses can also be used with encoders. But, while DeviceNet or Profibus may be available, the update rate and real-time synchronization of position data may drive the application to use a resolver or encoder with discrete signal outputs.
“When an incremental encoder is used and a power outage occurs, upon reapplying power to the system, the actual rotational position of the encoder is unknown.”

The resolution of incremental and absolute encoders is commonly available up to 8,000 ppr or so, but resolutions well over 250,000 ppr are available. Maximum rotational speed must be considered, but many encoders, often built with ball bearings, can rotate at very high speeds. Maximum rotational speeds of 10,000 rpm are common.

Encoders often have electronic components built within the housing to provide differential line driver, open collector, push-pull and other output types with normal output voltages of 5, 12 and 24 Vdc. The differential line driver is a good choice for output, and yet selection is dependent on the device the encoder is connected to. Regardless of the signal level, the electronics will be subject to any shock, vibration and temperature variance the encoder is exposed to.

If the encoder resolution and speed is very low, the encoder can be connected to the standard digital inputs of a control device. Some control devices have special inputs that can be configured to act as high-speed encoder connections or offer high-speed counter input modules.

Both resolver and encoder devices are available with a wide variety of environment tolerances, many different physical mounting options and variations in the sensing technology. Selecting what to use is going to be heavily influenced by the manner in which it will be used.
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Why coordination is key for specifying a motion control system

When specifying a motion control system, the need to coordinate motion requirements should be well understood to meet system requirements.

By Tom Stevic, contributing editor

Being engineers, at some point in our lives, some of us may have disassembled a small mechanical toy just to see what makes it work. Inside the toy is a wonderful collection of gears, cams and shafts connected to a windup spring or motor. All of the pieces are interconnected in such a way that, when the main power was applied, the gears and shafts interact with each other moving the toy in a predefined fashion.

This toy is an example of mechanical coordinated motion. As a spring winds down, a battery loses power or a hand inhibits motion, the toy slows down but still operates with the same motions. Early machine tools used the same mechanical techniques along with motors, clutches and brakes to usher in the industrial revolution.

Although these machines were very sturdy and produced the products for which they were designed, there were problems with this method of manufacturing. Gears and cams would eventually wear, and clutches and brakes would slip, requiring maintenance to continue producing high-quality products. A bigger challenge came if machine changes were required to make another product or due to modifications in the product’s design.

When servo and stepper motors and electronic control systems became available, pure mechanical motion control was no longer necessary. With the introduction of computer-ized controllers, it became easier to design one machine with the capability to produce
multiple products and to compensate for mechanical wear.

MOVING TO COORDINATED MOTION
A coordinated motion control system has at least two axes, but not all multi-axis motion systems require coordinated control. Examples of multi-axis motion systems include a gantry crane, a drilling machine and a waterjet cutting machine.

A gantry crane has two axes of motion. The horizontal axis moves back and forth over the top line of machining centers and the vertical axis moves up and down to grip, lift and lower a part. The first operation is with the vertical axis raised, where the horizontal axis moves into position over a machining center. When in position, the vertical axis lowers and grips the part; it then lifts the part from the machining cell. With the part raised and clear of the machining cell, the horizontal axis then moves the part over a second cell. The gantry vertical axis lowers the part into the second cell tooling and releases it. The vertical axis then raises and waits for the next operation. This motion is not considered coordinated because, although there are two axes of movement, each axis is moved only when the previous axis has completed its motion.

The example of the drilling machine uses an x-y table that moves a part to a set of coordinates. The drill head lowers and proceeds to drill a hole. When done, the drill head raises, and the table moves to a second x-y coordinate to drill a second hole. This is not coordinated motion, even though the two axes are moving at the same time. Positioning or speed corrections to coordinate the x or y axis motion is not necessary. Each axis may finish its motion a few milliseconds or even a few seconds before the other axis without affecting the final position of the drill head.

A final example is a waterjet cutting machine where coordinated motion is required to cut a circle out of the workpiece. As the x and y axes move the workpiece under the cutting head, any position or velocity error in one axis must be compensated by the other axis. If the compensation does not occur, the round disc will end up as an oval or have jagged edges. Coordinated motion is used to produce quality parts by following an accurate motion profile.

COORDINATING ERROR
Position error is the difference between the commanded position and the actual position of the axis or servo motor read by the feedback device. The coordinated motion control system combines the errors of all axes and adjusts the velocity of each axis to produce the programmed path, or trajectory, of the workpiece.

Most motion control systems operate with some degree of error between the
commanded position and the actual position for every axis under control. These errors may be very small, or they may be significantly large depending on the controller performance, feedback resolution and motion actuator specifications. Additional position error or velocity errors are produced by a number of factors including imperfect tuning of a servo system, dynamic load changes, excessive acceleration or deceleration rates and underpowered servo motors or drives.

With a coordinated motion control system, all of the axes belonging to a group are aware of position, velocity and acceleration errors that exist with any of the axes within the group. The kinematic equations built in to a coordinated motion drive correct the errors and predicted errors within the motion system’s capability.

Motion control systems that can control more than one axis often include a master-follower mode where the master axis is commanded to some position and the follower axes attempt to follow the master axis’ trajectory at some ratio. This loose coordination between the master and the follower does not necessarily take into account positioning or speed errors generated by the follower axes, so it would not be considered the coordinated action required for some applications.

**LANGUAGE OF MOTION**

One problem in the motion control industry is that different manufacturers often use different terms to describe the same motion function, but the IEC 61131 standard can help with the descriptions. Some manufacturers use terms such as synchronized motion, interpolated motion, cross-coupled motion and multiple-input, multiple-output (MIMO) motion, which may or may not refer to coordinated motion. A good term to look for in the manufacturer’s literature is a method of grouping multiple axes into a single system without one axis designated as the master. This is the term used by IEC 61131 and PLCopen.

Programming of a coordinated motion control system is typically accomplished using the motion controller’s specific programming language or G-code. Robots, with their multiple-degrees-of-freedom, kinematic-linked motion, typically offer computer-aided motion design software to simulate robotic motion during development. They
also include a teach mode that allows a programmer to slowly move to the point of interest and to check the robot motion path at a slow velocity. Motion controllers, robots and CNC machining centers often have a means to transfer a CAD drawing directly to the controller or include methods to convert the drawings into G-code that is downloaded into the controller.

TYING MOTION TOGETHER
In most coordinated motion control applications, tying the servo drives together via a communication cable works well and is common in industry. Protocols such as SERCOS, EtherNet/IP and Profinet are capable of updating position and velocity loops up to 8,000 or more times per second.

For very high-speed applications, selection of a multi-axis motion controller that can handle the number of expected axes in a single controller may have some benefits. It can be argued that single-axis motion controllers or servo drives that are linked together with a communication cable will operate just as well as a single multi-axis controller. However, keep in mind that communications take time and there will already be some communication link between the controller and the drive.

Even with closed-loop coordinated motion, there are time delays between a controller issuing a position command to the servo drive and the motor’s reaction to the change in the drive output. It also takes time for the controller to process the feedback signals from the servo motor encoder or resolver. The design of a multi-axis controller and its built-in, efficient bus communication speed will likely operate with faster closed-loop position control than a communication cable is capable of operating. Check the controller and drive specifications, and test the motion profile as needed in high-speed applications to ensure performance requirements are met.

It is strongly recommended to specify motion controllers, amplifiers and servo motors from the same manufacturer or as a kit from a vendor. Buy it as a package. Although a coordinated motion system could be specified from different vendors and combined, it has its risks, such as additional engineering and vendor finger-pointing when the system doesn’t work. Hearing one vendor say, “It’s the controller’s fault” or another vendor say, “It’s the drives' fault” is not a fun experience. It’s not that a system can’t be built by picking the best performing or most cost-effective parts from several vendors; it’s dealing with problem resolution when the system doesn’t work that should be a concern.

Finally, if you know anyone that actually put that mechanical toy back together and made it work, let me know. I think I have a cymbal-playing monkey around here someplace with most of the parts.
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How do I synchronize conveyor speeds?

Variable frequency drive opens many options.

Control Design reader writes: I’m adding a conveyor section to the end of an outfeed conveyor that changes speed due to production demand, and I plan to install a variable frequency drive (VFD). With some products, both conveyors must match speed. What are my options for synchronizing the speed of the new downstream conveyor to the existing conveyor?

Also, depending on the product run, the downstream conveyor will need to run faster to singulate the product, and the distance between product will need to be programmable (+/-0.75 in). What do you recommend?

ANSWERS

Pass it on

There are a few different ways to synchronize the speed of the two conveyors. The easiest might be to pass the speed reference from the VFD on the outfeed conveyor to the VFD on the new downstream conveyor. If the downstream conveyor needs to be operated at a different speed (faster), most VFDs have a trim scale that would allow you to program +/-% of line speed. If the gap between products needs to be precise and programmable, you will most likely require a PLC and other control products.

SIMILAR OR SYNCHRONIZED?
First, you will need to decide if you need similar speed or synchronized speed. Similar speed is akin to setting two VFDs at 60 Hz; they should be running at the same speed, but they will be a few rpm off due to slip. Synchronized speed is where the second conveyor turns 10° when the first conveyor turns 10° (electronic line shaft).

If you need synchronized speed (either 1:1 or 1:1.23), you will need an encoder on the outfeed conveyor and a closed-loop drive that supports electronic gearing with adjustable ratio for your different product requirements. You will need to supply a product signal to the drive to choose the desired ratio.

If you need similar speed, you will need a basic VFD that supports different presets and use the same command signaling the outfeed VFD uses. You will need to supply a product signal to the drive to choose the desired ratio (for example, same speed or 3% faster). If possible, alter your machine PLC to incorporate the signaling of your conveyor so the user only needs to go to one location to change the product.

– Scott Cunningham, engineering manager, KEB America, www.kebamerica.com

Let’s work together
There are a couple ways this can be accomplished, but the common principle is that there needs to be a signal that relates the speed of the existing outfeed conveyor to the VFD on the new conveyor. First, I will assume that the existing outfeed conveyor already has a VFD installed since the reader says it is already variable speed based on production.

Next, you will need a signal to reference the speed of the new conveyor. If there is an available analog output signal from the existing VFD that can be used to reference its speed, then that signal can be used as the reference speed input into the new VFD. Another option would be to install an encoder on the existing conveyor, which can be used as an input speed reference to the new VFD. The first option would typically be less expense, while the second option could be easier since you would not need to interface to the existing conveyor control system. A distributor can typically provide you with all of the components you will need, including VFD, encoder, enclosure and safety, and can ensure you the components will work well together, provide the correct performance requirements and are sized properly for the motor on the new conveyor.


Photo eyes on control
The required distance between product on the downstream conveyor would most likely
be best accomplished with PM servo-motor technology for its programmable acceleration and deceleration capability. A typical VFD controller will control velocity (open or closed loop); but position-loop closure with this technology is much less common. PM servo controllers are commonly used to close a velocity and position loop with other available features such as electronic gearing. Product displacement is achieved as the first or next downstream conveyor picks up the individual product from the outfeed of the previous, while accelerating said conveyor and thus the individual product, faster than the product's production speed.

Depending on things like the product size, mass, coefficient-of-friction of the product to the conveyor belt and required displacement, a second downstream conveyor may be required. For explanation, we will assume two servo-controlled downstream conveyors are needed to properly separate the product. First, I would recommend mounting a 4096 LPR mMaster quadrature encoder for 16,384 CPR (minimum) to the machine’s outfeed (upstream conveyor or equivalent). Why not a lower resolution? Because the displacement repeatability of the downstream servo-controlled conveyors is affected by the resolution of the outfeed conveyor’s master encoder (+/-).

Remember, the downstream programmable servo drive/controller cannot perform better than its master input. In general, if the product on the machine outfeed is back-to-back, there is no need for photo eyes to measure distance between the individual products. For example, outfeed could be a product magazine or conveyor. The consistency of back-to-back product running at a given product velocity accurately measured by the master encoder can allow the first downstream conveyor’s programmable servo drive/controller with predetermined programmed algorithms, to appropriately accelerate and decelerate its conveyor for a given displacement between individual products. In the event one or more of the product types to be separated cannot meet or cannot consistently meet the required separation displacement/tolerance specification, a second downstream servo-controlled conveyor can be added to fine tune the displacement between individual products before packaging. In this case photo eyes over the first downstream conveyor can be used to measure present distance between individual products.

The second downstream conveyor’s programmable servo drive/controller would determine the present distance (from time and speed) between the individual products from its inputs and adjust the acceleration and deceleration of its conveyor by predetermined programmed algorithms. More photo eyes over the second downstream conveyor could be utilized to determine actual displacement before packaging and/
or feedback to the downstream conveyors’ programmable servo drive/controller for dynamic adjustments of a displacement between given product types.


ENCODER, AHoy!

With the range of adjustment synchronization outlined in the question, it would appear this is a somewhat precise synchronization requirement, but a lot of information is not provided. I’d use an encoder on the existing conveyor segment to get a line speed reference for the conveyor segment we’re adding. There may be one there that we can reasonably tap into, but a new one may need to be added. Likely, the best place to add this encoder would be on the driven motor itself. I’d utilize another encoder on the shaft of the motor on the new conveyor segment to assure optimum speed regulation. The Danfoss drive itself can be used to alter the ratio of speeds required as the product changes. Typical Danfoss solution would include either the VLT FL300 series or the Vacon NXP series. Both would require optional encoder interface cards to complete the package.

- Tim Park, regional applications engineer—eastern zone, Danfoss Drives Americas, www.danfoss.us

Move it

Users can more easily synchronize VFDs from Rockwell Automation with their integrated motion capabilities and Logix-based embedded instructions. Through integrated motion, users can easily create master/slave relationships, and a few instructions can accommodate this—from simple electronic gearing to complex electronic camming. These relationships can be turned on or off programmatically, and the ratios can be changed quickly and easily, all within ladder logic. The Allen-Bradley PowerFlex 527 and PowerFlex 755 drives from Rockwell Automation would work well in this case. The deciding point would be on preferences for features such as power range and feedback support.

For example, in this application, we can create motor synchronization with a simple motion axis gear instruction where we set the slave axis to gear to the master at a ratio of 1. We would simply change the ratio value in this instruction to modify our system and execute corrective moves using motion axis move commands to move the conveyor either forward or backward to create the desired spacing.

- Franklin Ruffin, commercial engineer for drives and motion, Rockwell Automation, www.rockwellautomation.com