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control design

Motors, Motion & Drives

PART I

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Take a fresh look at VFDs

What's driving your decision?

By Rick Rice, contributing editor

Twenty four years ago, in my native country of Canada, I worked for an original equipment manufacturer (OEM) that made conveyors, palletizers and depalletizers for the food and beverage industry. Having graduated from college in 1988, I was still in the early years of my career, and this was my first job where my primary focus was programming and commissioning packaging equipment

My first project with this OEM was to re-write the software application for a two-car shuttle-car palletizer that unitized bags of dog food. If that wasn't daunting, the president of our company, upon meeting me a week after I was hired, casually mentioned that the last time a rewrite was attempted, it just about broke the company.

My only previous experience authoring a PLC program was on a product once offered by Allen-Bradley called a modular automation controller (MAC). It was basically a printed circuit board with spaces on the circuit board where one could plug in input and output modules.

The project was a conveying line that brought field product in, washed it and conveyed it through various processes with the result being a bottle of pickled onions. To go from this to rewriting the controls algorithm for a major packaging machinery manufacturer was nothing short of terrifying for a young controls engineer.

Perseverance is essential in a controls engineer, and, as you might have guessed, I did manage to rewrite that program, the company did not go broke, and I have made a career out of this fascinating line of work.

The controls in packaging equipment of that vintage came in the form of an Allen-Bradley PLC-5 with 1336 variable frequency drives. For those who may not remember, the PLC-5 was a huge boat anchor of a processor utilizing the 1771 I/O system.

The 1332/3/5/6 drives were equally large by today's standards and were often mounted on the outside of the control cabinet because they generated so much heat that mounting them inside the enclosure would cause issues for the other components in the panel. Commands and status for the variable frequency drive were entirely digital, via terminals on the control board of the VFD.

As one can imagine, being restricted to digital signals to and from the variable frequency drive limited the capabilities of the control system. Hardware providers of the day expanded the capabilities of the VFD by adding analog input to the drive command structure; and, since parameters in the drive had to be entered manually prior to operation, they added terminals to give more options to the control of the drive. Typical selections via the terminal interface included multiple speed selections by using binary coded input and a second set of accel/decel commands that could be engaged while the drive was in motion.

The flexibility of variable frequency drives was greatly enhanced by the introduction of machine-level network protocols. With the advent of Modbus, Profibus, ControlNet, DeviceNet, SYSMAC and others, the wiring of drives was simplified to just the enable/disable input, and the rest of the control could be accomplished via the network connection.

These early connections basically duplicated the digital interface in a memory block transfer format. PLC programming in those days was memory-based, unlike the tag-based programming of today. A typical drive interface would have four integers, two for input and two for output. The input would be in the form of a status register and feedback register, while the output would be a command register and an output frequency.

Remembering back to my first big programming project, we really did a lot with a system that would be considered archaic by today's standards. Our primary mover on a multiple car palletizer was a shuttle car that moved back and forth to stop in multiple positions underneath a stationary palletizing tower.

All major motions were accomplished by a variable frequency drive and creative use of flags and proximity sensors to tell the control system where the various axes of motion were. To move shuttle car positions, we would ramp up to a running speed, sense the presence of a flag on the shuttle at the desired stop position, ramp down to a slower speed and stop when the stop sensor on the shuttle was triggered by a stop flag at the desired stop position.

This use of a variable frequency drive really hasn't changed all that much in the ensuing years. I was pleased to meet up with my former colleagues, who like to say you can't spend your whole career with the same company, when my current employer bought a shuttle car palletizer from that same company that I worked for so many years ago.

There is an expression: If it isn't broke, don't fix it. That same control approach from 24 years ago, as it turns out, is still a great way to control a shuttle car today.

As many readers know, I like to take a look at where we came from in order to have a better understanding of how the technology of today has evolved. While the first half of this piece seems to suggest that the use of a variable frequency drive hasn't changed much in the past 25 years, nothing could be further from the truth.

The transition to machine-level networks was really just the start of the journey. Since then, hardware manufacturers enhanced the PLC to VFD interface by including additional blocks of memory into the data exchange. The advent of tag-based PLCs has opened up the potential interface to seemingly limitless possibilities.

Now one might ask why we need an expanded interface. While the control of the variable frequency drive might seem unchanged for many years, there is much more going on in the background.

A VFD, even in those earlier days of automation, has many parameters that can be manipulated to more finely tune the performance of a drive-motor combination. Motor technology has continued to advance over the years and the driving technology has matched pace with it.

Today's VFD might have 400 or more parameters that can be manipulated. With the ability to access parameters via the machine network, today's VFDs are usually configured using that network interface, using the programming software application itself in many cases.

As with all other sectors of automation, more performance in a smaller package, combined with the constant progress of technology, has moved servo and stepper motors into the forefront of automation projects. One of the primary motivations for moving in the direction of servos was the open-looped nature of VFD and stepper control.

As the control method described earlier suggests, much can be done with just sensors and some control over speed and acceleration, but, without feedback, open-loop control can only do so much. With the presence of the VFD on the machine-level network, the ability to use a linear or rotary encoder to provide positional feedback has added a way to partially close the loop. While not quite the same thing as true closed-loop control, being able to use an encoder instead of digital sensors makes for a more finite way to use a VFD to accurately provide motion control.

In the past couple of years, a new method of control has been introduced for a variable frequency drive. Some manufacturers have closed the gap between a VFD and a servo drive by producing a variable frequency drive that accepts encoder feedback directly into the drive. Now, motion is controlled at the drive level, instead of using the PLC algorithm to approximate closed-loop control.

These drives are less costly than a servo drive solution but are actually controlled using the same commands as a servo. Not to be outdone, some manufacturers of servo drives offer the option to additionally control a VFD from that same servo drive.

The benefit of these latest developments is purely in the hands of the designer and programmer: accurate control of motor-driven components for less money and with a complete tool chest of parameters to clearly define the behavior of the motor application.

Further sweetening the pot, today's VFDs also make use of integrated safety features that provide a safe torque off (STO) function. With STO, the drive is prevented from producing any torque-generating energy. When this feature—a physically wired, dual-channel connection—is used in conjunction with a safety relay, there is a means by which to guarantee that a motor is disabled when a safety device is tripped.

Finally, with all things related to automation technology, today's VFD is a much smaller package that its ancestor. A 10-hp drive in that older technology would occupy a space that was 10 inches wide by 18 inches tall by 9 inches deep. The equivalent version today would be 5 inches wide by 10 inches high by 8 inches deep. One half the footprint and generating far less temperature during operation means the same control system can be in a much smaller electrical enclosure.

The great part of these advances in technology is the designer doesn't necessarily have to invest in a servo drive to get servo-like behavior. For the maintenance team, the new machine doesn't need someone with servo knowledge to troubleshoot a machine failure. Even if, ultimately, a servo is not needed, the ease with which today's VFD can be commissioned and operational makes it an excellent choice for control of a motor. What's driving your decision?

VFD control with the right speed and torque

Just as each application will dictate the VFD needed, fieldbus protocols range from simple to high-performance

A Control Design reader writes: What are the minimum standard features and any regulations for a variable frequency drive (VFD) that needs tight speed and torque control? And what is the best fieldbus protocol for applications using motor control—speed and torque dynamically—via variable frequency drive (VFD)?

ANSWERS

FROM LOW SPEED TO HIGH PERFORMANCE

For tight speed and torque control on a VFD, there are several options, with each having different strengths depending on the type of speed and torque control needed for the end-use application.

- For low-speed, high starting torque applications, we recommend drives that employ Sensorless Flux Vector Control (SVC). SVC uses a high-speed DSP microcontroller to maintain a mathematical model of the rotating magnetic flux within an induction motor and thus can determine the motor's speed and position. From this, it can calculate the optimal timing of the voltage pulses to deliver to the stator windings in order to maintain the proper speed and torque. SVC can provide optimum speed and torque control, but it cannot deliver full torque at near zero speed. If the application calls for this (i.e., extruding and metering), then closed-loop control, with an encoder to give positive motor speed and position feedback, is required.

- For high-performance applications, like elevators, cranes and hoists, which require holding a load and not moving, drives that employ Closed Loop Vector (CLV) are a reliable option. CLV uses a vector algorithm to determine output voltage and the critical difference for this option is that it incorporates an encoder. Encoder feedback paired with the vector control method allows for 200% motor starting torque at 0 rpm. This feature is a selling point for applications.

- When simplicity is the priority, we suggest drives that employ Volts-per Hertz, commonly called V/f. This method is often preferred due to its plug-n-play simplicity that requires very little motor data is needed by the drive. Tuning the VFD to the connected motor is not needed (but still recommended), and no motor encoder is required.

As usual with engineering, it's not so much that there is a single best protocol for every situation, but rather several options depending on the application:

- Modbus Remote Terminal Unit (RTU) protocol is a good choice if simplicity is desired. It is straightforward to support and as a result, is one of the most widely used for industrial automation applications.

- EtherCat, a less common option, is an excellent fieldbus if the VFD is being controlled from a remote PLC. It is inherently self-healing and uses standard RJ-45 to create a network, so no switch is required. Ethercat runs at Layer 2 (Data Link) on top of bare Ethernet frames, with payload substitution happening at each device. Thus, there is no network layer overhead, which allows for maximum raw speed; on the other hand, it is not routable – the devices must be on the same physical Ethernet. It can attain cycle times of 100 microseconds.

- Profinet Isochronous Real-Time (IRT) is also a solid choice for a fieldbus. It is a superset of Profinet that uses PTP (Precision Time Protocol – IEEE 1588) to maintain device synchronization. It can attain cycle times of 250 microseconds. Both Ethercat and Profinet allow standard Ethernet frames to be delivered during the slack time between real-time frames.

ALLEN BENNETT AND JOHN CLEMENT
field application engineers / Allied Electronics & Automation / www.alliedelec.com

SCALAR, VECTOR AND DIRECT TORQUE CONTROL

Great question, and for us to answer it, we need to discuss the various methods for variable frequency drives control of ac induction motors. There are three methods in the industry:

1. Scalar Control (also referred to as V/Hz or V/f): varies both the voltage and frequency of power supplied to the motor in order to maintain a fixed ratio between the two. With this technique, sometimes

known as scalar control, field orientation of the motor is not used. Instead, frequency and voltage are the main control variables and are applied to the stator windings. The status of the rotor is ignored, meaning that no speed or position signal is fed back. Therefore, torque cannot be controlled with any degree of accuracy. Furthermore, the technique uses a modulator, which basically slows down communication between the incoming voltage and frequency signals and the need for the motor to respond to this changing signal.

2. Vector Control (also referred to as field oriented control, or FOC): controls the magnetizing and the torque-producing components of the stator current independently to control both motor speed and torque. To achieve a high level of torque response and speed accuracy, a feedback device is required (an encoder for example). This can be costly and adds complexity to the traditional simple ac induction motor. Also, a modulator is used, which slows down communication between the incoming voltage and frequency signals and the need for the motor to respond to this changing signal. Although the motor is mechanically simple, the drive is electrically complex.

3. Direct Torque Control (DTC) technology was developed by ABB. Field orientation

is achieved without feedback using advanced motor theory to calculate the motor torque directly and without using modulation. The controlling variables are motor magnetizing flux and motor torque. With DTC there is no modulator and no requirement for a tachometer or position encoder to feed back the speed or position of the motor shaft. DTC uses the fastest digital signal processing hardware available and a more advanced mathematical understanding of how a motor works. The result is a drive with a torque response that is typically 10 times faster than any ac or dc drive. The dynamic speed accuracy of DTC drives will be eight times better than any open-loop ac drives and comparable to a dc drive that is using feedback. DTC produces the first "universal" drive with the capability to perform like either an ac or dc drive.

So, to answer the question, vector control is the bare minimum method used to tightly control speed and torque. The main drawback of VC is the need for a feedback device such as an encoder. This adds complexity and costs to the control system. DTC is recommended over VC due to its accuracy, simplicity, and lower total cost of ownership.

On the fieldbus question, it is irrelevant to tightly controlling speed or torque

since the motor control algorithms are embedded in the control module of the VFD. The VFD is controlling the motor directly without any fieldbus interaction. With that said the most common industrial fieldbuses are Modbus/TCP, Ethernet/IP, ProfiNET, EtherCAT and Ethernet Powerlink.

RALPH CONTRERAS

OEM business development manager, food and beverage segment / ABB Motion Division - Drives Products / new.abb.com/us

EASIER SELECTION AND SET UP

Selecting the proper VFD drive for your application can be very time consuming. Fortunately, times have changed: easy selector tools and apps are available to help select the proper drive for your application.

Standard Drive Control (SDC) is ideal for pumps, fans, compressors, mixers, kneaders, agitators or horizontal conveyors of all types.

Dynamic Drive Control (DDC) is ideal for vertical conveying, gantry cranes, lift tables, escalators, elevators or closed loop extruder control, just to name a few.

Using Dynamic Drive Control (DDC) could include braking resistors. Feedback for close loop control can be from SSI encoders, incremental and / or absolute position measuring systems. This will allow precise control.

Commissioning VFDs has become a lot easier. Gone are the days of punching in 130 parameter settings! Easy to use graphical parameterizing software is available to setup base parameters and fine tune the VFD to your application. User-friendly automatic PID controller optimization makes setup easy, and you will be the boss!

VFDs are being used more these days, and the price for the drives are to the point where it makes sense to use them for both energy efficiency and control benefits. Commissioning, monitoring and controlling VFDs can be simplified utilizing common industrial communication protocols like Profibus and Profinet.

WERNER LAMBERGER

technical support engineer / Automation24 Inc. / www.automation24.com

VFDS VS. SERVO DRIVES

Users can achieve different levels of velocity control with the various solutions available from automation suppliers. The differentiation between servo drives and VFDs has shrunk significantly. Historically, servos were preferentially used for applications requiring positioning and dynamic operation, where tight control of speed and torque were essential (closed-loop operation). VFDs were more cost effective in applications with generous operating windows for speed (and often operated in open loop). Today's servos and VFDs offer open-loop (V/Hz) and sensorless vector control functionality. The addition of a feedback card for closed-loop operation

will achieve the highest speed regulation and accuracy.

COMPARISON OF SPEED CONTROL RANGE:

- 1:50 >> V/f (V/Hz)
- 1:200 >> SVC (sensorless vector control)
- 1:1500 >> Vector control with feedback
- 1:5000 >> Servo drive with fast loop updates and high resolution feedback.

TORQUE CONTROL REQUIRES A CLOSED-LOOP SYSTEM.

With regard to functional safety, variable frequency drives typically offer only safe torque off (STO) and motor free-wheeling must be taken into consideration.

Servo drives use motor encoders for velocity and position feedback and therefore can offer STO and many other safe motion functions.

In industrial manufacturing today, Ethernet-based communication protocols are the most prevalent. Fieldbus protocols such as EtherNet/IP, Modbus TCP, ROFINET are typically used with VFDs. Increasingly, VFD devices also offer real-time synchronous protocols, such as Sercos automation bus and EtherCAT to operate on the same network as the servo drives and IOs. These protocols support multiple control modes. A few vendors offer an interface card capable of multiple protocols. This will be an advantage for machine builders who integrate different control platforms based on end customer preference.

MIKE MUELLER

product support manager / Bosch Rexroth / www.boschrexroth-us.com

HOW FAST DOES THE VFD NEED TO RESPOND

Minimum standards and features for VFDs are often hard to differentiate, as different products not only have different performance ratings, they also use different terms and slogans. To further muddy the waters, applications require different performance levels.

These can be defined as the goals of the entire system or may be defined by a specific industry standard or customer specification. What may be acceptable for a high performing crane or lift with an induction motor, may not be acceptable for a positioning application with a permanent magnet or servo style motor.

Ultimately, it boils down to the entire application and how the VFD fits within the system. Utilizing VFD application specialists, reference stories and other experiences can help someone define their required performance levels. Questions such as feedback device requirements (encoders or resolvers) and understanding system response times can help to identify how well the VFD can perform in certain situations. Looking into speed and torque accuracy values, with or without feedback devices, will allow you to compare products and their performance. As in most things, the higher the performance level, the more investment that will be required. You may even discover newer technologies that can meet your performance requirements and not require a feedback device, which will ultimately lead to savings.

Fieldbus protocols and performance will also vary from product to product. The protocols are individually defined; however, some will have different communication rates as well as different VFDs have different capabilities in how fast they can process the information and deliver results. Further, one must also consider the controller they are using and its preferred network. Depending on your application needs you may or may not require fast fieldbus communication. As an example, using a line speed feedback such as an encoder for an electronic line shaft application, is often best served through the VFD itself, as it eliminates time for the signal to travel through controls and over fieldbus communications. This provides higher performance without additional controls and costs. Another impact to the fieldbus discussion is how will it integrate into existing infrastructure and what knowledge base may already exist to make the transition easier. Often in industry, Ethernet is used as it pairs well with existing IT infrastructure and resources. However, in building automation (such as HVAC) BACnet is typically preferred as it is understood by most technicians in the field.

For both fieldbus and VFD selection, it is important to determine how fast you need to respond before beginning the selection process. From there you can examine how fast controllers can process, the length of time the information takes to travel over the network and then how long from when the signal is received at the VFD to when it generates a response to know whether it meets system needs. This will prevent one from not getting what they require, or possibly overpaying for something they do not need. Further, keep in mind as technology advances, VFDs are becoming more intelligent controllers, often eliminating the need for smaller PLCs, or allowing users to program fast sequences in the VFD that outpace some external controllers.

Overall, to state a minimum standard is extremely difficult. Rather, it may be better to ask what the application really requires, and who can partner with you to find a proper and affordable solution. Often, the best performance can be found in the right partner who will walk alongside you through installation, startup and the entire lifecycle of your VFD.

JONATHAN MOSTERD

Manager/ Danfoss Drives, Center of Excellence, NAM / www.danfoss.com

BASIC, ADVANCED AND CLOSED-LOOP

VFDs are typically grouped into three performance categories: basic, advanced and closed-loop. Basic VFDs are meant for simple variable speed applications, do not provide speed control at 0 rpm nor do they provide any torque control. Advanced drives (often called open-loop vector drives) provide improved speed control, near 0 rpm control and some torque control (mostly used to guard against over-torqueing the mechanics). Closed-loop drives (vector drives) require a shaft feedback device and provide full speed and torque control over the whole range of operation. For non-lifting/hoist applications, there is a sensorless closed-loop (SCL) technology that uses advanced technologies to replace the shaft feedback with a software model. SCL has been shown to provide as good as closed-loop speed and torque performance. The limitation is at 0 rpm – depending on the motor (servo or induction) you may only have between 50% and 100% of rated torque available. Most applications can benefit from this latest technology.

Fieldbus technologies have thankfully narrowed to a few popular platforms. Most have moved to TCP/IP hardware platforms (one exception being CAN over serial wires, which is still used extensively). But don't be fooled by "number of nodes in the field" claims – when a device manufacturer standardizes on a protocol, they count every device they ship as a "node in the field" – whether the fieldbus is used or not. Focus on the number of different device suppliers available for the fieldbus. One platform that has gained high adoption from many different control manufacturers is EtherCAT. EtherCAT was designed from the ground up to support synchronized communications for coordinated motion, yet have simplified node-to-node or star wiring without the need for managed switches or protocol "upgrades" common with non-deterministic fieldbus solutions. It is also very fast: low end controllers typically run at 4 to 8 ms communication update rates, while high end controllers run under 500 us update rates with 50+ drives. This means machine builders can standardize on EtherCAT and support easy and difficult applications out of the box.

SCOTT CUNNINGHAM

product and application manager, controls and automation / Keb America / www.kebamerica.com

PRODUCT SPEED, TORQUE AND COMMUNICATION REQUIREMENTS

In addressing this question, first we must define the application and plant standards for communication. We must investigate the packaged control to make sure we meet the needs of the application and plant system. As always, there are many product choices that work as a system to perform the requirements of the application as well as to satisfy the communication needs of the drive, control and plant requirements.

The application defines the product speed, torque and communication requirements, and the components are chosen to operate together to satisfy those requirements. Normally, you will be defining the precision requirements of speed or torque control – not necessarily in combination. Many VFDs can add modules and provide exceptional

Typical performance specifications of various drive manufacturers:

Type	Torque Response	Accuracy	Speed Range	Feedback Loop
V/Hz	500-1000ms	10%	Approximately 10:1	Open Loop
Voltage Vector	50-300ms	.2% - 2%	Approximately 100:1	Open Loop
Flux (Current) vector	5-60ms	.02% - 0.1%	Approximately 1500:1	Closed Loop
Servo	2-8ms	.007% - .08%	Approximately 2000:1	Closed Loop

*These are typical performance results for many manufacturers' motor control techniques.

speed and torque response (open/closed-loop), along with communication protocols of choice. As expected, this is not a quick rule-of-thumb answer because every application defines the needs.

Coming to the best solution will involve answering questions relative to load, acceleration, deceleration, position and dynamic movements, environment, cabling and control options. There are additional limitations that must be addressed relative to speed/torque demands on the VFD and motor, thermally and mechanically, along with other criteria that envelope a "Packaged Drive System." With today's sophisticated drives and fast processors, we can achieve very good performance open loop with standard Voltage Vector AC Drives. For very tight speed/torque regulation, we would consider a Flux Vector Current Control Drives with Feedback (Either resolver or encoder). For very dynamic moves or high accuracy positioning; we would look toward servo performance drives and controllers. The VFD package is still only a small part, as the power transmission, machine dynamics and specifications will also play an important role.

Fieldbus: This subject can get lengthy, as it is very specific to application, plant standards and product availability. Normally an experienced plant engineer will determine the required communication platform to be used. CANopen for many years worked well and is still in the industry. Ethernet/IP has been becoming the plant standardization for many years and works very well in demanding motion control applications, especially well-suited for VFD applications.

EtherCAT's ability to handle bandwidth and information transfer has made it a leader in the servo motion control arena. The two communication platforms that are very popular in today's motion control world are Ethernet/IP and EtherCAT. EtherCAT is proving to stand out in those high-end servo control applications.

Communication with the plant engineer and manufacturer(s), as well as early involvement in the design, will ensure the proper needs are addressed and the correct package solution will perform to expectations.

JACK KORZYP, business development manager / Motion Industries / www.motionindustries.com

TIGHT SPEED OR TORQUE CONTROL

There is a wide range of applications out there: from basic "shaft spinners" to complex multi-axis automation applications with varying degrees of requirements to the control system.

A first step is to understand different fundamental VFD control methods commonly used. Each provides varying degrees of speed and torque control.
A few are listed below for reference.
V/F

- speed regulation: +/- 2.3% of max frequency
- speed control range: 1:40

Open-loop Vector (Sensorless Vector)

- speed regulation: +/- 0.3% of max frequency
- speed control range: 1:200

Closed-loop Vector (Flux Control)

- speed regulation: +/- 0.01% of max frequency
- speed control range: 1:2000 … 1:5000

Generally, applications require either tight speed control or tight torque control with some form of speed limitation. Open-loop control offers a good overall value and is capable of providing reasonable speed control without external feedback. However, using external feedback greatly increases the speed and torque capability. On the downside, it increases the price and adds additional points of failure to a system. It is crucial for the machine builder and the automation provider to understand the technical details of the application in order to select a suitable VFD and control method.

As the VFD market encompasses a variety of VFD types and application fields, minimum features are hard to define, but here are some basic criteria that should guide the selection process: The controls concept determines the selection of a VFD: from controlling via discrete I/Os all the way to fieldbus operation of the drives. VFD types can range from centralized single or multi-axis control cabinet mounted drives, to motor-mounted or even remote-mounted VFDs – all with different "standard features."

Safety demands of the application are another aspect: from Safe-Torque-Off (STO) all the way to fully drive-integrated safety functions such as safe limited speed (SLS), safe limited position (SLP), safe brake control (SBC) and many others. Depending on the control method, open-loop VFDs do not need integrated encoder feedback, but many multi-axis VFDs offer integrated encoder feedback to allow closed-loop operation as a standard. Also, the number of I/Os that can be directly tied into the VFD is another differentiator in the market and might be relevant when selecting the VFD.

Before selecting a specific VFD or motor type, please note that some automation suppliers enable their VFDs to control different motor types, such asynchronous and synchronous motors. This even includes using encoder feedback on AC induction motors to solve sync, leader/follower and load share applications.

Please talk to your automation provider, consider different suppliers and make an educated choice based on the application's requirements. Advertised "standard features" in the VFD market are mainly a marketing tool and are the outcome of the pricing and product strategy of the VFD suppliers.

The choice of a fieldbus protocol depends on a variety of factors: the application's requirements, the machine and factory periphery/environment, preferences of the machine builder as well as the end user.

Analog speed and torque control remain an industry standard as it offers a familiar, proven and cost effective solution.

The best choice depends on the application dynamic requirements and if the system requires deterministic control. Most modern fieldbus solutions are capable of providing speed and torque information at a rate suitable for common applications.

Higher dynamic systems may benefit from the use of Ethernet or EtherCAT based systems, which are standard in industrial control solutions, provide very high throughput, and are supported by the majority of machine control systems. When collecting data from the drives for predictive maintenance and IoT functionalities, Ethernet or EtherCAT based fieldbuses are a good choice for transmitting this data via fieldbus.

By shifting control logic from the upper-level PLC into a motion controller or directly into the VFD, the choice of the main fieldbus becomes less critical. The use of pre-programmed and parametrizable software modules facilitate fieldbus-independent motion control. This for example allows for the creation of motion control systems running on EtherCAT that can be easily tied into any upper-level PLC or fieldbus that is Profibus-based.

ARNE VALENTIN
technology manager machine automation /
Sew-Eurodrive Inc. / www.seweurodrive.com

CLOSED-LOOP CONTROL WITH ENCODER FEEDBACK

VFDs should provide closed-loop control with encoder feedback, if the precise control of the speed and torque is required in the application. This feature is commonly available in most of the VFDs available on the market today. Users can select the VFD that is ideally suited to their application requirements.

There aren't any regulatory or minimum requirements for VFD speed and torque control. However, users are encouraged to select the VFD that has an Efficiency Class of at least IE2 according to IEC 61800-9-2

(EN 50598-2), and is UL 61800-5-1 listed for UL applications.

When it comes to the fieldbus protocol for motor control using a VFD, there are a variety of different industrial fieldbus network protocols available. These include ProfiNet, EtherNet/IP, EtherCAT, Modbus TCP/IP, Modbus RTU, BACnet IP, BACnet MSTP, USS, PROFIBUS, etc. There isn't a single protocol that can be claimed as the best since the selection of fieldbus type for VFDs is generally specified by the customer and/or application requirements, and the type of industry. ProfiNet, EtherNet/IP and Profibus are examples of the most popular fieldbus protocols globally.

NIKUNJ SHAH
product manager, digital Industries — motion control business / Siemens Industry, Inc. / www.siemens.com

Encoder feedback and closed-loop vector motor control capability

THE IMPORTANCE OF ENCODER FEEDBACK

When it comes to selecting a variable frequency drive for an application that needs tight speed and torque control, you want to look at a VFD that is capable of the following:

- Encoder feedback. When it comes to knowing what the speed of the motor is, there is no substitute to having an encoder mounted directly on the motor and providing true speed feedback. Whatever the type of encoder you have on mounted on your motor, differential is most common, make sure the VFD that you select has an option that can accept the encoder signals.

- Closed-loop vector motor control. Vector motor control is a tried and true motor control algorithm that can accurately regulate the flux and torque in the motor. Being able to provide an accurate speed of the motor, hence the importance of having encoder feedback, to the algorithm will help make the regulation of torque in the motor more precise.

VFDs have come a long way since they were first introduced, which has led to their speed response and torque accuracy improving dramatically over that time. Even with those improvements, you may want to still be cognizant of a VFDs speed response and torque accuracy, e.g. 50 Hz speed response and +/- 5% torque accuracy. What you'll find is that a lot of VFD manufacturers will have response and accuracies that are very close to each other.

One more thing to consider is how critical is your application. Typically, a VFD that'll be used for an application, which requires very tight speed and torque control, is a very important and critical part of the manufacturing process. If that's the case, look for a drive that has a track record of high quality and reliability. You can get a VFD that has the highest speed response or the best torque accuracy, but all those great specifications can mean nothing if the VFD results too much unexpected downtime.

When it comes to choosing a fieldbus for the application, there's no clear cut answer. If you talk to the governing bodies for the different protocols that are out there, they'll each tell you that theirs is superior to the other. However, if you plan on building your control system around the network that you choose, then pick one that is Ethernet based. Good ones to start with are EtherNet/IP, ProfiNet, and EtherCAT. Each of these protocols are considered real-time and capable of high-speed messaging.

An alternate way of choosing which protocol to use for your system is to see what your controller of choice supports. The implementation of the VFD will go more smoothly for you if you're working in an environment that's familiar to you. If the controller supports multiple fieldbus networks, narrow it down to the Ethernet based protocols and go from there.

Another thing that you may want to consider is what else you want to achieve with a VFD that's networked. If you and your company have plans to monitor and record various data points from your VFD and use it on a larger scale, predictive maintenance for example, then choose a VFD that provides access to a large assortment of monitors that it has available. This will give you the flexibility to set up your system how you want to at that moment and also provide you the flexibility to expand if the need arises.

EDWARD TOM

product manager, drives / Yaskawa America, Inc. / www.yaskawa.com

HIGH SPEED AND TORQUE PERFORMANCE

Any application that requires high speed and torque performance should use a VFD with Flux Vector motor control that is derived from Field Oriented Control (FOC). This means the torque producing component of the stator flux can be controlled independently. Couple that precise control with some type of motor feedback, such as an encoder, and high bandwidth control of the motor can be achieved. There are many technical papers written about this method of motor control.

For fieldbus protocol, industry communications have been migrating to EtherNet/IP in recent years. EtherNet/IP is an open fieldbus standard managed by ODVA that provides reliable, high speed communications. Most drive manufacturers have several communication options available that can be used with the VFD. Finding and partnering with a drive manufacturer that has all these options available is key to a complete system solution.

JEFF THEISEN, STEVE WIRTZ and MARK HARRIS

commercial project engineer, commercial project engineer and senior project commercial engineer / Rockwell Automation / www.rockwellautomation.com

SEW

Motor into the future

A look back on how Davenport, Faraday and Henry started the journey to where we are

By Rick Rice

The driving force behind most automation starts with a motor. Now the more challenging readers might be thinking, “not if it is air.” Well, one might confidently argue that even air needs a motor to get it in motion. After all, air and hydraulic systems need a motor to drive the pump to give force to the medium.

Motors have been around for a long time. According to the Edison Tech Center, the first “real” electric motor was invented by Thomas Davenport of Vermont in 1834. While earlier experiments by Joseph Henry and Michael Faraday dabbled in the use of electromagnetic fields, it was Davenport that made a motor that was powerful enough to actually perform work. The groundwork, of course, was laid by Henry and Faraday.

Faraday, an English scientist, studied the magnetic field that projected around a conductor when direct current was applied. Henry, an American, discovered that the wires wound around an iron core need to be isolated (insulated) in order to induce magnetism in that core. After moving his studies to Princeton University, Henry was able to make a trip to England where he met Faraday, and their joint efforts are the basis of electromagnets and transformers that we use today. The measure of induction is called Henry, in honor of Joseph Henry, and the SI unit of capacitance is called the Farad, in honor Michael Faraday.

The principle of the electric motor starts with the electromagnet. Insulated wire, wrapped around an iron core, causes the core to develop a magnetic field when electricity is applied to the wire. If a secondary coil is introduced to the magnetic field developed by the primary coil, motion can be generated. In a motor, the outer stationary coil is called the stator, and the inner rotary coil is called the rotor. The rotor, also called the armature, contains tightly wound coils contained in a smooth housing to protect the coils from damage while rotating. The rotor is subjected to the magnetic poles of the outer (stator). Rotation is induced as the poles of the rotor are attracted and then repelled by the poles of the stator.

The strength of a motor is determined by the applied voltage and the length of the wire that makes up the windings on the core of the stator. Copper is the most common material used in windings; aluminum can also be used, but the size of the wire must be of a larger diameter to conduct the same amount of current as the copper version.

Another early pioneer, Hippolyte Pixii, discovered that, if you spin the rotor on a motor, then electrical pulses can be generated from the stationary (stator) of the motor. This is commonly known as a generator and is the base principle used in the generation and transmission of electricity the world over. The well-known power generation centers at Niagara Falls (Canada and New York) use the change in elevation from Lake Erie (upstream) and Lake Ontario (downstream) to direct water over the vanes of a turbine that is connected to the rotor of a generator.

Electrical motors come in both ac and dc versions. There are four basic types of ac motors, including induction, universal, synchronous and shaded-pole.

In a universal motor, the primary coil is on the rotor with the secondary coil on the stator. This type of motor can be driven by either alternating current (ac) or direct current (dc), thus the name, universal. Current is transferred to the rotor by means of brushes. These brushes are flexible metal that make contact with the wires of the primary coil. As the rotor moves, the brushes make and break contact with sections of metal—called a commutator—connected to the wires of the primary windings. These motors feature a high starting torque and can run at high speeds. As such, a very common use of the universal motor is in hand tools and small appliances, such as vacuum cleaners and washing machines. One downside of the universal motor is the brushes wear out over time and need to be replaced.

The synchronous motor was developed in 1925 and is similar to an induction motor but moves based on line frequency. At a given frequency, the motor turns at a steady speed. The speed is determined by the number of coils used. Motors of this type can't handle varying torque and can stall out. A common use of the synchronous (synchro) motor is in the manufacture of clocks. A steady line frequency will result in a steady speed, or rotation, and accurate representation of time.

The shaded-pole motor is a single-phase ac motor that has only one coil with the shaft spinning in the middle. The shaft is made up of steel with interlaced copper bands. When electricity is applied to the coil, a lag in the flux passing around the coil causes the intensity of magnetism to move around the coil, causing the shaft (rotor) to turn. This type of motor is slow to start but, once at speed, generates a good steady torque. For this purpose, it is commonly used to drive a fan or a can opener.

The dc motor comes in two types, brushed and brushless.

The function of the brushed dc motor is the same as the universal motor described earlier. There are five types of brushed motors, shunt wound, series wound, permanent magnet, pancake and separately excited.

The shunt wound dc motor has the field coil (primary) and the armature coil wired in parallel. A shunt motor regulates its own speed. This means that when an additional load is applied to the armature, the counter-electromotive force (CEMF) decreases, causing the armature to slow down in response and more torque is applied. When load is removed, the CEMF increases, limiting the current and torque decreases as a result. A common application of the shunt wound motor is conveyor belts.

The series wound dc motor has the field and armature coils wired in series. The function is similar to the shunt wound motor, but higher currents can be applied, and, as such, larger wires is used for the field coils to handle those higher currents. This is often used for a starting motor as it has great starting torque.

The permanent magnet dc motors can be operated at high speeds, making them excellent for use in conveying applications.

The pancake dc motor, as its name suggests, is a low-profile motor. It is an ironless motor, in that the armature windings are embedded in epoxy and sandwiched between two high-flux magnets. These motors can start, stop and reverse direction very quickly, making them very useful for high-speed applications such as toys, medical devices car windshield wipers and servo systems.

The separately excited dc motor, as the name suggests, uses a separate power supply for the field and armature coils. This permits flexibility in applications by giving more control over the excitation of the two coils of the motor, resulting in smoother performance.

In brushless dc motor applications, the main types are stepper and coreless (or ironless) motors.

The stepper dc motor moves the rotor in incremented steps. This is done using toothed electromagnets around a gear-shaped piece of iron core. The excitation voltage comes in the shape of a square wave. Each step equates to one step of the core. Speed is varied by increasing or decreasing the frequency of the steps. A second signal is used to change the direction (polarity) of the square wave signal.

A coreless (ironless) dc motor uses a wound cylinder rotating around a magnet. This type of motor is light and fast to start and stop. For this reason, it is used in computer disc drives. However, since it doesn't have an iron core to act as a heat sink, it can tend to overheat and must be cooled with a fan.

Today, we can use a combination of the motors detailed thus far, but it is the further development of the stepper that has provided the largest advance in technology. A stepper is precise, in that it provides movement based on the number of steps (pulses) provided to it. However, the stepper is an open-looped system, in that it doesn't have a feedback device. In order to execute a precise move, the stepper must be referenced on power up to know what position it is in. Steppers are limited in their function because they can't drive anything above their capabilities. Doing so will result in missed pulses and inaccurate positioning.

Taking the stepper to the next level, an encoder is added to create closed-loop control. This closed-loop system is what we know as a servo system. The main difference from a stepper is in the software. There isn't a specific class of motor that makes it a servo. It is in the amplifier and software algorithm that the motor and method of feedback create the precise movement, high speed and torque that we expect from a servo system.

Advances in motor technology are focused around better efficiency to reduce the cost of operation and, across all types of motors, better performance in ever smaller packages. Servo systems have evolved to the point where the amplifier and motor are in one package. Field wiring is simplified to the level where a single cable can carry power, control and communications.

Electromagnets were being toyed with back in the early 1800s. Henry was not only the father of inductance but the inventor of the basis for the transformer. One of Henry's early inventions was an ore separator. Creating a large electromagnet and then magnetizing spikes mounted to a rotating drum, this separator could draw large amounts of ore out of substrate in a mining operation. It was in 1831 when Davenport, the Vermont inventor, first witnessed this device and a few years later came up with the first electric motor. Five years later, in 1836, Henry developed the "intensity battery," a device later used by Samuel Morse to send electrical pulses across the wires over great distances. Henry was the first secretary of the Smithsonian, important to the development of the National Weather Service and the second president of the National Academy of Sciences. He was President Abraham Lincoln's science advisor.

We are nearly 200 years beyond those first experiments of Henry, Faraday and Davenport. Amazing advances have come our way in the ensuing years.

How to handle heavy lifting

Flexible hydraulic/electric motion control brings demanding die/mold cart design to completion

By Mike Birschbach, John Henry Foster

Located in Mt. Zion, Illinois, Green Valley Manufacturing has been making die and mold handling equipment for nearly 25 years. Die or mold carts don't seem glamorous at first. Functionally, they are cousins to forklifts, but these carts specialize in moving awkwardly sized and sometimes very heavy dies or injection molds, some exceeding 100,000 lb, from one point to another with exceptional speed and stability. Client industries for Green Valley's carts span from aerospace and automotive to medical and military. Practically every job is in some way a custom order.

A tier-one passenger vehicle parts manufacturer approached Green Valley in 2019 with a novel challenge. The client wanted a mold cart capable of lifting 70,000 lb. Moreover, because of the tight spaces in the manufacturing environment, they needed the cart built with four-wheel drive, four-wheel steering and an extremely precise four-cylinder lifting system. The client wanted Ackerman steering to increase tire traction, steering range and precision when executing turns. Essentially, the cart needed the ability to turn on a dime as well as crabwalk sideways by turning all of the wheels in the same lateral direction. The cart required four different steering modes—an impossibility with conventional mechanical linkage.

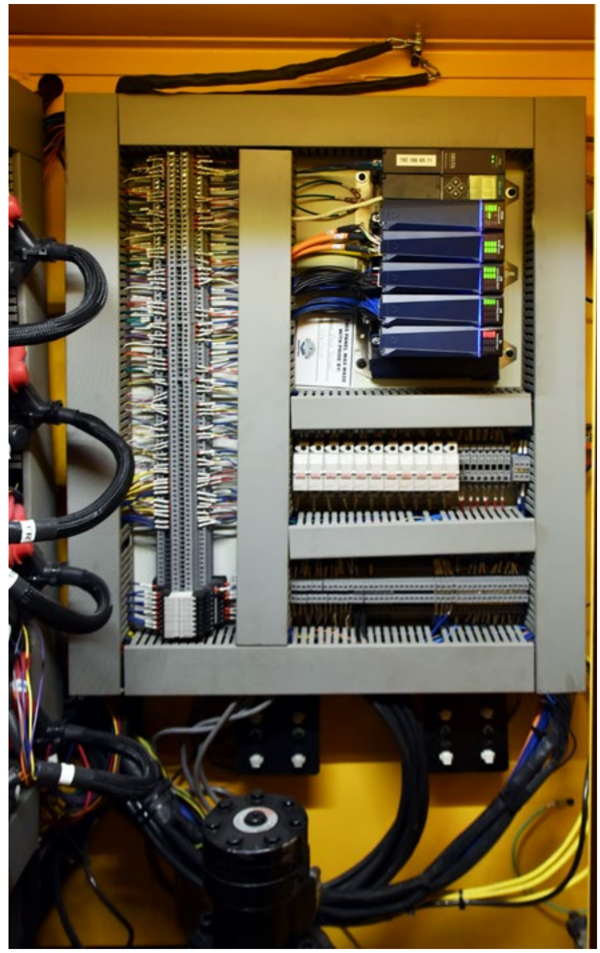
The application demanded combining simultaneous but different motion across the left and right. Ackerman steering requires geometry, trigonometry and calculus to determine each wheel's angle, because it's impossible to execute a turn with two wheels at the same angle.

Doing such maneuvers with a typical PLC would be incredibly difficult, and so Green Valley found itself too limited by its existing programming environment and hardware.

THE ROLE OF THE RIGHT CONTROLLER

In order to meet the more demanding client requirements, Green Valley knew where to turn. The company partnered with John Henry Foster, a St. Louis-based firm that specializes in custom pneumatic and hydraulic systems. Having worked with Green Valley in the past, John Henry Foster devised a solution to the challenge of expanding Green Valley's mold cart maneuverability required three sets of curves. The first mapped the relationship of wheel angles as they moved through their range of motion. The second conveyed the relationship between the wheel angle and wheel rotational speed. The third curve represented the speed throttling needed as steering angles increased. This last point was particularly valuable for Green Valley's client.

John Henry Foster is a longstanding distributor for Delta Computer Systems motion controllers and had used Delta on previous projects with Green Valley. The company selected Delta's RMC200, which it felt to be the best, most adaptable controller on the market, capable of both electric servo and hydraulic motion control and support for up to 32 control axes.



INSIDE THE BOX
Figure 1: The cabinet contains the RMC200, complete with power supply, CPU, and I/O modules.

This particular Green Valley cart project used four hydraulic axes for steering and four axes of electric control for wheel speed. With most controller brands, this would require at least two four-axis controllers, with one controller addressing the hydraulic domain and another the electronic. However, because the Delta RMC200 is a 32-axis controller capable of supporting both hydraulic and electric motor controls, the wheel-steering and wheel-speed functions could be handled by a single control unit (Figure 1).

If one controller is managing the steering and a different platform is managing the wheel speed, they have to share that information back and forth and make sure that all the math is being done correctly. That adds complexity and can introduce issues. With the Delta application, though, we can take care of all the math and basically put all the motion inside one controller. That allowed Green Valley to focus on other aspects of the cart handled by the PLC.

TWEAK THE CONTROLLER
Figure 2: Technicians work on the RMC200 installation.

The lifting system is comprised of four hydraulic cylinders with internal transducers. Each cylinder is separately controlled by the RMC200. This offers a tremendous benefit in adjusting for off-center loads. As Green Valley describes it, one might have 25,000 lb on one side of the table and only 3,000 lb on the other, but with continuous, microsecond-speed pressure detection, all four cylinders can lift and lower uniformly to within 0.05 inches of variance across all four corners. This motion control could have been done with a separate controller, but being able to run all 12 axes—wheel control plus lifting control—from the RMC200 yielded a simpler design with more efficient management and lower total parts cost.

None of Green Valley's prior cart solutions offered this many axes of control, and the added steering complexity, along with the client's specific demands, presented a new challenge. Armed with the advantage of using the RMC200, though, the John Henry Foster team made the two-hour trip from St. Louis to Mt. Zion, installed and configured the Delta controller in Green Valley's cart, and drove home, all in the same day.

John Henry Foster sales representative and certified fluid power specialist Mark Certa notes, "Once we had it set up, Green Valley could go into Delta's software and change that steering/speed relationship on the fly, like in two seconds, just by dragging points around on the curve."

While vastly simplified on the surface, this ease of use is enabled by a lot of hard work on Delta's part. The company spent many years refining its Windows-based RMCTools software, which encompasses a range of time-saving features and capabilities, including the Curve Tool.

In addition, Delta invests in creating the customizable source code necessary for its controllers to communicate with other devices. The controller manufacturer has amassed a considerable library of sample programs for its own as well as third parties' controllers and accessories. Without this library, available for free to developers, RMC integrators may need to write their own code from scratch.

Despite these advantages, even Delta's RMC setup still wasn't quite plug-and-play simple (Figure 2). The controller code needed tweaking to the mold cart's specific configuration. After building the cart from the ground up and handling all of its nonsteering programming, Green Valley still had to invest time in on-site development, testing and validation of the steering system. Green Valley engineers state the curves computed by John Henry Foster and Delta saved loads of time, but there was still a minimal phase of trial-and-error refinement. What was shown on the screen wasn't always entirely what played out in real life, and so some adjustment was inevitable.

SUCCESSFUL COMPLETION
Figure 3: The automotive client's successfully completed mold cart marked the third project in which Green Valley turned to John Henry Foster and Delta Computer Systems.

TRUSTING THE TRACK RECORD

The automotive client's successfully completed mold cart marked the third project in which Green Valley turned to John Henry Foster and Delta Computer Systems (Figure 3). Not long after the mold cart, though, Green Valley had another project that needed specialized two-wheel steering, which provided another application for Delta RMCs. Green Valley had five days to get the motion control configured. The company turned to Delta's support department for assistance and had all the needed code in hand the next day.

John Henry Foster prioritizes several factors when selecting motion control solutions, including ease of use, feature depth, precise movement and steering, and exceptional end-user support. Because of these criteria and others, Delta remains among the few vendors Green Valley and John Henry Foster prefer as new challenges arise.

Mike Birschbach is a controls engineer at John Henry Foster (www.jhf.com) in St. Louis. Contact him at 800/444-0522.