Powering a tube mill with AC vector drives

By David B. Stephan and Michael J. Webb

A new application for the technology

Alternating current (AC) vector drives have not achieved widespread use for steel processing. However, the first installation of a major tube mill using the technology, recently completed in Canada, has shown AC vector drives to be technically and commercially feasible for use in tube producing equipment.

This article discusses AC vector drive technology and describes the specific tube mill project.

DC Motors and Drives

Drives and motors convert electrical power to the mechanical power required to move metal through a mill to form pipe or tube. The torque produced by the motor drive system must be able to pull the metal from zero speed to full speed through each of the mill process stands.

To understand the issues surrounding the direct current (DC) and AC designs, it is useful to review basic DC motor theory, because the traditional mill electrical architecture capitalizes on the torque characteristics of a DC motor.

DC motors provide relatively easy speed and torque control by varying armature voltage and current respectively, and this has made DC motors the primary choice for steel processing applications. The torque and horsepower versus speed curves of a DC motor are shown in **Figure 1**.

Much like the accelerator pedal in a car allows you to control the speed of the car, the drive allows you to select the speed and/or torque of a motor to suit the application. Three major types of drive control strategies have been applied over the years: motor generator (M-G) sets with analog control, thyristors with analog control, and thyristors with digital control.

M-G Sets. M-G sets have provided a simple and effective method for converting electrical energy to mechanical energy. Many are still in use, although they are no longer actively sold.

M-G sets use AC power to rotate a synchronous motor, which turns a DC generator. The DC generator powers DC motors. The fields in the generator and the motors are used for control. M-G sets are simple and effective.

Thyristor Drive - Analog and Digital Control. The development of thyristor drives provided a better means of transferring power because it eliminated the need for the synchronous motor and DC generator. They were replaced with semiconductors that could handle high currents. Maintenance was no longer required for the rotating equipment in the M-G set, and the responsiveness of the control system improved.

Analog control uses potentiometers and operational amplifiers for control. Temperature and humidity changes may cause this type of system to "drift" and become uncalibrated.

Digital control incorporates one or more microprocessors to digitize signals and employ control algorithms which cannot be implemented in an analog system. Drift is reduced, and machine settings such as gains and tuning can be documented and stored on disk.

This documentation is valuable for understanding and improving internal machine processes, eliminating unwanted variations, and diagnosing system problems. This, in turn, can help users reduce setup times, improve machine performance, and reduce the need for troubleshooting.

AC Motors in Metals Industries

The three motor drive system technologies are refinements on the fundamental DC motor system. AC motor systems are another option. They are typically smaller than DC motor systems of similar power. They do not need brushes, which require maintenance, and are typically totally enclosed, fan-cooled motors that do not need clean air for internal ventilation, eliminating a source of contamination.

An AC motor operates differently than a DC motor. Its speed depends on two parameters:

1. The number of poles, determined by the motor's construction.

2. The frequency of AC voltage applied, determined by the power system (typically 60 Hz in North America and 50 Hz in Europe) or by a variable-frequency drive powering the motor.

An AC motor's torque depends on the slip of the motor, a variable which is not easy to control.

Typical **AC variable-frequency drives** allow the user to vary the electrical frequency applied to the stator windings, which, in turn, varies the synchronous speed of the motor. However, the torque and slip are both still unknown and uncontrolled.

AC motors cannot provide full torque at low speed (see **Figure 2**), which is unacceptable for applications such as metal forming lines in which controllable torque over a broad speed range is essential.

AC vector drives control several variables to produce one result: motor torque or speed. AC vector drives use normal AC motors (although inverter duty motors are best), except that an encoder is mounted to the rotor shaft. This allows the drive to know the rotor's position relative to the stator's flux.

The drive regulates the speed or torque by using an active motor model which separately controls the motor-flux current and the torque-producing current. The algorithm dynamically determines these control variables by monitoring the field flux position versus voltage and current vectors. This results in torque regulation similar to that of a DC motor (see **Figure 3**).

AC vector drives were first developed in 1967 but have become viable products in recent years with the development of high-power semiconductors and microprocessors.

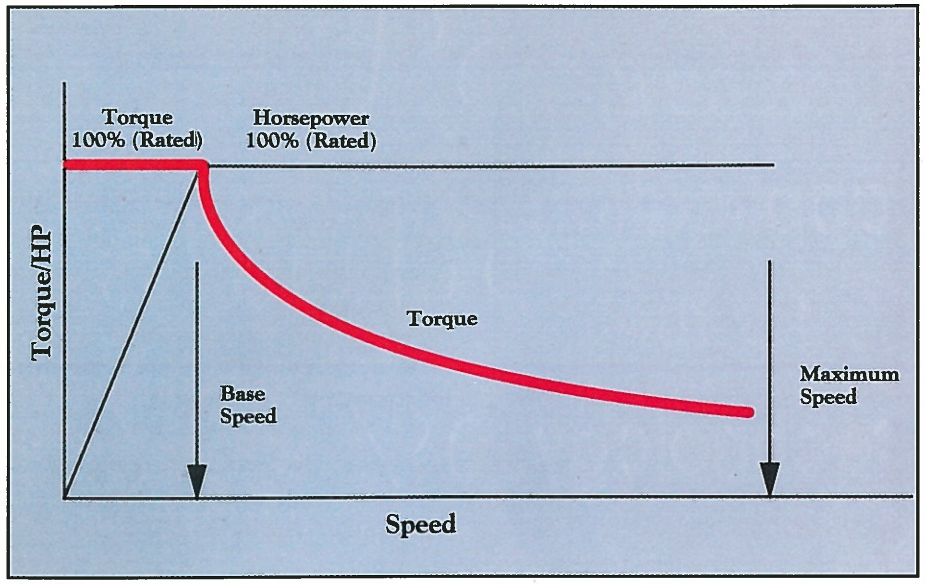

FIGURE 1 *The torque and horsepower versus speed of a DC motor is shown here.*

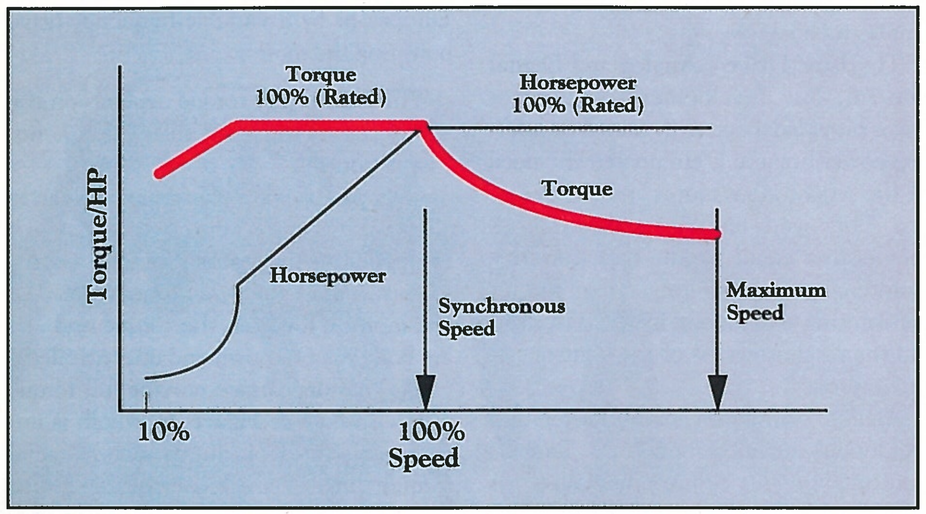

FIGURE 2 *This is the torque and horsepower versus speed of an AC variable-frequency drive. As shown, AC motors cannot provide full torque at low speed.*

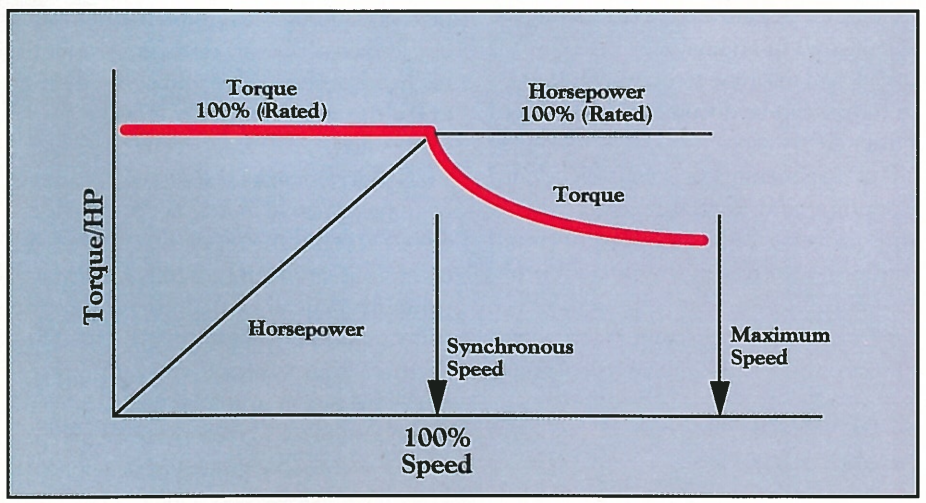

FIGURE 3 *The AC vector drive has a torque regulation similar to that of a DC motor.*

AC vector drive technology has been successfully used in the paper industry, in which caustic chemicals and harsh environments increase the maintenance required on DC motors involving brush replacement and internal ventilation.

AC vector drives have typically been more expensive than equivalent DC drives, making them attractive mostly in cases in which DC was not viable. To date, AC vector technology has not caught on generally in the steel processing and tube producing industries.

The Tube Mill Project

AC vector technology has been installed on a tube mill at Atlas Tube in Harrow, Ontario, Canada. This installation involved the cooperation of several companies: One to supply all the mechanical components and the functional engineering; one to provide the mill electrical control and drive equipment used on the project; and another to provide the tube mill system electrical design, programming, installation, and start-up service.

Investigation for the project began in 1991. The tube producer sought to obtain a mill that met its requirements for throughput, reliability, and size. The company chose digital technology for its diagnostics ability and precision. It then decided on the tube mill design and chose the electrics and drives supplier.

In addition to AC motors and drives, the mill design incorporates quick size changing and numerically controlled (NC) roll positioning, with a data bank for the entire size range as well as steel grades to be processed. The mill has increased the company's production capacity and enables the production of a broader size range.

A general arrangement sketch of the mill is shown in **Figure 4**. It includes a coil carriage, uncoiler, spiral accumulator, tube mill, traveling cutoff saw, and bundling system.

Motor and Drive System Sizing Considerations

Because the AC motor drive system does not have the characteristics of the DC equipment it is intended to emulate, the AC motor drive system must be engineered to meet the torque and horsepower requirements across the entire speed range of the application. This usually results in the selection of larger horsepower AC motor drive systems than "equivalent" horsepower DC motor drive systems.

Motor breakdown torque of an AC induction motor depends on the motor design. Typically, it ranges between 200 and 300 percent of motor rated torque.

Breakdown torque is constant in the constant torque range. However, it varies inversely as the square of speed in the constant horsepower range. This means it decreases faster than continuous torque in the constant horsepower range.

Breakdown torque can actually be lower than continuous torque in the higher speed ranges. Care must be taken to size the motors and inverters for this possibility.

Figure 5 illustrates the torque and horsepower curves, and the calculations required in this kind of application are shown in **Figure 6**.

Project Challenges

As might be expected in any ambitious project, some challenges arose in the installation of the AC vector drive tube mill.

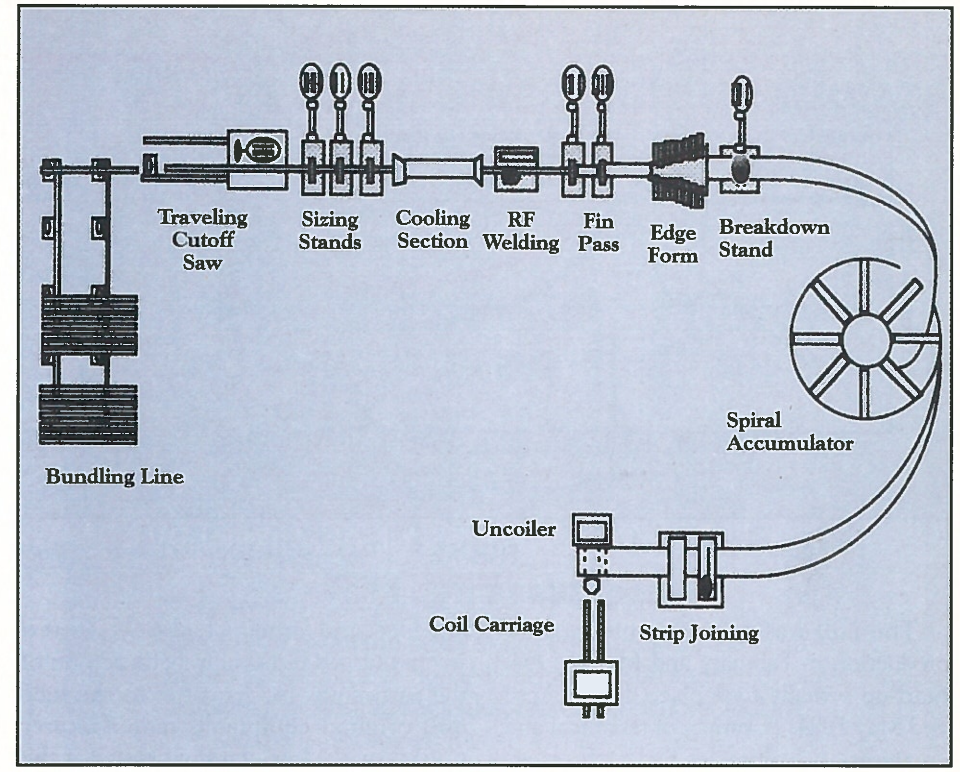

FIGURE 4 *Here is the arrangement of the AC vector drive tube mill.*

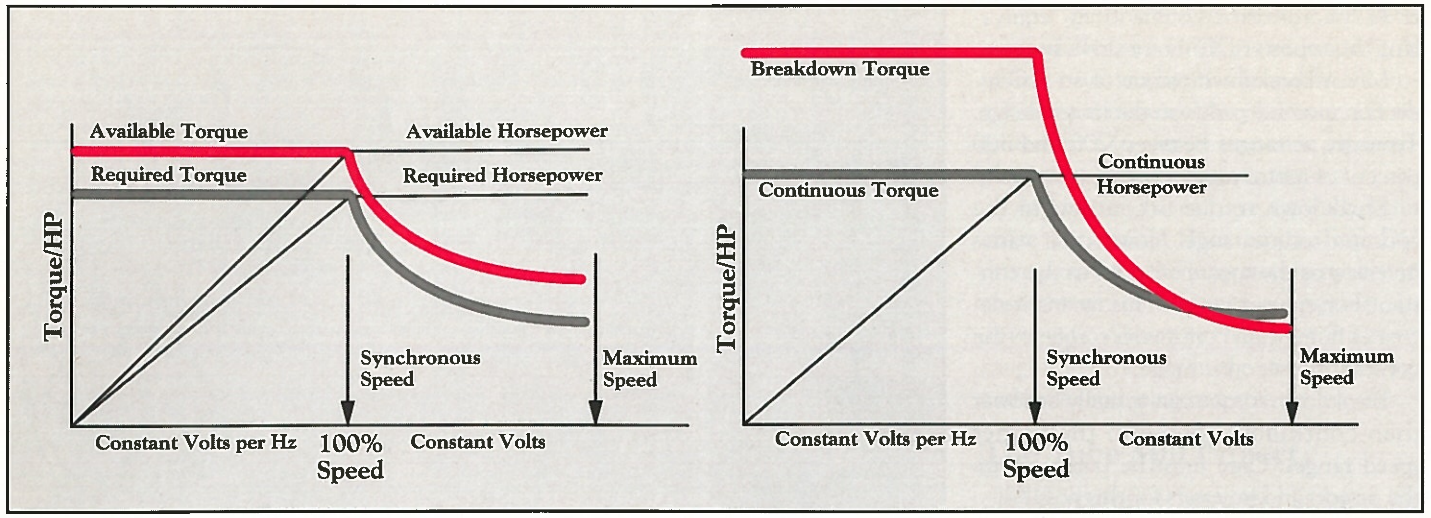

FIGURE 5 *Torque and horsepower curves are shown here.*

The mill was originally planned for production in February and March 1994. Start-up actually took place during April and May 1994. A variety of technical and organizational obstacles had to be overcome, delaying various stages of the work.

Coordination between the mechanical and electrical vendors had to be aggressively pursued, especially because one of the parties was in Germany. As the tube mill original equipment manufacturer (OEM) worked on the final stages of the design, the control requirements (input/output, or I/O) fluctuated substantially.

Last-minute difficulties cropped up in the installation involving contractor management of installation wiring, conduit, and other details. Attempts to solve these problems posed a challenge to the skills of all parties to the project.

The tube producer could have had the OEM simply turnkey the entire project. However, this would likely have increased the costs and caused a loss of control in selection of the electrical vendor. If the OEM had been given a turnkey project with the electrical vendor specified, the costs may have gone up further because of the OEM's perceived risk in using an unfamiliar electrical vendor.

Another alternative would have been to use an engineering firm to perform the interfaces and supervise the vendors during the installation phases. However, this arrangement usually works well only if the engineering firm is familiar with the type of process equipment being used.

In this case, the complex electrical and control elements of the system may have been outside a typical architectural, construction, or machine installation firm's expertise.

A third alternative would have been to hire a smaller engineering firm familiar with the process to be responsible for these aspects of the work. While the firm would have the necessary experience, it might not have the financial strength to turnkey the project. The tube producer felt more comfortable dealing with a major corporation.

System Considerations

Several factors about AC vector drives were considered before the tube mill installation.

Expense. An AC motor drive system may or may not be more expensive than DC systems. Depending on how fast the mill must run and the constant horsepower range required, substantially larger horsepower may be required for an AC versus a DC motor drive system.

AC vector drives control several variables to produce one result: motor torque or speed.

Motor Sizing Equations

T = *torque*

$$T_{load\ @\ gearbox\ input} = T_{load\ @\ gearbox\ output} \times \frac{1}{Gear\ ratio} \times \frac{1}{Gearbox\ efficiency}$$

$$T_{motor\ rated} \geq T_{load\ @\ gearbox\ input}$$

$$T_{motor\ breakdown} \leq 2.9 \times T_{motor\ rated}$$

$$T_{motor\ max} = T_{motor\ rated} \times 1.6$$

$$T_{motor\ breakdown} = T_{motor\ max} \times \frac{1}{0.7}$$

Continuous load torque over the entire speed range at the gearbox output, as well as gearbox ratio and efficiency, were provided by the mechanical equipment supplier. Therefore:

T = *torque*

$$T_{load\ @\ gearbox\ input} = T_{load\ @\ gearbox\ output} \times \frac{1}{Gear\ ratio} \times \frac{1}{Gearbox\ efficiency}$$

Motor rated torque at the gearbox input must be equal to or greater than the continuous load torque over the entire speed range:

$$T_{motor\ rated} \geq T_{load\ @\ gearbox\ input}$$

Motor breakdown torque must be equal to or less than 2.9 times motor rated torque so that peak currents from the inverter will be less than the inverter overcurrent trip setting. Greater than this requires derating of the inverter:

$$T_{motor\ breakdown} \leq 2.9 \times T_{motor\ rated}$$

Motor overload requirements specified by the mechanical equipment supplier are 160 percent load for 5 seconds every 5 minutes from minimum speed to top speed:

$$T_{motor\ max} = T_{motor\ rated} \times 1.6$$

Motor breakdown torque must be equal to or greater than motor maximum torque divided by 0.7, to account for the 90 percent power supply voltage which would cause the motor torque to be reduced to 81 percent of rated torque, as well as transients in load torque:

$$T_{motor\ breakdown} = T_{motor\ max} \times \frac{1}{0.7}$$

Voltage, Speed, and Power Equations

V = *volts*

$$T_{motor\ breakdown} \propto \left(\frac{V_{applied}}{V_{rated}}\right)^2$$

N = *speed*

$$T_{motor\ breakdown} \propto \left(\frac{N_{rated}}{N_{actual}}\right)^2$$

Motor breakdown torque is proportional to the square of the ratio of applied voltage to rated voltage at a given frequency:

V = *volts*

$$T_{motor\ breakdown} \propto \left(\frac{V_{applied}}{V_{rated}}\right)^2$$

Motor breakdown torque is also proportional to the square of the ratio of rated speed to actual speed at rated voltage over the constant horsepower range:

N = *speed*

$$T_{motor\ breakdown} \propto \left(\frac{N_{rated}}{N_{actual}}\right)^2$$

Thus, if motor rated speed is 1,200 RPM and motor top speed is 2,400 RPM, motor breakdown torque at top speed is 25 percent of motor breakdown torque at rated speed. When applying AC motors that operate above rated speed, motor breakdown torque must exceed load torque throughout the speed range, or the motor will stall.

FIGURE 6 *These are the calculations used for "sizing" AC motors.*

> AC vector drives have become viable products in recent years with the development of high-power semiconductors and microprocessors.

However, as horsepower increases, AC motors become more less costly relative to DC motors. In addition, newer AC vector drive products are more cost-effective than older products.

Training. Maintenance personnel who are used to DC motors, thyristor power supplies, or M-G sets need to be trained to maintain AC vector drives. Maintenance is not necessarily more difficult, just different.

Engineering. Motor sizing and horsepower must be calculated accurately to ensure that the system is being sized properly. AC motors have different power curves and torque characteristics, so motors and drives must be carefully engineered. This activity is critical to the success of any application, whether AC or DC drives are used.

Maintenance. Just like any AC motor, an AC motor (or an inverter duty motor) powered by an AC vector drive requires grease a few times a year. Other than that, little maintenance is required.

Power Efficiency. DC motor drive systems become slightly less energy efficient at less than full load. AC motor drive systems are slightly more efficient over the full speed range and provide a better power factor under certain conditions, helping conserve energy.

Size. AC motors are smaller than DC motors of the same horsepower.

Project Outcome and Conclusion

The tube mill has performed as planned. The AC drives posed no abnormal start-up difficulties and caused no problems in the line's operation. The work performed in the line is the same as if DC motors were used.

This project has shown that AC vector drive technology can perform on the same level as traditional DC drive technology, enabling AC vector drive use to move beyond pulp and paper and into the metals industry.

David B. Stephan is Project Engineer, and Michael J. Webb is Sales & Marketing Manager, with PCT, Inc., Davenport, Iowa. *The authors thank Alan Zekelman, President of Atlas Tube, for his participation in the preparation of this article; Bill Sampson, Project Manager for Allen-Bradley Company, for his contribution to the motor sizing calculations and other technical issues presented in the article; and Wilhelm Bungert of Mannesmann Demag for his support in the preparation of this article. Lead-in photo courtesy of Siemens.*

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GLOSSARY OF TERMS

Analog: Control architecture that uses potentiometers and amplifers for control.

Armature: Rotating elements inside a DC motor which generate magnetic flux (force) when electrical current passes through them. They must be fed electrical current, usually via brushes.

Digital: Control architecture that uses microprocessor technology to implement digital control algorithms.

Drive: Device used to power and control electric motors.

Electrical Current: The transfer of an electrical charge from one point to another.

Encoder: Device which signals the position of a rotating mechanism through optically or magnetically induced electrical pulses.

Flux: Magnetic force created within an electric motor as a result of electrical current flow through the motor windings.

Horsepower: Output power rating of a motor.

Inverter: Part of an AC drive which converts DC energy into pulse width modulated AC to power an AC motor.

Inverter Duty Motor: AC motor specifically designed to accommodate the electrical power produced by inverters (AC drives).

Power Factor: Ratio of the actual power as measured by an AC watt meter to the apparent power as indicated by ammeter and volt meter readings.

Rotor: Rotating element inside an AC motor.

Stator: Stationary field coils of a generator or motor element inside an AC motor.

Synchronous Speed: Speed at which the motor turns when rated voltage and current are applied (assuming no slip).

Synchronous Motor: AC motor which turns at a rate determined by the frequency of its power source (Hz) and the number of poles in the motor.

Thyristor: Power semiconductor used in DC drives. Also known as an SCR.

Torque: Turning or twisting force produced by a motor.

Vector Drive: Drive for an AC motor which produces torque and speed control similar to DC motors.

Voltage: Unit of electromotive force which produces current in conductors.