SPECIAL REPORT

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CHOOSE A WINNING **DRIVE STRATEGY**

Electric variable-speed drives on lubricant-cooled and lubricant-free rotary air compressors are not a cure-all for system woes--chemical plants must implement them correctly and at the right time to achieve maximum energy savings

In the 1990s, extra large storage with high-pressure and regulated flows often was the "silver bullet" for all compressed air system woes. The electric variable-speed drive on lubricant-free and lubricant-cooled rotary screws now is trying to take its place as the "silver bullet" for the new millennium.

Of course, no silver bullet exists for air system problems. However, like proper storage with controlled flow, the variable-speed drive," particularly on today's rotary screws ," is an excellent tool to help increase system efficiency.

Electric motor variable-speed-driven compressors are not new and have been employed many times during the last 30 to 40 years. Most of these drivers historically were variable-frequency drive (VFD), and the units usually were built as specials by the manufacturer or packaged by specially trained and experienced organizations.

However, modern electronic control systems have significantly improved control response time and often compress the effective operating pressure band to a 1-pound-per-square-inch-gauge (psig) or 2-psig variance. New types of variable-speed drives have become available in addition to VFDs. VFDs themselves have become more efficient and responsive.

Today, almost all manufacturers offer some form of variable-speed drive as a "standard" product in their rotary screw compressor packaged lineups.

Reviewing the Basics

A number of "basic truths" cover all variable-speed drives.

All types of electric variable-speed drives are less power efficient at full load than comparable constant-speed units. An electrical energy loss always is associated with variable-speed-drive equipment and will show up dramatically at higher load conditions.

For example, two 100-horsepower (hp) lubricant-cooled rotary screw compressors at full-load pressure, by the same manufacturer, can be compared ," one at a standard constant speed and the other at a variable speed.

Each unit delivers a rated 490 actual cubic feet per minute (acfm) at a 100-psig full load pressure and a power draw of 110 brake horsepower (BHP). The BHP is the power required at the compressor shaft to deliver full flow at full pressure. The scenario assumes the plant's electrical energy bill is based on input kilowatts (kW) to the electric motor (electric energy cost = kW x hours x rate per kilowatt-hour [kWh]).

The variable-speed-drive model draws 124 amps at 460 volts at full load. The motor has a 0.944 power factor (PF) and a 0.958 motor efficiency (ME) at full load. The constant-speed drive model draws 133 amps at 460 volts at full load and has a 0.84 PF and a 0.923 ME at full load.

The variable-speed-drive motor pulling 124 amps is more power efficient than the constant-speed motor pulling 133 amps ," right? Wrong. Consider:

$$\text{Input kW} = \frac{(\text{amps})(\text{volts})(1.732)(\text{PF})}{1{,}000}$$

Variable-Speed Drive:

$$\text{Input kW} = \frac{(124)(460)(1.732)(0.944)}{1{,}000}$$

= 93.26 kW/$40,848/yr.@$0.05 kwh/8,760 hr.

TABLE 1. ACTUAL INPUT KW PERFORMANCE

(100-hp class actual specific power, variable-speed drive compared to four most popular constant-speed drives from 50% to 100% flow)

Percent load/ Type control	100% Flow (cfm)	100% Flow power (kW)	100% cfm/ kW (cfm)	80% Flow power (kW)	80% Flow	80% cfm/kW (cfm)	50% Flow power (kW)	50% Flow	50% cfm/kW
Throttled inlet, no blow-down	490	89.01	5.50	392	84.56	4.64	245	75.66	3.24
Throttled inlet with blow-down, gal./ cfm effective storage	490	89.01	5.50	392	84.56	4.64	245	62.31	3.93
Two-step full load/no load with blow down, 5 gal./cfm effective storage	490	89.01	5.50	392	83.67	4.64	245	62.31	3.93
Variable displacement with blow-down, 5 gal./cfm effective storage	490	89.01	5.50	392	75.66	5.18	245	57.86	4.23
Variable speed with 5-gal./cfm effective storage	490	93.26	5.25	392	74.61	5.25	245	46.63	5.25

Note: 1.732 is a constant in the input kW formula, converting the number for three-phase power.

Constant-Speed Drive:

$$\text{Input kW} = \frac{(133)(460)(1.732)(0.84)}{1{,}000}$$

= 89.0 kW/$39,986/yr.@$0.05 kwh/8,760 hr.

At full load, the constant-speed-driven unit is approximately 5% more efficient and costs $862 less per year to run at $0.05 kWh. The "break-even" point between similar-size constant-speed controls and variable-speed drives usually will be approximately 70% to 80% of load, depending on the true operating characteristic of each unit.

Therefore, variable-speed drives should not run at higher loads for a significant number of hours per year. They are effective "trim" units, not base load. Most plants will need only one appropriately sized variable-speed-driven unit as a trim compressor.

Most capacity control performance data are presented as a "percent of full-load power." Regardless of the type of capacity control, it is unwise to use "percent of load" to determine the best choice for the plant's operating environment. This rule of thumb is particularly true with variable-speed drives.

The "percent of load" should be translated into actual input kW throughout the operating load profile and applied to the number of hours of operation to determine the total kWh per year (See Table 1).

The calculations should compare some typical capacity controls at various loads. The manufacturer is capable of providing actual input kW. The conventional method of using BHP x 0.746 or 0.7457 and dividing by ME is misleading. It will miss the variable-speed-drive equipment loss and/or belt losses in belt-driven equipment.

Keep in mind that the variable-speed drive starts at a higher full load (kW) than a comparable constant-speed model. Accurate performance charts will show where the break-even point is and where the plant can start saving energy.

Applying Variable-Speed Drives

Of all the capacity controls available on lubri-

TABLE 2. VARIABLE-SPEED-DRIVE SYSTEM COMPARISON		
Typical operating characteristics	VFD	DC variable-speed drive
Operating badn from set point in trim	±1.5 psi	±0.5 psi
Rise in pressure above set point to fully unload	4.5 psi	4 psi
Time after valve shuts to full stop	—	—
Time required to restart to full flow	21 sec.	2 sec.

A 500-cfm unit running at 20% flow with 500 gallons (gal.) (66.84 cubic feet [cu. ft.]) of effective storage is delivering 100 cfm to the system. If the demand flow is 60 cfm and the compressor inlet valve closes and unloads and the motor stop[s, the available time for a 5-pound-per-square-inch, differential (psid) operating band would be:*

$$\text{Time (sec.)} = \frac{(66.84 \text{ cu. ft.})\ (5 \text{ psid})\ (60)}{(14.5)\ (60 \text{ cfm})} \qquad \text{Time} = 23 \text{ sec.}$$

The same conditions with 2,500 gal. (334.2 cu. ft.) of effective storage will allow 115 sec. of off time. With the "mistaken" but often-stated: "One gal. of storage per cfm of capacity," the VFD drive with the above operating specifications would require an additional 19 sec. of off load before it could deliver flow to the system. This would allow an additional 4 psig of system pressure drop. It might or might not be meaningful, depending on the situation.

$$^*T \text{ (sec.)} = \frac{(V)\ (P2 - P1)\ (60)}{(\text{psia})\ (C)}$$

Where: V = volume storage cu. ft.; T = time pumping or decay; C = net flow; psia = atmospheric pressure

cant-free and lubricant-cooled rotary screw compressors, none are more power efficient in their effective turndown range than variable-speed drives. Variable-speed drives can operate at a partial load at basically a full-load efficiency.

This effective turndown range will vary with different manufacturers, different types of variable-speed drives and the performance profile of the rotary screw air end. For estimating purposes, the most effective turndown range usually will be from 40% to 80% of full flow. Lubricant-cooled rotary screws usually have a wider effective turndown range than lubricant-free versions. The plant should review the unit's specific performance data to verify this.

Variable-speed drives also can pull down to very low loads (15% to 25%) rather efficiently and then shut off and restart more times per hour than a similar constant-speed induction motor. Certain types of drives have a greater ability for unlimited starts and stops per hour than others. When reviewing various options for a specific load profile, the plant should not overlook this very important feature ," it can and will save significant energy dollars under certain conditions.

Almost all manufactures offer unlimited starts and stops per hour. The plant should review this start and stop performance with careful detail to its application. At one end of the spectrum are DC motor drives that have virtually no heat buildup, while some other types have a 20-second (sec.) or more ramp-up time.

A lubricant-cooled unit with a 20-sec. ramp-up time must have enough effective storage to allow it to fully unload, blow-down if required, coast down and restart to full flow ," without collapsing system pressure if it shuts off.

Table 2 compares two typical variable-speed systems.

Variable-speed drives with lubricant-free or lubricant-cooled rotary screw air ends, when properly applied, can bring about great energy and cost savings. In addition, they:

- Provide excellent trim capability when required.
- Deliver an effective steady pressure of 1 psig to 2 psig operating band within their turn-down range.
- Start and stop the motor effectively more often when required.

It is critical for the plant to accurately ascertain the demand before considering the cost-effectiveness of any new compressors," whether the compressors involve a variable-speed or another type of drive. Only then can the plant accurately review the projected input kW and the overall impact on the facility's electrical energy costs.

Other articles and publications detail how to perform a complete air system review. The chemical plant can do this itself, or can ask the variable-speed-drive sales personnel to do it. Independent consultants also are available. Plant operators should not make major decisions unguided, potentially missing "golden opportunities."

A Plant Example

One processing plant has a 1,526-cubic-foot-per-minute (cfm) compressor and a 1,026-cfm, 200-hp compressor. Both are fixed-speed, lubricant-free two-stage rotary screw compressors. The 1,526-cfm model runs base load, and the 1,026-cfm, 200-hp model is used as the trim machine.

The demand profile is between 2,000 cfm and 2,500 cfm, with an average flow of 2,300 cfm to all three production shifts (6,240 hours per year) and about 900 cfm for limited production and maintenance during weekends and holidays (2,520 hours per year). The plant has large air receivers and piping for effective storage.

A sales presentation on a 1,526-cfm class variable-speed-drive two-stage lubricant-free rotary screw compressor pointed out that at 50 % load (750 cfm), the compressor was at only 50% of full-load power, while the conventional units with effective two-step unloading would consume approximately 60% of full-load power. According to the sales presentation, a new variable-speed-drive 1,526-cfm trim unit in the system could slash electrical energy costs by as much as 40%.

The data sheets supplied by the salesperson included BHP (shaft horsepower) ME and full-load amps, but not PF or input kW. The manufacturer then supplied input kW data at various loads to allow an accurate comparison. The plant was able to fill out a load profile/operating cost estimate sheet.

For the plant example, the total estimated annual electrical energy cost with the existing 1,526-cfm baseload unit and 1,026-cfm trim unit is $142,784. The total estimated annual electrical energy cost with the existing 1,526-cfm baseload unit and "new" 350-hp class variable-speed drive unit is $149,616.

In this particular case, the existing 200-hp two-step control unit acting as the trim unit has an estimated $6,832 lower electrical energy cost (at 0.05 kWh) than an alternate variable-speed-driven lubricant-free rotary screw compressor. However, in another profile with other equipment ," or even the same equipment ," the variable-speed-driven unit might offer significant savings and quick payback. (For example, a measured lower load at longer hours; lubricant-cooled rotary screws with a wider efficient speed range, etc.)

The key point is that plants should NOT simply assume the variable-speed drive will be the silver bullet that will reduce compressed air energy costs. It is important for plant operators to:

- Obtain all the important data, particularly input kW, for all units at critical percent-of-load points. Plants can and should evaluate existing equipment.
- Identify and optimize demand or load profile over all pertinent conditions ," production, nonproduction, etc. Assign hours per year to each of these conditions to evaluate the true operating cost. The plant example provided here is somewhat simplistic in that the production process does not vary much. However, the example is based on an actual processing plant's logged data.
- Identify blended electrical power costs in $0.0/kWh, but do not lose sight of the effect on demand charge if a smaller or variable-speed drive can trim and shut off a larger unit.
- Prepare an operating cost comparison.
- Optimize the system. Is air on necessary on weekends and holidays? How much air is essential? How much air is being lost to leaks?

Conclusion

The variable-speed drive, particularly in rotary screws, is an excellent tool for optimizing the electrical energy cost to drive chemical plant air compressors. However, it is only one of many available tools. Like other tools, it must be implemented correctly and at the right time to avoid misapplications and missed opportunities. Its capabilities and drawbacks must be clearly understood.

Because most compressor manufacturers now offer excellent "factory packages," these manufacturers have the tendency to oversell the variable-speed drive. Remember, it is not a cure-all for every application and might use more electrical energy than other options, depending on the facility's unique requirements.

The purchase of a new air compressor as a base or a trim unit is a major capital expenditure; therefore, plant decision-makers should evaluate their options carefully. In all likelihood, the plant will spend about the same amount on electrical energy per year to run the unit as it initially paid for it. A mistake or misapplication in this area not only has the potential to waste capital money with little or no offsetting gain, but also could bring with it continuing higher operating costs each year over the life of the compressor.

RECOVERING EXHAUST HEAT FOR **CONDITIONED AIR FACILITIES**

Preventing energy dollars from going up the stack

As detailed in an earlier *Chemical Processing* article ("Managing Wastewater Treatment Odors," September 2001, p. 38), mixed-flow technology systems can eliminate wastewater treatment facility exhaust odors, effectively diluting the exhaust gas stream by mixing it with outside air. These systems mix fresh air with wastewater process exhaust gases until a suitable concentration is released and the odor no longer is perceptible or objectionable.

Mixed-flow impeller technology offers another key advantage to the chemical process industries, however. At facilities such as research laboratories and/or chemical process areas requiring 100 percent conditioned makeup air, these systems — when used with accessory heat exchanger coil modules — can recover heated or chilled ambient air before it is exhausted into the atmosphere. They then can recirculate it into the building's intake system, potentially providing substantial energy savings.

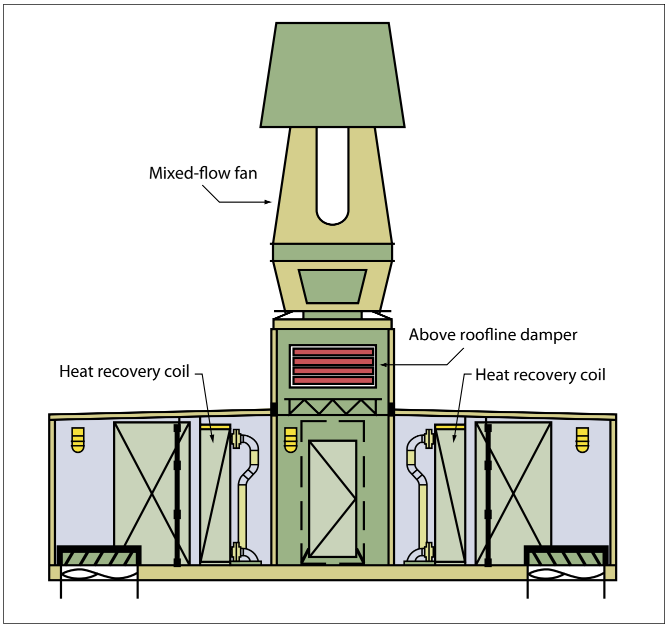


Fig. 1 shows a typical roof-mounted heat exchanger/mixed-flow impeller system.

Slashing Energy Use

With the high energy costs for heating and cooling, building operators, owners, contractors, managers and designers are looking for relief from many sources. Heat-recovery coil modules, essentially heat exchangers, combined with mixed-flow impeller exhaust systems are highly efficient: For each 1°F of heat added to makeup air, for example, energy costs are reduced about 3%. It is not unusual to see yearly heating energy cost reductions of 30% or more. Similar savings — although not quite as dramatic — also can be realized for cooling.

In many industries, energy represents an extremely high proportion of expenses. It is not unusual in some chemical processing facilities to use 15% or more of an entire operating budget for energy. Although today's energy costs are relatively stable, they have fluctuated wildly over the past few years. And they could do so again — particularly in light of the current geopolitical conditions around the world in general, and in many of the oil-producing countries in particular.

Major energy users are shelling out thousands or even hundreds of thousands of extra dollars for heating and cooling, and these costs are increased substantially when conditioned air is mandated to comply with health and safety requirements. When laboratory workstation fume hoods are exhausted, for example, or ambient air is exhausted from a controlled environment at a chemical processing facility, conditioned air must replace the ambient air lost during the process. This air has to be heated or cooled, depending on climate.

Mixed-flow impeller systems with heat-recovery modules can provide building owners with a return on investment (ROI) as short as two years. In general, these systems are usable when outside air temperatures are below 40°F or above 80°F, because a large enough difference in temperature must exist

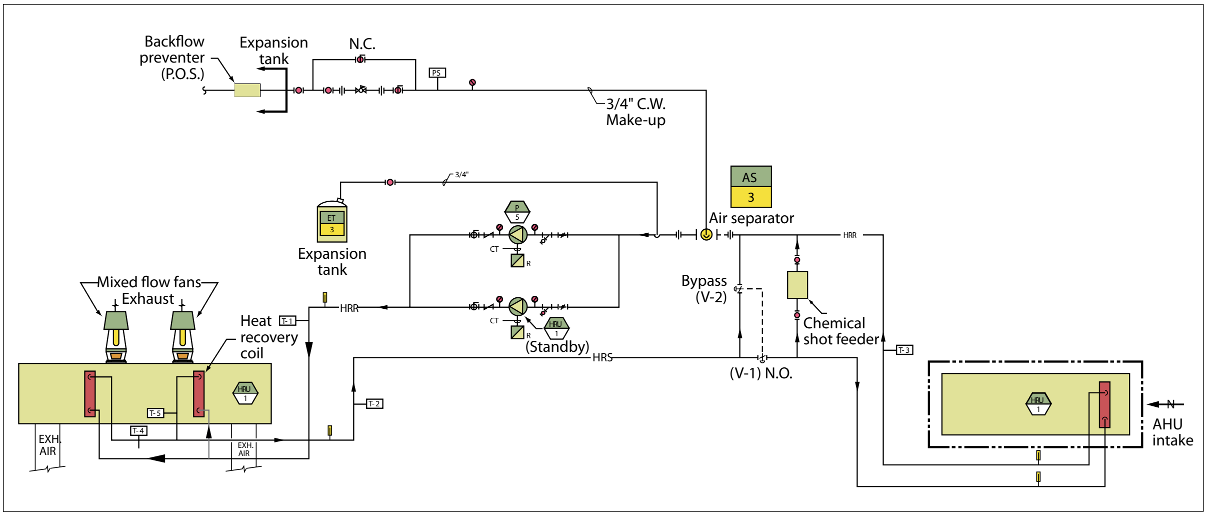
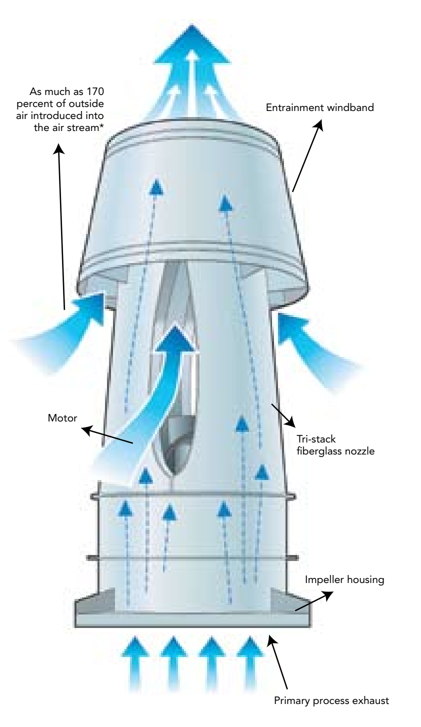


Fig. 2 provides a flow diagram of a heat exchanger system with two mixed-flow impeller exhaust systems.



*The exhaust air is moved or pushed by the fan motor and is enhanced by approximately 170 percent, adding mass and diluting the exhaust air stream.

Mixed-flow impeller-type roof exhaust systems dilute outside air with plenum exhaust air at high discharge velocities, sending a powerful vertical exhaust plume up to 350 feet high.

These systems reduce noise, use less energy and provide a faster payback than conventional centrifugal fan exhaust systems, with a typical energy reduction of $0.44 per cubic feet per minute (cfm) at $0.10/kilowatt-hour, resulting in an approximate two year ROI. Energy consumption is about 25 percent lower than that of conventional centrifugal fans, with substantially reduced noise levels, particularly in the lower octave bands. They conform to all applicable laboratory ventilation standards of the American National Standards Institute/American Industrial Hygiene Association's (ANSI/AIHA) Z9.5, as well as the American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE) 110 and the National Fire Protection Association's (NFPA) 45, and are listed with Underwriters Laboratory under UL 705.

The systems are designed to operate continuously without maintenance for years under normal conditions. Direct-drive motors have life spans of 200,000 hours. Nonstall characteristics of the system's mixed-flow wheels permit variable-frequency drives to be used for added variable-air-volume (VAV) savings, built-in redundancy and design flexibility.

between outside and inside air for operating efficiency. If heating and cooling costs represent a large expense item at a chemical processing facility, mixed-flow technology might offer dramatic relief to the bottom line.

Beyond Energy Savings

Mixed-flow impeller technology for process exhaust applications offers benefits beyond energy savings — it also eliminates air pollution problems, prevents exhaust re-entrainment, controls odorous emissions and costs less to operate than traditional centrifugal fan systems with tall exhaust stacks.

It also provides a low-profile solution — eliminating the "smokestack" look and the associated negative perceptions. In addition, the technology could help a chemical facility conform to applicable architectural/aesthetic ordinances. The low-profile mixed-flow impeller fans do not require structural reinforcements on the roof or complex, nor do they require expensive mounting/stabilizing hardware such as guy wires, elbows, flex connectors or spring vibration isolators. Mixed-flow impeller systems also are virtually maintenance-free — they have no belts, elbows, flex connectors or spring vibration isolators.

Conclusion

Energy costs for conditioned make-up air burden many organizations in the chemical process industries. Depending on the circumstances, this air must be filtered, heated, cooled, humidified or dehumidified (or some combination). Conditioned environments such as laboratory workstations and many process facilities require safe, energy-efficient, pollution-free exhausting. In applications such as these, mixed-flow impeller technology with heat recovery modules offers a practical alternative to many current methods for accomplishing these objectives.

Before investing in this technology, however, a chemical plant should evaluate its climatological conditions. Plant personnel should review a full year's worth of outside temperatures to help make a better determination.

TAKE THE RIGHT FIRST STEP TO **MANAGE YOUR ENERGY COSTS**

Conducting an energy assessment provides a business plan for improvements

Imagine trying to construct a chemical plant without a piping and instrumentation diagram (P&ID). Just get a bunch of people together at a site and tell them to "make it happen." Could the plant be built? Well, maybe, but the task would certainly take longer and the result would be a confusing maze of systems, some incomplete and many working at cross purposes. Once the plant is finally done, the operations staff would probably spend all their working hours simply untangling the mess made during construction.

Clearly, the P&ID makes the job easier and leads to a better plant. Similarly, such a blueprint — an energy assessment or audit — is crucial for successfully controlling energy costs. It will underscore the value of system-wide improvements, pursued in stages so that process interruptions are minimized, and of using early savings to pay for later projects. Trying to manage energy without an assessment will yield results that at best fall short of expectations or at worst interfere with the plant's core mission.

An energy assessment provides a summary of how much energy is input to a plant and its distribution to various departments and systems. It summarizes fuel, power and water use required by process activities as well as by site heating, ventilation, lighting, sanitation, etc. The assessment summarizes energy inputs over a period of time (usually a year) and expresses consumption relative to production levels and weather conditions.

An energy assessment is a blueprint for improving plant performance.

Plant managers often resist the suggestion of conducting an energy assessment. Perhaps the most common objection is: "We don't have the money to pay for an assessment." Let's say we're talking about a typical medium-sized plant that spends perhaps $2 million on energy each year. Studies by the U.S. Department of Energy and others suggest that the average facility can cut 10% to 20% of its energy consumption. Having a 10% potential savings equates to admitting that $200,000 is being wasted annually. A very good energy assessment might take a few days and cost about $20,000. So, what we're really being told is: "We don't have the money for an energy assessment because we need to pay for the fuel that we're going to waste." Too bad, because it only gets worse: energy prices are likely to rise faster than the price of an assessment. Plus, energy assessments often can be had for free through utilities, state energy offices and university-based industrial assistance programs (see www.oit.doe.gov/iac).

The knowledge gained from an assessment will return value in many ways:

- The audit itself probably will reveal a number of low- or no-cost adjustments that immediately pay for themselves. One good example is shutting off steam mains that serve abandoned process lines.
- Armed with knowledge of its energy consumption, a manufacturer has a lot more leverage to negotiate contract terms with marketers through whom fuel commodities are purchased. Marketers earn fees based on the amount of fuel they broker; an uninformed energy consumer gives the marketer a blank check.
- Energy consumption information provides a baseline for quantifying the actual impacts of energy improvements. Managers can't claim victory if they don't know where they started.
- Baseline energy data help decision-makers prioritize improvement opportunities by targeting the prime movers that consume the most fuel.
- Knowing fuel consumption is essential for accurately determining the operating costs of individual pieces of equipment — and thus for understanding the need for upgrades, replacement or fuel-switching.
- The assessment also provides an inventory of emissions sources. It will present and prioritize opportunities to reduce the risk of non-compliance with emissions regulations.

The energy assessment is a blueprint — a business plan — for improving plant performance through smart energy choices. As the term "business plan" implies, outcomes aren't accomplished all at once but as a part of a measured process. A business plan will identify resources, milestones and planned outcomes. Perhaps most importantly, an energy assessment describes how a plant manager can make energy decisions that contribute directly to business goals.

TACKLE ORGANIZATIONAL OBSTACLES

For energy cost control, aptitude plus operational style equals results

A company will invariably have competing priorities and turf issues between departments, and key decision-makers with different influence. Unless addressed, these factors may limit what's possible for energy cost control. Mike White, Sunoco Chemicals' vice president of operations, says energy management (EM) capability reflects the attributes of an organization's people and management systems.

Ideal people attributes: Strong technical skills in engineering, finance and data management. Can-do work ethic with the ability and willingness to learn and change. Ability to communicate the impact of their tasks in business terms. Balanced respect and expectations between management and staff.

Ideal systems attributes: Multi-year, organization-wide planning discipline. Performance benchmarks, goals and staff accountabilities. Focused, ongoing leadership support for goal attainment. Information systems for collecting and communicating performance metrics. Cooperation both functionally and fiscally across departmental lines.

Together, people and systems attributes determine an organization's operational style which shapes EM strategies that determine the quality of EM outcomes. Strong people attributes allow an organization to at least initiate energy projects on an episodic basis. Strong systems allow EM to become a durable process that gives ongoing support to the core business agenda. Let's look at some examples of how organizational attributes characterize operational style.

Style — Fire drills: Maintenance agenda is reactive, not proactive. Problem definition and solutions are local; little or no coordination across departments or facilities. Strong, influential individuals are key to improvements — optimizing results for their department, if not for the whole organization.

Style — Excellence: Focus on continuous improvement. Top management demands and supports departmental collaboration by creating incentives to cooperate. Able to pursue opportunities that are best for the organization as a whole.

Style — Chaos: Questionable management ability to detect and react to business environment changes. Uncertain leadership focus and/or control. Basic business viability is in question.

Style — Bureaucracy: Manipulate statistics to make results look better on paper than in reality. Short-term results take precedence over long-term. Delay action, let others "deal with it." Tacit undermining of corporate control.

EM strategies reflect organizational attributes.

Strategy — Capital projects: Bet on a series of hardware investments to solve problems. Look for solutions that you install and carry on business-as-usual. Or pursue quick and easy one-time projects from operating budgets. May or may not document best practices and making these standard operating procedures.

Strategy — Continuous energy improvement: Benchmark and inventory energy use. Implement a multi-year business plan for action. Set goals, accountabilities, and incentives. Document and replicate behavioral, procedural, and technology solutions. Measure progress and document impacts. Demonstrate contribution to business performance.

Strategy — Do nothing: Make no moves with respect to EM. Simply pay utility bills on time.

Strategy — Price shop: Declare that "we're already as efficient as we can be"… non-technical corporate leaders probably won't know the difference. Switch fuels or shop for lowest-priced fuel — this alone may satisfy top management.

Continuous energy improvement helps identify, justify, implement and sustain the most savings potential. Ongoing progress reports show EM's support for core business objectives.

Well-chosen capital projects can save operating expenses. Financial risk is reduced if staff skills and operating procedures also are improved. Quick and easy projects can be pursued in-house. But, gains are temporary if energy discipline isn't a documented part of standard operating procedure.

Price shopping prevails when energy expenditures are perceived strictly as a price-driven issue. Short tenures allow managers to deny or ignore energy waste if the consequences are expected to accrue to the succeeding manager.

Energy solutions often require unprecedented coordination.

Doing nothing may be acceptable if the company is extremely profitable and earnings targets aren't threatened by energy costs. Meanwhile, companies with management turmoil may have no choice but to do nothing about energy expense. EM outcomes depend on strategy which depends on operational style which relies on organizational attributes.

PUT ENERGY **INTO PEOPLE ISSUES**

It's time for a little industrial energy waste amnesty

A lot of people in the chemicals industry are afraid to admit that they waste energy. Consider the typical comment, "We are already as efficient as we can be." Top managers, especially, have no practical choice but to say this. If a facility manager says "Sure, we have a number of inefficiencies, and they've accumulated under my watch," how long can he expect to stay employed? Admitting to energy waste is an embarrassment with potentially dire consequences.

Wasted energy is wasted money — a cost that the U.S. chemicals industry can no longer afford to ignore. The efficient use of steam, process heating, compressed air and other common plant utilities is the key to saving energy and money. This is a human endeavor as much as it's technical. The latter should be straightforward — there's a ton of technical how-to references available, especially at www.eere.energy.gov/industry. But all of those resources are useless if people aren't willing to admit they need them.

Manufacturing leaders need to declare "amnesty" for plant personnel who are on the front lines of energy use. People shouldn't risk losing their jobs because of yesterday's energy decisions. These causes took time to manifest, and are never limited to one individual's actions. Similarly, energy solutions often require unprecedented coordination of people across facility departments. Effective energy improvements really depend on the quality of management systems.

Most industrial facilities, as well as their production processes and procedures, were designed when energy was relatively cheap, and therefore not a strategic concern to business managers. Certain work habits evolved on the facility floor that saved time and effort and had little financial consequence when energy costs were less significant. However, the trade-offs between time and money change as energy prices escalate and become more volatile. Equipment efficiency and reliability deteriorate through years of use. At the same time, new, higher-efficiency replacement equipment becomes available. These changing conditions and opportunities force facility managers and their staffs to rethink their approaches to energy use.

Depending on the facility, 30% to 50% of the potential energy savings can come from better management of current assets and operating procedures (see www.eere.energy.gov/industry/pdfs/energy_opps_analysis.pdf and www.steamingahead.org/library/enbridge05.pdf).

Industry's decision-makers need to be made aware of the benefits and the hurdles to energy efficiency. Specifically:

- Top managers must recognize and untangle organizational barriers that prevent departments within their facilities from collaborating to achieve potential energy savings. For example, it's common for equipment operators to never see invoices for fuel and power consumed by their department. Accounting staff may not fully understand how energy consumption is related to invoices they review. Disconnects like this show how energy waste can go unchecked.
- Finance people need to understand the monetary impact of energy improvements. Financial payback analysis often fails to account for energy improvements' indirect impact on productivity, safety, product quality, and other non-energy benefits.
- Facility maintenance staff need access to training and analytical tools that will help them to diagnose energy problems and evaluate solutions.
- Many procurement professionals need a better understanding of energy use and its relationship to equipment selection and operations. Equipment purchased at the lowest initial cost will often prove to be more costly to own over its economic life, due to excessive operating and maintenance requirements. Procurement directors need to develop total-cost-of-ownership criteria.

Revised procurement specifications can prevent decisions that inadvertently erode energy efficiency. Engineering and procurement staff can collaborate to make standards for energy-efficient equipment purchases. They can establish a list of commonly-replaced equipment that's pre-approved to meet efficiency standards. This list can be a reference point both for staff seeking to order replacement equipment as well as for vendors who serve the facility.

NEXT GENERATION CARBON **SYNCHRONOUS BELTS**

Making Roller Chain Obsolete?

Introduction

Is a synchronous belt drive system really any match for a roller chain drive in high-torque applications? Thirty years ago one might have answered no, but that's not the case today. New materials, construction and designs have led to synchronous belt drive systems that outperform equivalent size roller chain drives in a wide range of applications, yielding cost advantages for users, and greater design versatility for engineers.

Content

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- Six Key Problems with Chain Drives
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- Addressing Chain Drive Problems
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- Resources

Roller Chain History and Development

The chain drive is one of the oldest forms of power transmission known to man. There is evidence of chain driven water lifts as early as 225 B.C. Leonardo da Vinci's sixteenth century sketches of a chain drive bore a strong resemblance to the modern silent chain. However, real advancements in the use of chain drives in power transmission applications began in earnest during the late 1800s with development of cast iron detachable chain, quickly followed by cast pintle chain—the forerunner of chain as we know it today.

In the beginning of the twentieth century, chain expanded into applications such as bicycle and automobile drives, both for transmitting power to the drive axle and for synchronizing cam shafts. Industrial applications soon followed; by 1913 the roller chain industry was one of the first in the world to publish user standards.

The popularity of chain drives today stems from their ability to transmit high torque, at relatively low cost, while utilizing readily available stock components. Furthermore, until recently, chain drives were the only practical method of creating low speed, high torque applications that would work over a wide range of ratios with virtually unlimited center distances.

Both equipment manufacturers and maintenance departments in today's industrial plants have used chain drives for years and are very comfortable with the technology; but this reflex reaction has its down side. Chain drives have inherent weaknesses that have long been accepted in the belief that no other practical option existed. In fact, a practical alternative does exist in the form of the modern carbon synchronous belt drive.

Anatomy of a Roller Chain

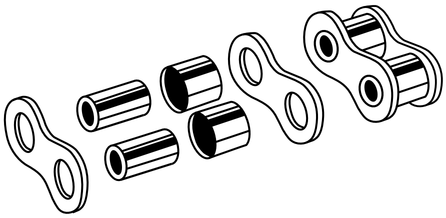


Figure A. Standard Roller Link

Roller chain consists of alternating inside and outside links that are interconnected. Inside links are generally comprised of six pieces. *Bushings* are press fit in sets of two into two *roller link plates* so that they are spaced apart appropriately, and remain parallel. Free turning *rollers* are included on the outside of the bushings, and are restrained between the two roller link plates. This entire assembly is called a *roller link*, as illustrated in Figure A.

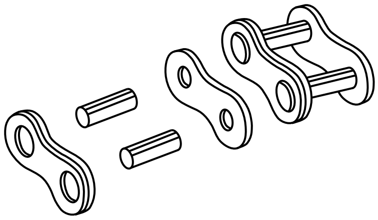


Figure B. Standard Pin Link

Each roller link is joined to the next by outside links that are generally comprised of four pieces. *Two pins* that pass through the bushings of adjacent roller links are either press fit or held in place with cotter pins between a pair of *pin link plates*. These pin link plates separate the adjoining roller links at the appropriate distance. This assembly is called a *pin link*, as illustrated in Figure B. When in operation, the rollers engage into the teeth of mating sprockets to transmit power and motion.

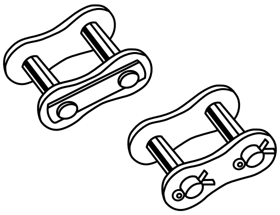


Figure C. Spring Clip and Cotter Pin Connecting Links

Connecting links join the ends of a length of roller chain to form a continuous or endless chain. Connecting links look much like pin links, but with one pin link plate detachable. Spring clips are used to retain the detachable pin link plate onto the pins in roller chains up to the #60 size. Roller chains in the #80 size and larger use cotter pins through the pins instead of spring clips. (See Figure C.) In some heavy duty roller chains, pin link plates are press fit onto the pins. Connecting links add two pitches to a length of roller chain, so that the total number of rollers remains even.

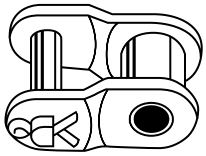


Figure D. Offset Link

Offset links also join the ends of a length of roller chain, but add only one additional pitch, making the total number of rollers odd instead of even. An offset link appears like a normal roller link on one end, but the pin link plates are flared outward so that the other end can connect to the roller chain via a cotter pin. (see Figure D.) Offset links are generally used in conjunction with connecting links to connect the roller chain to the roller link-like end of the offset link.

Individual connecting links reduce the normal power rating of roller chain by up to 20% (up to 35% for offset links), depending on the manufacturer. This reduction in the maximum allowable load must be taken into account when designing or evaluating roller chain drive systems. The strength-decrease ratio can be greatly reduced by using *tap-fit connecting links,* or avoided altogether by using *endless roller chain,* which is produced by the manufacturer in specific lengths, but available only on a made-to-order basis. The vast majority of roller chain is sold in non-endless form and joined together using connecting links.

Six Key Problems with Chain Drives

A roller chain drive today is not really much different than it was 50 years ago. While gains have been made in horsepower ratings, increased operating life, reliability and reduced maintenance, these improvements are what you might expect from a mature technology. The real issue is that chain drives are a high maintenance drive system. There are six key problems associated with chain drives.

1. Stretch or Elongation

Roller chain wear results in stretching, or elongation. Elongation is caused primarily by pin/bushing wear due to joint articulation during sprocket entry and exit, as illustrated in Figure 1.

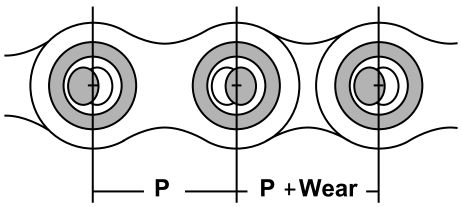


Figure 1. Roller Chain Pin and Bushing Wear

Pin/bushing wear results in pitch elongation as illustrated in Figure 2. Pitch elongation increases interference between the roller chain and sprockets, and results in a cumulative effect over the entire length of roller chain. Manufacturers recommend roller chain replacement when elongation reaches approximately 3%.

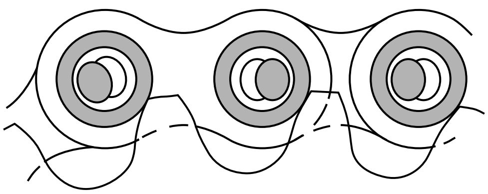


Figure 2. Elongated Roller Chain Meshing With A Sprocket

When the chain has "stretched" 3%, it is heavily worn. All the components of the chain (rollers, pins and bushings) have lost their case hardened surface, and failure is imminent. In everyday terms, what does 3% "stretch" mean? It means that maintenance personnel will have to adjust the chain tension several times over the life of the drive. To be more precise, a 100-inch (254 cm) chain drive will require about 1.5 inches (3.81 cm) of center distance "take-up," which equates to 3 inches (7.62 cm) of apparent chain stretch.

2. Lubrication

Lubrication is absolutely essential for reasonable chain and sprocket life expectancy. Proper lubrication reduces the wear on all moving surfaces of the chain, and helps cushion the drive from the impact of shock loads. Thus in designing or selecting a chain drive, the method of lubrication is every bit as important as any other drive design factors being considered.

The loads and speeds under which the chain drive operates determine the lubrication system required. The higher the speed, the more sophisticated and costly the lubrication system. On many drives it is not uncommon for the lubrication system to cost considerably more than any other component.

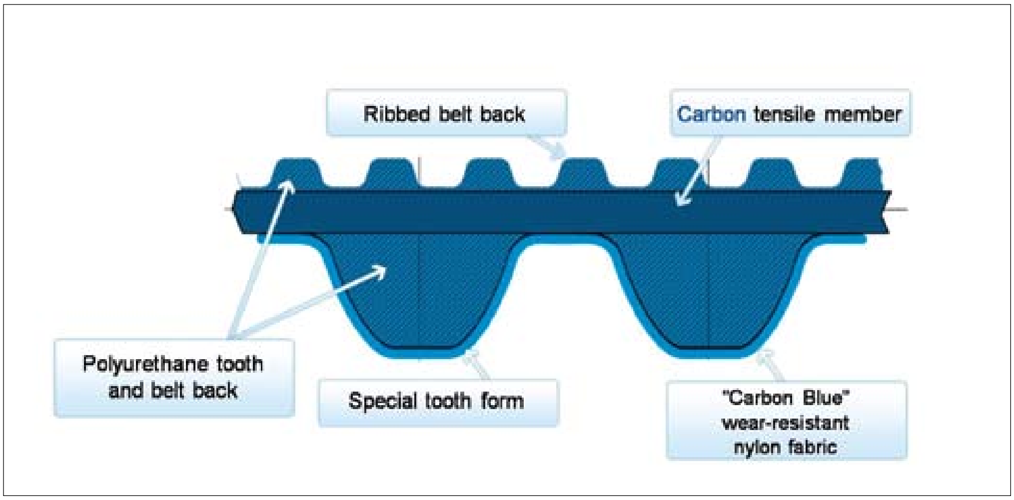
Even without a sophisticated lubrication system, it is essential that chain drives be enclosed in many areas of a plant, to avoid contamination of the finished product. For this reason, some plants choose not to lubricate certain chain drive applications, even though the chain industry estimates that a non-lubricated chain will wear up to 300 times faster than one properly lubricated.

3. Speed and Ratio Limitations

Roller chain is predominantly used for low speed, high torque applications. Capacity starts to decline between 2,000 to 3,000 feet per minute (610 to 914 meters/minute). For higher speed applications, silent chain and HV chain are used. Silent chain capacity will peak at about 5,000 ft/min (1524 m/min), while HV chain has a peak of approximately 6,500 ft/min (1981 m/min).

There is a price to pay for this higher speed. Silent chain drives will cost 4 to 5 times more than standard roller chain drives, and HV is 30% to 35% more expensive than silent chain. In addition, both require sophisticated lubrication systems as well as proper chain cases, seals, etc.

Another problem arises in the servicing of these drives. Because there are so many variations of silent chains, some with center guides, double-center guides, side guides, or various combinations of all of the above,



rarely are the sprockets for silent chain stock items. Made-to-order products are very costly and have long lead times, all of which makes these drives rather undesirable, unless there are no other options.

Roller chain drives are capable of speed ratios as high as 12:1. However, single-strand roller chain drives with speed ratios above 7:1 are not recommended in order to maintain an adequate wrap angle on the small sprocket. For maximum service life with speed ratios above 5:1, compound (multiple stage) drive systems are recommended. Roller chain drives with high speed ratios should have at least 120° of wrap on the small sprocket so that $^1/_3$ of the teeth are in mesh.

4. Chordal Action

Another major problem with roller chain drives is the variation in speed or surging caused by the acceleration and deceleration of the chain as it goes around the sprocket link by link. This variation in speed is called *chordal action* or *polygonal effect*. It starts as soon as the pitch line of the chain contacts the first tooth of the sprocket. This contact occurs at a point below the pitch circle of the sprocket. As each roller engages with a sprocket tooth, the link plates remain rigid and the pitch line momentarily rises and falls until the next roller engages the sprocket. This rising and falling of the pitch line results in rhythmic velocity changes, which translate into tension changes, or vibration, during drive operation (See Figure 3). To further compound the problem, this chordal effect will be transmitted through the entire drive system, affecting the chain, the sprockets, bearings and seals, as well as the driven component.

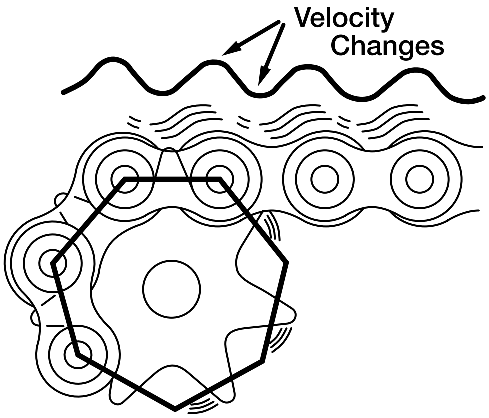


Figure 3. Chordal Action or Polygonal Effect

Chordal action is inversely proportionate to the number of teeth on the sprocket. As the number of teeth in the sprocket decline, the variation in the chain speed increases dramatically. For example, the velocity variation for a 10-tooth sprocket is approximately 5%, a 15-tooth sprocket is about 2%, and a 20-tooth sprocket is about 1%.

5. Shock Loading and Backlash

Shock loading and backlash can cause substantial damage to all components of the chain. As the chain and sprockets wear, the combined impact of shock loading and backlash will result in higher maintenance. This problem becomes even more complex because, contrary to manufacturers' recommendations to replace sprockets when replacing chain, few maintenance departments actually replace the sprockets until they are noticeably worn. This will dramatically shorten the life of the replacement chain.

6. Maintenance Cost

While initial costs of roller chain drives can be quite low, the cost of maintaining these drives can be substantial. In order to keep equipment running, it is absolutely essential that chain drives are lubricated and retensioned on a regular basis. The labor costs to perform this "regular" maintenance, along with the associated downtime and lost productivity, represent a significant investment in time and money.

The Synchronous Alternative

The engineers who developed the original timing belt, which was a light duty rubber synchronous belt for the sewing machine industry, had no idea that their original concept would someday have the capacity to meet and exceed the ratings for chain drives as well as heavy duty V-belts. New designs, materials and construction have yielded a belt drive system with performance characteristics that rival chain drives.

History and Evolution

Synchronous belt design underwent substantial development since the 1940s, much of it centered on overcoming the problems associated with chain drives. Early synchronous belts could not handle the torque of chain drives at low RPMs. Second generation synchronous belts, known as HTD belts, were developed in the 1970s to displace chain drives, but they were not a practical alternative in most low speed, high torque applications, because the belt had to be 4 to 5 times wider than the chain, and it cost significantly more. It took another 15 years for the materials and technology to evolve to a stage where a synchronous belt could compete with a chain drive. The first of these belts, the Gates Poly Chain® GT® belt, incorporated a patented curvilinear tooth profile that minimized meshing interference, while decreasing backlash by 45-50% over the HTD belt, and substantially more over roller chain. Made with polyurethane compounds combined with aramid fiber tensile cords, this belt provided a truly suitable replacement for many chain drives.

The Gates Poly Chain GT belt underwent several evolutions in design since its introduction over 20 years ago. The latest evolution incorporates a carbon fiber tensile cord that gives the belt greater strength, flexibility, moisture resistance and power density.

Anatomy of a Carbon Synchronous Belt

Unlike the many components that make up a roller chain, which lead to wear and high maintenance, the carbon synchronous belt is a single integrated unit with no maintenance requirements.

Why Carbon Cord?

Research and development surrounding carbon fiber has progressed steadily over the past three decades. First used by NASA in rockets and space capsules, carbon fiber is now a material of choice in commercial aircraft design, even superceding metallic materials in certain critical areas. Gates has pioneered the use of carbon fiber in a dynamic application, in the tensile member of a synchronous belt. This patented carbon cord design gives the belt performance attributes, including:

- High flex fatigue resistance (better than steel, glass and aramid fibers)
- High modulus (pitch fit stays constant at various loads)
- Dimensional stability (negligible elongation under load)
- High strength to weight ratio
- Environmental resistance (no degradation from water, oil, most contaminants)
- High power density for more compact drive designs

Addressing Chain Drive Problems

Carbon synchronous belt technology gives designers and users a synchronous belt drive system that can exceed roller chain capacities while maintaining the same dimensional characteristics. On a cost comparison basis, a Poly Chain® GT® Carbon™ belt drive will cost approximately one-third more than an equivalent roller chain drive initially. Over the life of the drive, however, the synchronous belt drive system will cost considerably less, considering the expense of maintaining the chain drive and the more frequent need to replace chain and sprockets as they wear. In testing and in field applications, Gates Poly Chain GT belts lasted three times longer than chain, and the sprockets lasted ten times longer than chain sprockets.

No Stretch or Elongation

As previously mentioned, the 100 inch (254 cm) chain requires about 1.5 inches (3.81 cm) of center distance takeup. A similar length carbon synchronous belt requires 0.04 inches (1.016 mm) over the life of the belt. The need to tension a carbon synchronous belt drive on a regular basis is virtually eliminated.

No Lubrication

A carbon synchronous belt drive requires no lubrication. Without the need for lubricant and lubrication systems, as well as the elimination of ongoing problems associated with contamination of the finished product, leaking seals and lubricant disposal, a carbon synchronous belt drive will yield a sizable annual saving.

Wide Range of Speed Ratios

Carbon synchronous belts will work well over a wide speed range, from the slowest speeds associated with roller chain, to the high speed applications common to silent chain and V-belt drives. The speed limitation for a carbon synchronous belt drive using standard cast iron sprockets is 6,500 ft/min (981 m/min). However, with made-to-order sprockets, speeds as high as 10,000 to 12,000 rpm 3,048-3,658 m/min) can be achieved with stock belts. Stock ratios available with off the shelf components go as high as 10:1.

No Chordal Action

Having a constant angular velocity, carbon synchronous belt drives are much smoother running than roller chain. The belt's modified curvilinear teeth enter and exit the sprocket grooves cleanly, eliminating speed variation and vibration as the pitch line of the belt moves around the sprocket relative to the pitch line of the sprocket. This single attribute will improve the performance of bearings and seals, as well as all associated equipment. In addition, it will eliminate the transfer of related shock and vibration to the finished product.

Handles Shockload

Because a carbon synchronous belt is manufactured in a one-piece construction, without an assortment of pins, rollers and bushings common to every link of a chain drive, shock loading is handled exceptionally well.

Lower Cost of Maintenance

Maintenance is virtually eliminated with carbon synchronous belt technology. Assuming that the belt is properly installed, it will never need to be retensioned. No lubrication is required. The absence of chordal action makes the belt smooth-running, reducing wear and tear on other drive components. There is no metal-to-metal wear.

Conclusion

Roller chain will continue to play a strong role in industry, for example, in extremely high-temperature applications, in applications that require attachments to the chain to perform a specific function, or in those that require an extremely long center distance that would be physically impossible to do with belting. However, don't assume that roller chain is the only viable alternative for high torque drives. Technological advances in synchronous belt design, materials and construction have now reached the point where these drives can match roller chain width-for-width in a wide range of applications, with the added advantage of a competitive initial cost and a minimal ongoing cost of maintenance.

Additional Resources

Engineering assistance is available from Gates Corporation. Contact the Gates Product Application Helpline, (303) 744-5800, or email ptpasupport@gates.com. For application-specific information on the Gates Poly Chain® GT® Carbon™ belt drive system, go to www.gates.com/nothingtougher.

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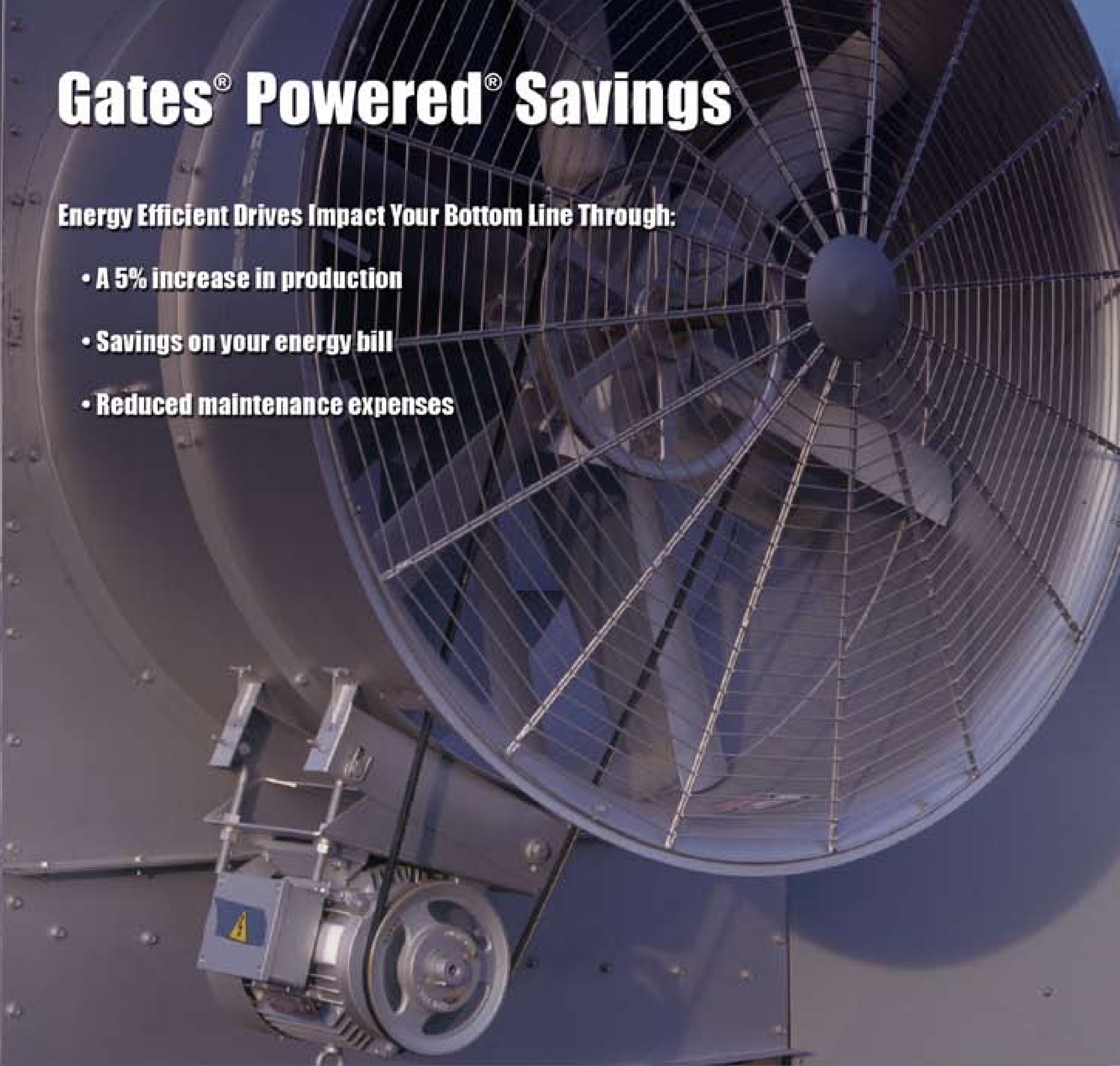

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