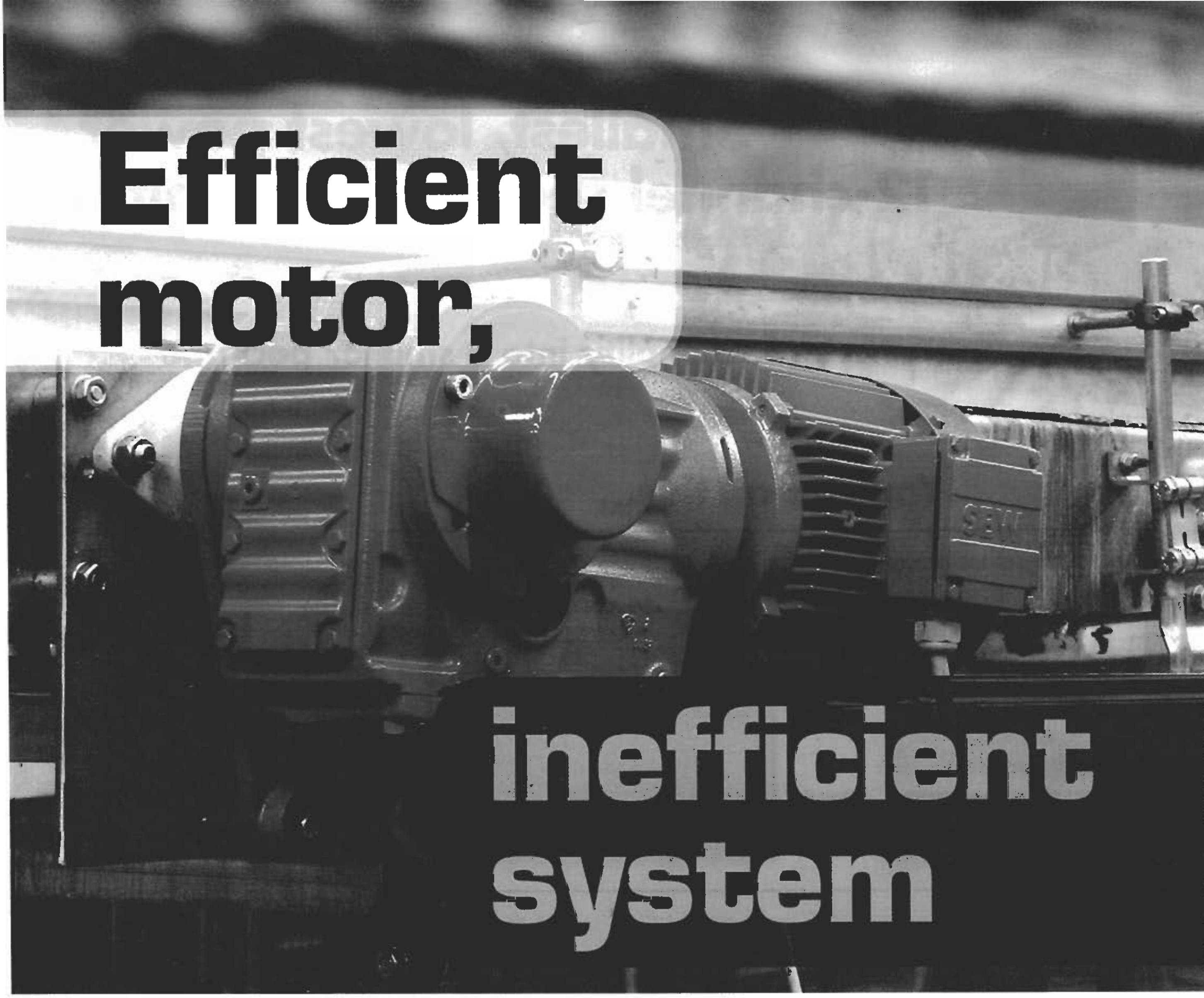
Efficient motor, inefficient system



Other elements in the drivetrain can swamp out the effects of super-efficient induction motors.

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Everyone wants to save energy. It's the "green" and "cool" thing to do. And the government may soon pay you to replace inefficient motors with new, energy-efficient NEMA Premium versions.

So, then, you might think that buying a premium-efficient motor is a no-brainer. But you would be overlooking something important: An energy-efficient motor is only one piece of the puzzle when it comes to saving energy. While premium-efficient motors do help reduce energy usage, they are by no means the cure-all to every energy consumption problem.

There are a number of misconceptions that surround energy-efficient motors. So it is interesting to explore some of them to be sure money invested in this area is spent wisely.

For one thing, extra efficiency doesn't always bring savings. Efficiency is a property, much like a color, or a material type; a value that doesn't change much. The Dept. of Energy certifies that a motor meets the "Premium" standard established by NEMA, based on that motor's ability to meet certain efficiency targets. So a NEMA Premium motor from one manufacturer will likely bring basically the same efficiency as a NEMA Premium motor from another manufacturer.

But simply installing a premium-efficient motor doesn't automatically save money, for several reasons. For example, your new motor may only be a few percentage points more efficient than the one it replaces; in cycling or intermittent-duty applications, the recognized savings could be so small as to be outweighed by the higher cost of the new motor.

It's important to look at the entire drivetrain when searching for ways to improve efficiency. It is possible that other parts of your drivetrain may be so inefficient that their effects swamp out the impact of a more efficient motor. And some kinds of energy efficient motors may not be well-suited to saving energy in your type of application, e.g. where there is high cycling. All in all, it's critical to evaluate your entire drivetrain for energy efficiency and remember that energy-efficient motors are just a single part of the efficiency equation.

A motor is only one component in the drivetrain. (And, truth be told, motors for some time have been comparatively efficient.) Each component in a system will inherently have some inefficiency, and these energy losses multiply to provide an overall system efficiency. Just one component that is relatively inefficient will quickly drag down the rest of the system.

Consider a theoretical example where six components in a drivetrain each have an almost-impossible efficiency of 99%. The product of the six 99%-efficient systems is 94.2%. Thus even in this example with six components of ideal efficiency, you still lose almost 6% of the energy that you started with.

Now, consider a more realistic example having six elements with efficiencies of 98, 96, 85, 75, 90, and 98% respectively. The 85% figure is pertinent because it corresponds to the efficiency found in older pre-Energy Act induction motors. The 75% figure is typical of geared drive trains. There are ohmic losses associated with wiring and other electrical components in the chain, as well as capacitive losses in the cabling. The product of the six efficiencies is 53.5%.

As an exercise, substitute the efficiency of a new NEMA Premium motor (92%) for that of the older pre-Energy Act motor. The new product of the six efficiencies becomes only 57.3%.

The exercise illustrates that mere substitution of a NEMA Premium motor in this case still results in a system that wastes over 45% of the energy going in. You can also see that substitution of a premium-efficient motor will boost system efficiency by 4%.

The lesson to be learned here is that less efficient components in the drivetrain lengthen the time it takes to recoup the investment made in a premium-efficient motor. Unless you factor these efficiencies into your plans, you may be disappointed in the length of the payback time.

This brings us to the myth that replacing the motor will automatically make a manufacturing line more efficient. This is actually true, but the improvement in efficiency is less than you might expect. Replacing some of the other components, as well as the motor, can provide some substantial efficiency gains, however.

Consider, for instance, replacement of the gearbox as well as the motor. Worm gear units, which are installed in most manufacturing environments, are inherently inefficient, as the gears essentially slide against one another. There are instances in which worm drives are essential (e.g. for withstanding heavy shock loads, or providing back-driving resistance). But in many applications a helical-bevel gearbox, which operates in a rolling-contact manner, will be a much better choice.

Return to the previous "real world" six-element example and replace both the motor AND the gearbox. Use of a 92% efficient motor and a 95% efficient gearbox brings the efficiency of the overall system to 72.5%. That is a double-digit efficiency gain of nearly 20%. A change of transmission elements from a V-belt to a positive engagement method, or even to a direct-drive method, brings even higher efficiency gains.

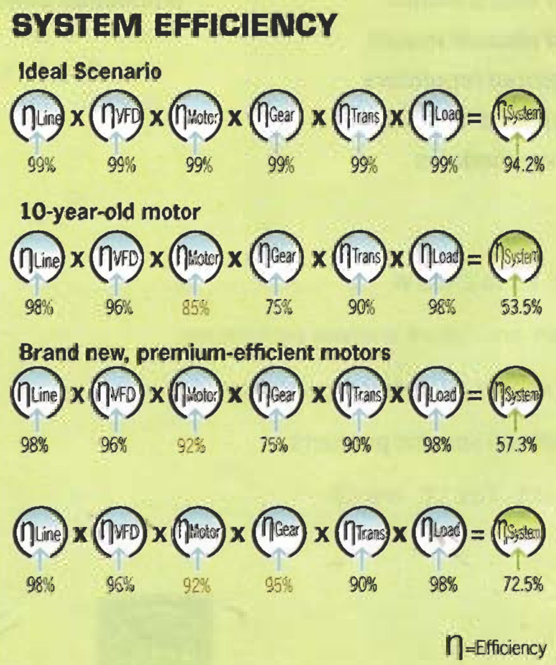
There is also a misconception that premium-efficient motors are appropriate for saving energy in all motor applications. Again, it actually depends. Most premium-efficient motors used in continuously-running applications will begin to show at least modest energy savings (depending, as we have shown, on the other elements

Heat and high-cycling motors

Starting a motor produces a great deal of heat in the windings. This heat is proportional to the current required to start the motor. In many premium efficient motors, the starting current is much higher than in standard efficiency models. Unless this heat is removed in some way, it will build up and cause motor failure.

Once a motor is started and running, the fan moves air across the motor windings to cool them. But, if the motor is stopped before this happens, heat dissipation takes much longer.

In high-cycling applications, frequent starts produce a great deal of heat, and poor air circulation rapidly leads to heat build-up. A motor's ability to manage this heat is what determines the allowable number of starts, or cycles, per hour.



A point to note about the overall efficiency of a system is that it is equal to the product of the efficiency of each element in the chain between input power and output work. It quickly becomes clear from these examples that over 45% of the energy going into a typical the system is lost because of non-ideal components. It is also clear that replacing a motor with a premium-efficient model saves only about 7% when other, less efficient components in the drivetrain waste energy. Sometimes the replacement of a gearbox or other drivetrain elements with more efficient versions will have a bigger impact than a more efficient motor.

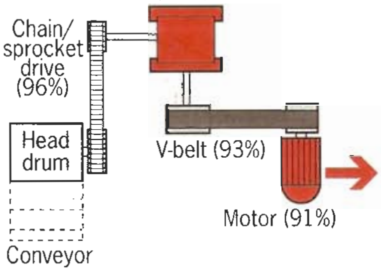
Which gear?

Worm gear reducers can have an efficiency range of 50 to 88% percent, depending on the number of starts (teeth) on the worm gear. Even the most efficient worm gears have only 88% efficiency, largely because of the sliding nature of the gear contact. Designers might instead consider moving to helical bevel gear reducers which lose only about 1.5% of efficiency for each stage of their gearing; a three-stage helical bevel gearbox would have a 95.5% efficiency rating.

In the worm gear/bevel gear comparison shown here, we assume a 20-hp motor operated 16 hr daily for 250 days annually in an application requiring the delivery of 9.1 kW to a conveyor head drum. The cost of energy is assumed to by $0.10/kWh and the motor in the standard example is a high-efficiency model as recognized in the EPAct of 1997. The motor in the optimized case is a premium efficiency model per EISA 2007.

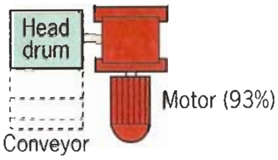
All in all, a switch to a more efficient motor/gearbox combo in this example boosts efficiency by 57% and uses 23.6 MWh less energy annually, saving about $2,360 per year.

Standard
Worm Gear Unit (69%)



Overall drive train efficiency= 56.1%
power required from utility = 16.2kW
Energy used = 64.8MWh per year
Cost of energy= $6,480 per year
Power loss to inefficiency = 7.1kW

Optimized
Helical-Bevel Gear Unit (95%)



Overall drive train efficiency= 88.3%
power required from utility = 10.3kW
Energy used = 41.2MWh per year
Cost of energy= $4,120 per year
Power loss to inefficiency = 1.2kW

in the drivetrain). But motors used in high-cycling applications may never achieve the efficiency gains that a premium-efficient motor is capable of. This is partly because the start-and-stop nature of the application fights against the rotor inertia, which tends to be higher in many premium efficient models than in ordinary motors. Hence, the extra investment in a high-efficiency motor may never be completely recouped.

That said, some NEMA Premium motors (such as DRP motors from SEW-Eurodrive) are engineered for high efficiency in high-cycling applications. These motors are designed for low rotor inertia, low losses, and less heat accumulation in the windings. These measures boost efficiency and allow for a high number (thousands) of starts and stops hourly.

A related issue is whether or not adding a variable frequency drive (VFD) will automatically make a manufacturing line more efficient. Actually, a VFD will initially reduce efficiency. The losses introduced by a VFD because of heat, electricity conversion loss and harmonics become part of the efficiency equation, resulting in a lower total efficiency.

The key to energy savings is smart control. By optimizing acceleration/deceleration ramps, slowing the motor, and turning it off when not in use, a VFD can optimize motor energy consumption. If you handle a motor with a VFD the same way you drive your car to save fuel, your energy consumption will drop similarly.

A VFD can also boost efficiency by recycling or sharing regenerating energy. When a motor is trying to stop a high-inertia load, it acts as a generator. All the kinetic energy stored in the machine must be removed. Connecting several VFDs through a dc link to a regenerative supply unit lets energy one drive regenerates power other drives. The regenerated energy feeds back to the mains if other drives don't need it.

In the absence of regenerative features, stored energy typically gets dissipated as heat from a braking resistor.

The bottom line is that motors account for, at best, one-sixth of the total energy-loss potential within an electromechanical drivetrain. What's more, they typically aren't even the most inefficient part of the system. Mechanical devices, such as external transmission elements, are much less efficient than electrical devices, so they are the first place to look to find large energy savings.

Moreover, you may actually be able to use a smaller motor and save money by revamping your entire drivetrain. You may be pleasantly surprised to find that upgrading your motor, drive, and gearbox, and eliminating external transmission components will boost system efficiency to a point where there is more motor power than you need. A lower-horsepower (and less expensive) motor may be able to handle the job.

For example, consider an application that needs 50 hp. If the system has an efficiency of 53.5%, the necessary motor must supply 50 hp/53.5% = 93.5 hp. Now consider the same system with an efficiency of 72.5%: 50 hp/72.5% = 69 hp. Thus the motor can be almost 25 hp smaller.

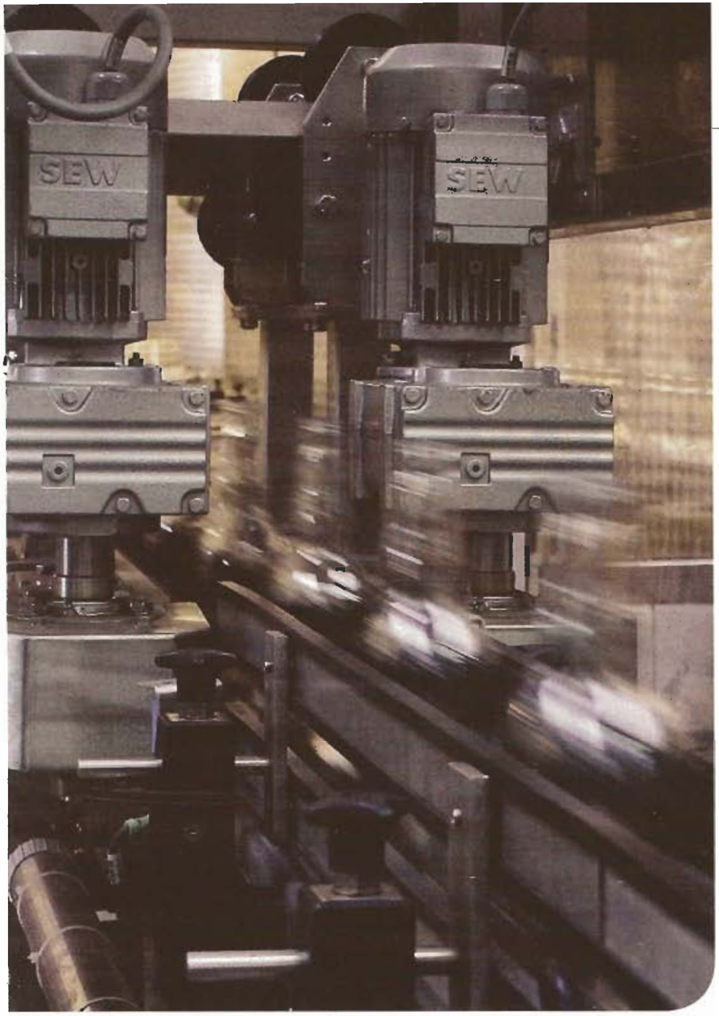
Designers should also understand that motors are most efficient when used with other drivetrain components from the same manufacturer. When the drive controller, motor, and gearbox are all engineered by the same company they are, by nature, designed to work well together. For example, integrating a DRP motor, helical-bevel reducer, and VFD from SEW-Eurodrive will provide dramatically higher energy savings than simply replacing the motor.

Though it may sound obvious, even an energy-efficient motor must be well-suited to the application at hand. Verify that the motor specifications fit the application, especially if the application involves cycling greater than 10 to 30 cycles per hour. If that's the case, use a premium- or high-efficiency motor designed for such an application with an integral brake, appropriately sized to the motor.

And of course, mechanical efficiencies matter, too. Worm gear reducers, which are attached to a large number of motors, can have an efficiency range of 50 to 88%, depending on the number of starts

Resources

SEW-Eurodrive,
www.seweurodrive.com/



The SEW-Eurodrive DRP NEMA Premium motor visible in this recycling application is noteworthy in that its internal construction is optimized to handle numerous stop-starts for applications characterized by 1,000 to 2,000 cycles per hour. It is also the only premium-efficient motor with built-in encoder and an integral brake.

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However, helical bevel gear reducers lose only approximately 1.5% of efficiency for each stage of their gearing; as such, a three-stage helical bevel gearbox would have a 95.5% efficiency rating. In addition, because of the drastically reduced friction inherent in the rolling contact of a helical bevel gearbox, the usable lifetime of such a system is many times longer than that of a worm drive system. Although helical bevel gearboxes have a higher initial cost, they save energy and will need replacement less often over the lifetime of the system.

Gearmotors eliminate even more efficiency losses. A gearmotor has rigid transmission elements, with the motor and reducer rigidly, permanently and precisely coupled and aligned. So the motor-to-gear connection has nearly 100% efficiency. By eliminating the friction and slippage associated with V-belts, pulleys, and even chains, you can quickly gain 12 to 15% more efficiency over the average flexible transmission system. (Plus, you'll save even more on the replacement and maintenance of belts.) **EE&T**