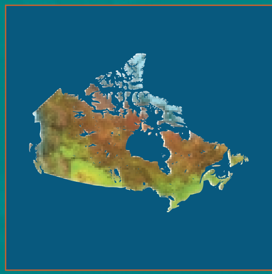
Canadian Industry Program for Energy Conservation
CIPEC

ENERGY-EFFICIENT MOTOR SYSTEMS
ASSESSMENT GUIDE



small adjustments
big savings

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Energy-Efficient Motor Systems Assessment Guide

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Energy-Efficient Motor Syste
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1 EFFICIENT MOTOR SYSTEMS MANAGEMENT

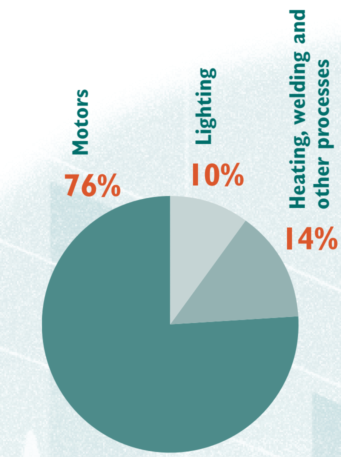
Efficient motor systems make a significant contribution to your bottom line

Motor systems consume more than 75% of a plant's electricity. Motors operate all types of process equipment and have a direct effect on your operation's productivity and product quality. Improved energy efficiency helps your business lower operating costs, be more productive and reduce greenhouse gas emissions that contribute to climate change.

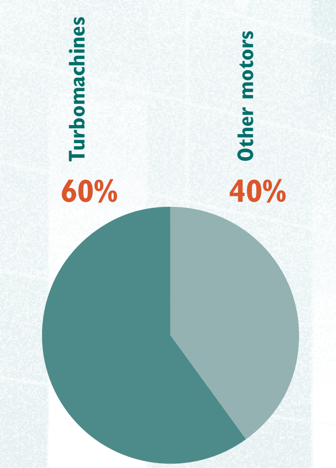
It makes good business sense to consider energy efficiency in the design and selection of equipment. Often, improving the efficiency of a motor system will uncover solutions to a number of production and maintenance problems. A motor system is defined as including all the components from the initial energy input to the final process use. Energy use defined in this manner reflects the power consumed per unit of product produced. Management of the motor system involves maximizing the value of capital assets and minimizing operating costs, while maintaining efficient and reliable production output. Effective motor system management develops synergies between preventive and predictive maintenance programs, equipment operation and process productivity to establish a repair/ replacement policy based on a commitment to energy-efficient equipment selection and operation.

Typically, the value derived from these benefits is more significant than the energy cost savings. Benefits can be obtained in the areas of productivity, reliability and cost reduction.

INCREASED PRODUCTIVITY	IMPROVED RELIABILITY	REDUCED COSTS
Greater control over process requirements	Scheduled downtime instead of breakdown maintenance	More efficient operation
Flexibility in meeting production requirements	Longer production runs between maintenance outages	Reduced maintenance costs
Reduced scrap and rework	Longer equipment life	Lower unit cost

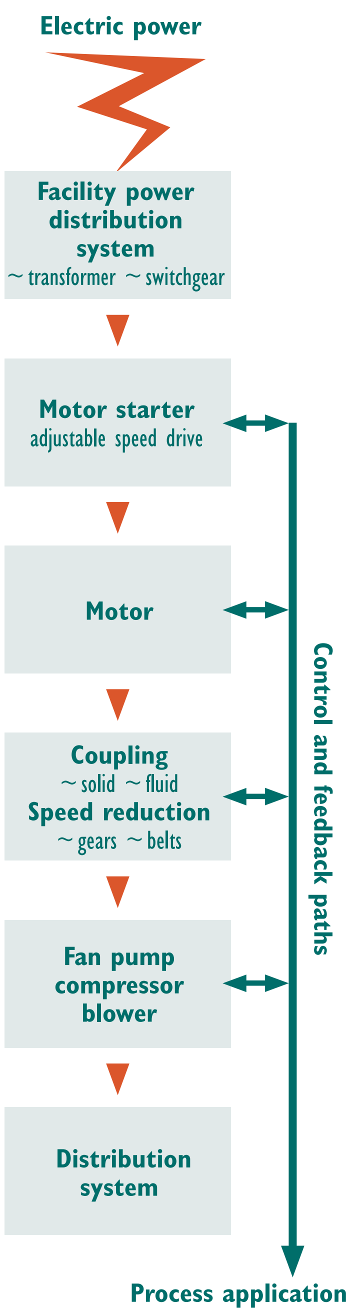


DISTRIBUTION OF INDUSTRIAL ELECTRICAL USE



BREAKDOWN OF INDUSTRIAL MOTOR TYPES

SYSTEM SCHEMATIC



1.1 ELEMENTS OF A MOTOR SYSTEM

Motor systems involve a number of components, as shown below. In every facility a number of systems can be identified, such as ventilation, process heating, refrigeration, boiler combustion air and compressed air systems. Common elements in all systems include power input, energy conversion equipment, control mechanisms and valued output meeting process demands.

The systems approach accurately and efficiently matches system output to industrial process requirements. This guide focuses on systems that consume most of the energy used in industry. These applications use fans, pumps and compressors to provide resources that meet specific performance requirements, which are necessary in order to keep productivity high.

APPLICATION	RESOURCE	PERFORMANCE REQUIREMENTS
Operate air-driven equipment	Compressed air	Adequate flow and pressure
Process temperature control	Hot or cold liquids/gases	Temperature differential, flow
Material handling, mixing	Fluid flow – liquid/gas	Maintain volume flow
Machine drives, conveyors	Motive power	Process-dependent speed/torque
Hydraulic power	Pressurized fluid	Adequate pressure and flow
Heating and ventilation	Airflow	Maintain volume flow

1.2 ECONOMIC CONSIDERATIONS

Life-cycle analysis can reveal new opportunities to increase profits

The energy consumed in your operation's motor systems directly affects your bottom line profit. Motor systems affect both variable and fixed costs. Although energy costs may not be a high percentage of your product cost, any reduction in these costs will increase your profit margin. For example, if your profit is 10% and electricity averages 4% of your product cost, then a 25% reduction in energy costs represents a 10% increase in profit at the same sales volume.

First cost versus life-cycle cost must be examined for each process application. Energy costs over the life of a motor or system are often many times the initial incremental cost of purchasing high-efficiency equipment. An estimate of the annual dollar value resulting from improved reliability, reduced downtime, lower operating costs and increased productivity should be included in any financial calculation. These benefits are often more valuable than the energy savings alone and should be considered when evaluating different energy-efficient solutions.

Comparisons are often simplified on the basis of the following:

- the incremental cost is the premium paid over that of a lower-efficiency component and should be used when a component is scheduled to be replaced; and
- the total purchase cost less the cost to rebuild the existing equipment to "as-new condition" is often used when considering immediate replacement of a functioning piece of equipment.

Industrial equipment remains in service for a long time. With good maintenance, a large motor (including rewinds) can last up to 25 years before it is replaced. Careful consideration for the selection of energy-efficient equipment should be made when evaluating new purchases to avoid losing these opportunities for efficient operation.

The most common methods to compare projects are

- Simple payback = cost of implementation ÷ average annual savings
- Net present value = calculation of value in present dollars of costs and savings over the life of the equipment. The value of the savings should be greater than the dollars invested.
- Internal rate of return = percentage return from savings compared with the cost of implementation. The percentage of return should be higher than the company's internal hurdle rate.

Determine which method is used by your company. Capital cost allowances and accelerated depreciation may further reduce the payback of energy-efficient equipment purchases.

When calculating electrical energy savings, be sure to include both demand and energy savings. The incremental cost of power should be used to calculate the payback from energy savings. The cost of power can be determined from your utility bill or rate card. Allocation of costs should be calculated on an average energy cost basis, by dividing total use by total energy cost. Savings from time-of-use rates and change-of-rate class should also be considered.

1.3 PRIORITIZING SYSTEM EVALUATION

Matching system capabilities with production requirements will yield remarkable rewards

The system approach accurately matches system flow and pressure output to process requirements. This approach can obtain energy savings of 20% to 50% compared with savings of 3% to 15% with component efficiency improvements. Various technical, operational and financial issues will need to be addressed. To get started, identify the people in your company's purchasing, maintenance, operations and planning departments who are responsible for ensuring that the plant operates smoothly. These people will need to work together and understand that all their departments can benefit.

In facilities that have many systems, the following guide can be used to set priorities:

- start with the systems that are problematic
- examine systems where motors or components are due for major maintenance or replacement
- identify motors that operate at least 2000 hours per year and are over 75 hp
- examine systems that have blowers, pumps, fans and compressors, especially where flow is controlled by throttling devices

The systems approach can be used to improve efficiency, and, more important, it can provide solutions to other problems experienced in the plant. Described below are typical responses to a common problem received from the plant floor about the lack of a plant resource, which in this case is compressed air. The principles apply to any motor system.

- Install more power: Purchase the lowest-cost 50% larger compressor, or double up using the existing unit for standby and peaking conditions. This is a high initial cost option (more energy is consumed).
- Component approach: replace or repair components not meeting original equipment specifications with the same or a more efficient model. The potential for savings is 15%.
- System approach: Carefully assess the problem and determine options to eliminate it, correct any deficiencies and properly size new, efficient components to meet process demands using the lowest efficient cost option. Potential savings are 20% to 50% or more.

At one company where the machine operators complained they needed more compressed air, the response was to fix hose leaks, reduce pressure from 125 to 110 psi, install a more efficient dryer and install a larger receiver for short-term peak loads. These measures allowed the company to replace the existing compressor with a smaller-sized efficient unit, resulting in a faster payback and higher energy savings than by replacing it with a larger unit. Added benefits included a potential for savings of 40%, improved reliability, better pressure control that improves product quality, lower scrap losses, increased equipment life, reduced employee frustration and better productivity since the receiver was located near the tools that required the highest pressure.

1.4 SEVEN STEPS TO MOTOR SYSTEM EFFICIENCY

1 Identify the problem or objective

It is important that at the start of the project the team consult with the people who operate the equipment in order to gain their support. Tasks to be conducted include a review of system documentation and definition of objectives; i.e., energy savings or process improvement. Identify whether problems experienced are sporadic or continuous, when they started to appear, and changes to production or plant operation, etc.

2 Gather information

Produce a line diagram that identifies all components and process loads that place demands on the system. Prepare a detailed description of the system documenting the type of motor system, operational requirements, motor controls and nameplate information. A site inspection will determine whether components are functioning and being operated correctly.

3 Measure system operation

Prepare a measurement plan that defines what is to be measured and under what conditions. Assess operational needs versus preferences. Compare measured data with design information.

4 Develop technical options

Develop alternative solutions, calculate savings and estimate cost to implement and determine financial and operational feasibility. Identify technical options to increase system efficiency and meet production needs.

5 Evaluate proposals

Evaluate the options, including system benefits, opportunities for improvement and recommendations. Involve expertise as required from contractors, suppliers or consultants.

6 Implement the project

Make the necessary changes and install the equipment. Once the project is installed, verify the savings with measurements and compare actual savings with calculated savings.

7 Communicate

Communicate progress to management and plant personnel. This will build support for further initiatives.

2 SYSTEM FUNDAMENTALS

The sum of the whole is greater than the value of the individual pieces

Each component in the system has its own efficiency. To achieve maximum overall system efficiency, each component should be selected to operate at its most efficient point of operation for the majority of the time the system is running. System efficiency should relate the amount of energy used to the useful work produced or number of units manufactured. If no useful work or product is produced, the system efficiency drops to zero. The total system efficiency at a given operating point is the product of each component's efficiency (E) in the system.

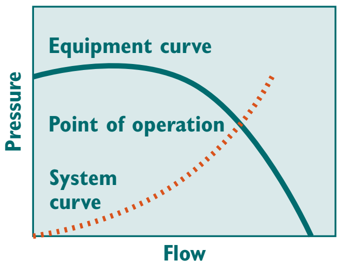
$$E_{system} = \frac{\text{system output}}{\text{total power input}} = \frac{\text{units produced}}{[\text{power required} / (E_{components} \times F_{system\ effect\ factor})]}$$

The system effect factor (F) is a multiplier that reflects the sum of friction and other losses of the distribution system.

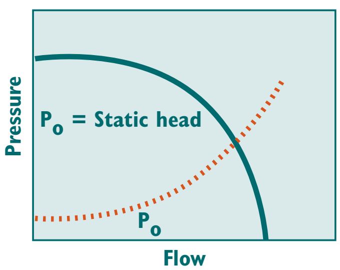
2.1 FACTORS AFFECTING MOTOR POWER CONSUMPTION

Motors provide torque to rotate fans and pumps at a specific speed. General rules of thumb imply that flow is proportional to the rotational speed of the motor, and power can vary as high as the cube of the speed. The system resistance curve (SRC) is used to determine how changes in flow affect pressure and is obtained by measuring and plotting the pressure or head at various system volume flow rates. The SRC can be superimposed onto turbomachine performance curves of pressure, flow, power consumption and efficiency. These curves can be obtained from the pump and fan manufacturers.

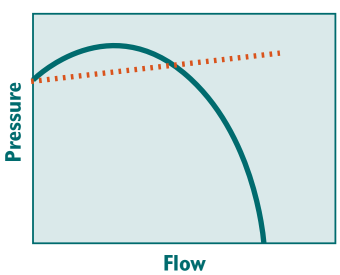
System curves will differ depending on the system design, and each SRC is unique. Determine the type of system you have at the start of the evaluation. The point of operation occurs at the intersection of the turbomachine performance curve and the system resistance curve. This intersection point determines the volume flow rate through the system.



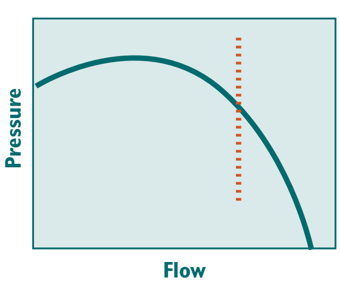
FIXED RESISTANCE SYSTEM
$P \sim Q^2$
FORCED-DRAFT FAN



FIXED RESISTANCE
WITH STATIC PRESSURE
$P \sim (Q^2) + P_o$
PUMP TO STORAGE TANK



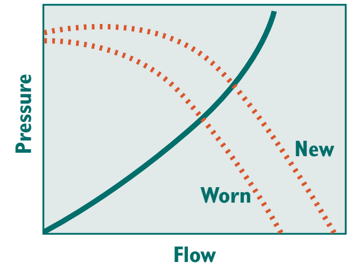
VARIABLE RESISTANCE
WITH CONSTANT PRESSURE
P = CONSTANT
INDUCED-DRAFT FAN



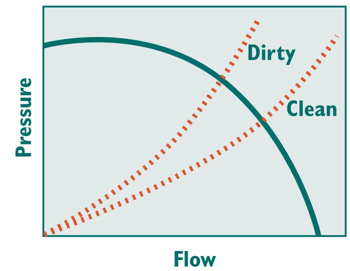
VARIABLE RESISTANCE
WITH CONSTANT FLOW
Q = CONSTANT
PNEUMATIC CONVEYOR

The point of operation can change due to

- change in turbomachine performance – worn impeller or casing, change in rpm
- change in system resistance – line extension, corrosion, holes or material buildup in ducts
- change in both system resistance and the turbomachine



CHANGES IN TURBOMACHINE PERFORMANCE



CHANGES IN SYSTEM RESISTANCE

2.2 DURATION CURVE OR CHART

Most systems will operate at different points of operation over the year due to changes in production volume, weather and type of product produced. The characteristics of the performance curve can be altered to meet system demand by using various control methods such as varying the rotational speed (adjustable speed drives), throttling the flow (increasing system resistance) or by changing the turbomachine characteristics (varying the pitch of the impeller blade). The load duty cycle is a curve or chart that represents the percent operating time versus percent maximum flow for each operating point. Applications with more than three operating points may be good candidates for adjustable speed drive technologies. Those with a few distinct operating points could benefit from the use of multi-speed motors. Constant flow applications operating at one point may require no flow control. Efficiencies and power consumption must be calculated separately at each point of operation and then totalled when doing the annual cost analysis.

2.3 AFFINITY LAWS FOR TURBOMACHINERY

In assessing various systems, affinity laws can be used to calculate how changes of one variable will affect other variables such as speed, flow, pressure and power consumption. Check with the manufacturer to determine how changes will affect the performance curves. In general where N = turbomachine rpm, Q = flow, P = pressure, hp = horsepower

$Q_2 \div Q_1 = N_2 \div N_1$ $P_2 \div P_1 = (N_2 \div N_1)^2$ $hp_2 \div hp_1 = (N_2 \div N_1)^3$

- For most turbomachinery, power consumption is proportional to the cube of the rotational speed; flow is directly proportional to the rotational speed. Dropping the speed by 20% reduces power consumption by approximately 50%.
- Trimming the impeller is a cost-effective method of reducing flow, pressure and power consumption where $Q_1/Q_2 = D_1/D_2$, $hp_1/hp_2 = (D_1/D_2)^3$, $P_1/P_2 = (D_1/D_2)^2$ where D = impeller diameter. Some pump efficiency loss may occur when trimming impellers more than 3%; however, this is often minimal when compared with the overall system energy savings.
- Friction increases as the square of the fluid velocity.

3 IDENTIFYING CANDIDATES

The more you know, the more you save

Before an analysis can be made, information about each system is needed to determine how the system operates. The accuracy of the analysis depends on the quality of the information used. At some facilities, the level of documentation can be poor. The effort taken to compile this information can also be used to set maintenance programs, plan resource optimization, allocate costs, check the spare parts inventory, review equipment specification sheets and analyse productivity flows to remove bottlenecks.

Single line diagrams can be helpful in organizing data. Energy consumption and performance and process requirements need to be shown. These should be assessed over a one-year period because changes in temperature, humidity, seasonal production and product mix will occur. It is not critical to have all the information; however, when estimates are used they should be noted as such, along with the assumptions made. The purpose of data gathering is to establish specific operating points that match the output capabilities of the system with the process requirements.

Information can be gathered from

- nameplate data on each component in the system
- manufacturer's specifications and performance charts
- production records, utility bills, operations charts showing power consumption, flow rate and pressure for a one-year period
- data on each process or piece of equipment using resources from the system
- process and instrumentation diagrams including the control system strategy
- field measurements

Some of the information may not be available and will require measurement. Using equipment often already installed, information can be obtained about the system. Drawings should be checked to ensure they have included the latest field changes. Data gathering in typical pump, compressor and fan systems should include

- power supply – voltage, conductor size, breaker rating, transformer capacity and tap settings, switchgear rating, phase balance, power factor and peak current
- motor controller – type, overload setting, starting characteristics and safety interlocks
- motor – type, horsepower, efficiency, manufacturer, voltage, peak current, frame size, hours of operation, model number, rpms, multi-speed capability and NEMA design rating

- power transmission – type, adjustable speed capability, speed ratio and torque rating
- driven load – type, efficiency, power and speed rating, manufacturer and model
- system effects – flow restrictions, valves, dampers and inlet and outlet conditions
- process load requirements – flow, pressure, temperature, speed and hours operated
- control methods – automatic, manual, measuring devices and operating techniques

3.1 OPPORTUNITIES FOR FAN, PUMP AND COMPRESSOR SYSTEMS

Just because it works doesn't make it efficient

It is necessary to understand how fans, pumps and compressors are applied, if one is to design an efficient motor system. The following charts identify possible opportunities for motor system optimization. The term "fluid" is used to represent both gases and liquids.

OPPORTUNITY	INEFFICIENT SYSTEMS
Poor Selection Point	• due to process changes, systems operate at a different point on their performance curve, resulting in a drop in efficiency • systems operating with a large range of turndown ratios due to production changes and seasonal temperature swings • oversized machines that continually operate in a throttled mode
Age	• older equipment was generally designed with little thought for energy consumption or efficiency • machines that have been overhauled a number of times • modern machinery uses new materials and maintains closer tolerances
Alternative Methods	• some applications can be performed with other more efficient equipment, upgraded tools or other manufacturing techniques • adjust maintenance intervals to reflect new operating conditions for filter replacement and check that heat transfer surfaces are clean, that proper lubrication is maintained, and that linkages are adjusted and functioning correctly

OPPORTUNITY	EXCESSIVE FLOW AND PRESSURE
Excess Flow	• bigger is not always better; flow controlled by throttling valves and dampers may be controlled in a more efficient manner • it is important to understand the exact process demands and match the system output to these requirements
Flow Wastage	• some process cycles have periods where there is no need for the "fluid," so it is recirculated in a bypass loop or returned to a sump • system running while the rest of the process is shut down • some systems with a multi-port distribution arrangement may have ports left open unnecessarily or that are no longer required • excessive leakage of fluid due to damage, poor fit or corrosion • mismatched impellers to casing
Pressure Losses	• pressure loss increases exponentially with flow velocity • smooth transitions, especially at the suction side, reduce pressure losses • some piping/ducting system constrictions result from construction methods used to avoid existing structures or plant equipment • valves and dampers should be checked to ensure they have not "frozen" in a partially closed position • clogged filters, corroded piping and infrequent equipment service

OPPORTUNITY	OVERSIZING AND INEFFICIENT CONTROL

Continually Throttled	• some machines operate continually with throttling dampers or valves partially closed, wasting energy
	• an analogy can be made to driving down the highway with the accelerator to the floor and controlling speed with the brake
	• reasons this condition occurs include
	  · original safety margins too great
	  · the machine may be operating in a different application
	  · a component may have been removed, reducing pressure drop

Unnecessary Operation	• the machine was sized to handle a worst-case upset condition since focus is so highly directed to production in industrial facilities; sometimes simple energy measures go unnoticed • sometimes the addition of simple control sequencers can simply turn the turbomachine off when it is not required • feedback controls set to the maximum setting or are disconnected

4 HIGH-EFFICIENCY MOTORS

Consider specifying high-efficiency motors for new equipment and when standard motors require replacement or repair

The major advantage of high-efficiency motors (HEMs) is the energy savings they provide. They use from 1% to 4% less electricity than standard motors and are generally more reliable, last longer and result in lower transformer loading. HEM design enhancements include

- 20% to 60% more copper and up to 35% more high-quality electrical steel laminations
- lower loss rotor bar design
- optimized manufacturing methods and production techniques that reduce losses

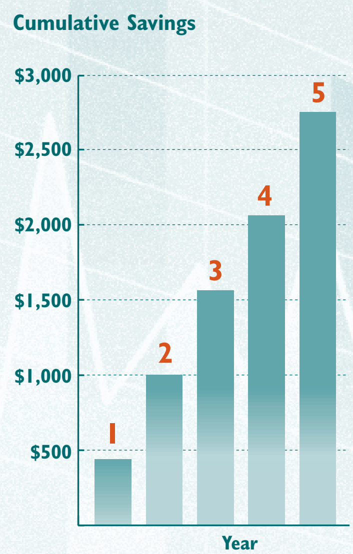
Benefits of Choosing High-Efficiency Motors

- extended winding and bearing life
- increased ability to cope with short-term overloads
- capable of withstanding higher voltage fluctuations or phase imbalance

4.1 LIFE-CYCLE COSTING

Consider both initial cost and energy consumption over the life of the motor

Wherever possible, companies should try to purchase the most efficient motors available. When it comes to electric motors, the true measure of what the item will really cost is seen only when we examine both initial price and operating costs. A standard motor costing $2,400 may consume over $144,000 of electricity in a 10-year operating period. An equivalent HEM may cost 15% to 20% more but may save over 600% of its initial incremental cost during the same period. This results in a payback of about 1.5 years or less.



Purchasing High-Efficiency Motors (HEMs): Rules of Thumb

- specify HEMs for new installations operating more than 3500 hours per year
- select HEMs for motors that are loaded greater than 75% of full load
- buy new HEMs instead of rewinding old, standard-efficiency motors
- specify HEMs when purchasing equipment packages
- use HEMs as part of a preventive maintenance package

4.2 FEDERAL MOTOR EFFICIENCY REGULATIONS

Ensure that the motors you purchase exceed these minimum efficiency levels

Canada's *Energy Efficiency Regulations* for 1-hp to 200-hp polyphase, single-speed, NEMA design A or B induction motors, amended in December 2002, specify minimum energy efficiency standards for motors sold in Canada. The "vendor" – not the "user" of the motor – is responsible for complying with the Regulations. Two classifications are addressed:

- Totally enclosed fan-cooled motors are used in dusty and corrosive environments. They use an integral fan for cooling.
- Open drip-proof designs draw ambient air through the motor for cooling. They are used in clean environments and will tolerate limited dripping liquids that strike the enclosure from any angle up to 15 degrees downward.

NEMA MOTORS – ENERGY EFFICIENCY STANDARD

POWER IN kW	HP	OPEN (PERCENTAGE)				ENCLOSED (PERCENTAGE)			
		2-pole	4-pole	6-pole	8-pole	2-pole	4-pole	6-pole	8-pole
0.75	1	75.5	82.5	80.0	74.0	75.5	82.5	80.0	74.0
1.1	1.5	82.5	84.0	84.0	75.5	82.5	84.0	85.5	77.0
1.5	2	84.0	84.0	85.5	85.5	84.0	84.0	86.5 (85.5)*	82.5
2.2	3	84.0	86.5 (84.0)*	86.5	86.5	85.5	87.5 (84.0)*	87.5	84.0
3	–	84.0	84.0	86.6	86.5	85.5	84.0	87.5	84.0
3.7	5	85.5	87.5	87.5	87.5	87.5	87.5	87.5	85.5
4	–	85.5	87.5	87.5	87.5	87.5	87.5	87.5	85.5
5.5	7.5	87.5	88.5	88.5	88.5	88.5	89.5	89.5	85.5
7.5	10	88.5	89.5	90.2	89.5	89.5	89.5	89.5	88.5
11	15	89.5	91.0	90.2	89.5	90.2	91.0	90.2	88.5
15	20	90.2	91.0	91.0	90.2	90.2	91.0	90.2	89.5
18.5	25	91.0	91.7	91.7	90.2	91.0	92.4	91.7	89.5
22	30	91.0	92.4	92.4	91.0	91.0	92.4	91.7	91.0
30	40	91.7	93.0	93.0	91.0	91.7	93.0	93.0	91.0
37	50	92.4	93.0	93.0	91.7	92.4	93.0	93.0	91.7
45	60	93.0	93.6	93.6	92.4	93.0	93.6	93.6	91.7
55	75	93.0	94.1	93.6	93.6	93.0	94.1	93.6	93.0
75	100	93.0	94.1	94.1	93.6	93.6	94.5	94.1	93.0
90	125	93.6	94.5	94.1	93.6	94.5	94.5	94.1	93.6
110	150	93.6	95.0	94.5	93.6	94.5	95.0	95.0	93.6
132	175	94.5	95.0	94.5	93.6	95.0	95.0	95.0	94.1
150	200	94.5	95.0	94.5	93.6	95.0	95.0	95.0	94.1

* Energy efficiency standard percentage when using kW to measure power output.

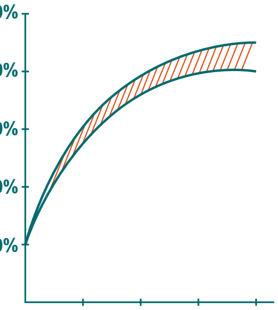
These efficiency levels should be considered as a baseline when making a motor purchase. Depending on their size, HEMs are generally 1% to 4% more efficient than those that meet the minimum standards set out in Canada's Energy Efficiency Regulations.

4.3 MOTOR INSTALLATION AND APPLICATION CONSIDERATIONS

Changes in application can change the performance of the system

Power Factor

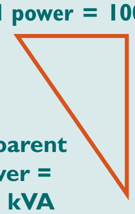
An induction motor requires both real and reactive power to operate. The real power (kW) produces work and heat. The reactive power (kVAR) establishes the magnetic field in the motor.



FOR EXAMPLE:

The power triangle illustrates that 100 ÷ 142, or 70%, of the current provided by the electrical system is being used to produce useful work. Power factor can vary depending on the design and loading.

$$\text{Power factor} = \frac{\text{Real power}}{\text{Apparent power}}$$



Induction motors are the principle cause of poor power factor. Electric utilities often levy a penalty for power factors that fall below a certain level, typically 90%. Some strategies for correcting poor power factor include

- minimizing operation of idling or lightly loaded motors
- ensuring correct supply of rated voltage and phase balance
- installing capacitors to decrease reactive power loads

Efficiency Gains Versus Motor Speed

A motor's rotor turns slightly slower than the rotating magnetic field in the stator. The difference between these two speeds is called the slip speed. Standard NEMA Design B motors run with a slip of 3% to 5% at rated load. Some HEMs operate with less slip, resulting in a slightly higher full-load speed of 5 to 10 rpm. For centrifugal loads, even a minor change in speed translates into a significant change in flow and energy consumption. When replacing standard motors, select an HEM of the same or lower speed when possible. If necessary, adjust sheaves and pulleys to capture the full energy savings benefits.

Motor Sizing

Motor efficiency is fairly constant down to approximately 50% of rated load, below which it drops off quickly. Care should be exercised in leaving an adequate but not excessive safety margin. The motor should be sized for the peak load expected. Oversized motors can significantly increase costs since all electrical components must be sized to the motor rating. Using HEMs makes additional sense because they are more efficient across a wider load range than standard motors.

4.4 MOTOR POLICY

Develop a motor policy to help assure continued productivity and efficiency

The purpose of a motor policy is to help plant personnel manage their motor systems in order to minimize lost production time and expense. A motor policy has three distinct aspects: planning, replacement guidelines and repair procedures. The following information can help design a policy that is suitable to your needs. Values shown are typical industry norms.

Planning

Sometimes in trying to get a motor back into service as quickly as possible, decisions are made that satisfy the short-term goal but negatively impact long-term efficiency and motor life. Implementing a comprehensive motor policy can help avoid this situation.

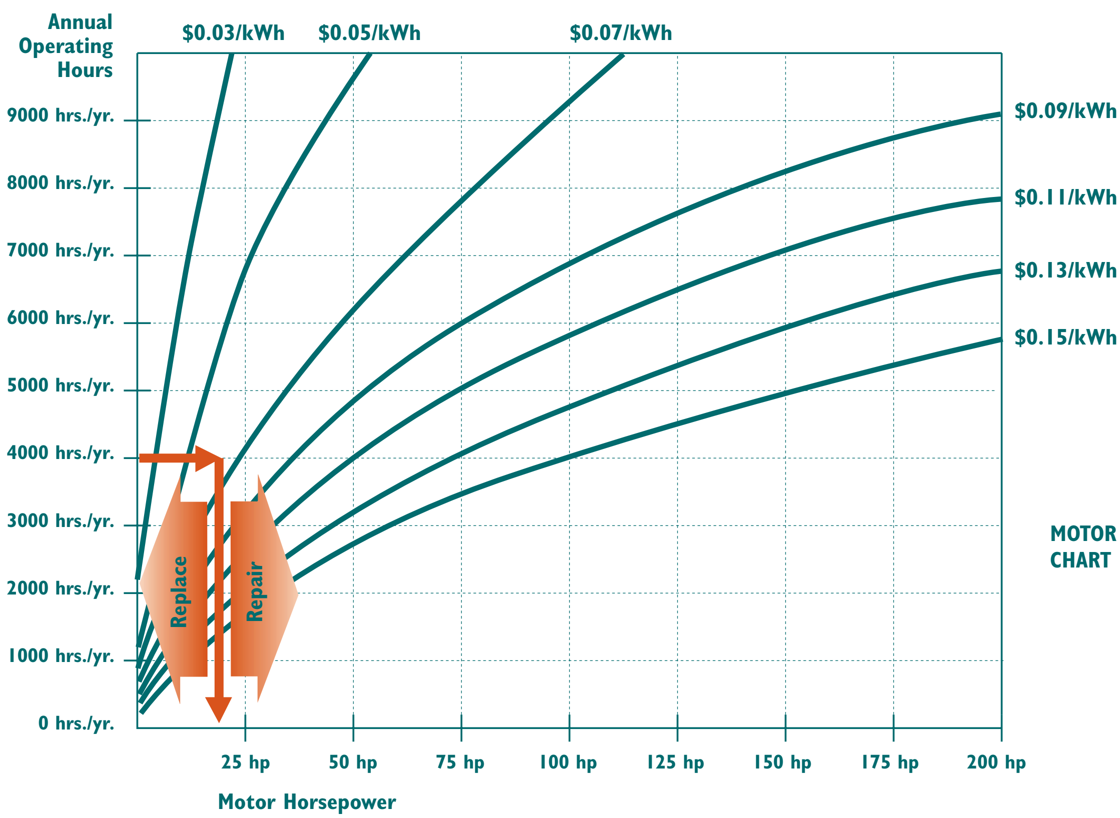
- All motors operating one or more shifts per day should be inventoried, assigned an individual equipment number and catalogued. Records should include nameplate rpm and hours of operation.
- Spare motors should be inventoried and assigned an individual equipment number. Recorded information should include nameplate data and the application(s) for which the motor is suitable.
- A plan should be developed for replacing all motors, including the source (inventory, supplier and repair) and the type of replacement motor (HEM, standard, repaired).
- All motors to be discarded should be partially dismantled, with the nameplate removed to prevent reuse, and disposed of in an environmentally suitable manner.
- The purchase of motors and repairs should be conducted with a selected number of high-quality suppliers who provide value-added services to ensure lowest total cost.
- Motors supplied with new equipment must meet Canada's *Energy Efficiency Regulations.* The full load nominal efficiency must be equal to or higher than those shown on the table in Section 4.2. Motors must also be designed for the voltage and frequency in which they will operate.
- New equipment purchases should specify that HEMs are used.
- Motors will be ordered based on CSA-C390-98 test standards.

Repair or Replacement Guidelines

When a motor fails or burns out, maintenance personnel have three options to consider:

- the cost of rewinding considering the age of the motor, its general condition, the availability of a new motor and special mechanical and electrical features
- rewinding versus purchasing a new standard motor
- purchase of a new, high-efficiency motor

The following chart will help determine the replace/repair decision breakpoint.



MOTOR REPLACEMENT CHART

Select the hours that the motor operates and draw a horizontal line until it intersects with the average electric cost curve. Then draw a line down until it intersects the motor size on the x-axis. Any motor size to the left should be replaced with a HEM; any motor size to the right should be rewound.

Motors to be Refurbished

- No motor with a defective stator core should be rewound. If the core cannot be restored to its original integrity, the motor should be replaced with an HEM.
- Motors that are 100 hp or larger with an annual operating time of less than 4000 hours should be rewound if core iron specifications are acceptable.

- Motors that are 50 hp or more should be rewound a maximum of three times, after which the motor should be replaced.
- All motors below the repair/replace breakpoint, as determined by the chart on page 15 (20 hp in this example), should be replaced with new HEMs and not be rewound.
- No standard efficiency motor should be rewound if the cost of the repair exceeds 60% of the cost of an HEM.

Repair Procedures and Specifications

- Motor repair shops should be EASA-Q or ISO 9000 registered.
- Companies may pay a nominal fee to shops for the testing, tearing down and quoting for a motor repair when a decision is made to purchase a new motor from another source.
- Repair the motor to its original design with respect to number of turns, winding design and coil configuration, wire cross-sectional area, bearing size and type and insulation quality.
- Damaged cores should be repaired or replaced.
- Stripping should occur in an oven with a water-quench temperature-suppression system with temperature not exceeding 400ºC (750ºF).
- The repair shop should endeavour to determine the cause of failure and report its findings.

Impact of Rewinding on Efficiency

The quality of workmanship and materials used in a motor rewind can vary significantly. The impact of a poorly rewound motor may not be immediately apparent; however, the results can include greater energy consumption and shorter life due to higher operating temperatures. When selecting a repair shop, consider its capabilities, experience and workmanship – not just the cost.

4.5 MAINTENANCE

An effective maintenance program affects reliability, performance and productivity

The purpose of maintenance is to keep equipment from failing prematurely, ensure optimum performance and minimize unscheduled downtime. Well-maintained machinery is also more energy efficient and exhibits lower frictional losses and decreased operating temperatures. The following sections cover major motor maintenance issues and make recommendations on servicing and testing.

Cleaning

Dirt attacks the insulation of a motor through abrasion and/or absorption. It can contaminate lubricants and damage bearings. Dirt buildup on the motor housing, fan and inlet openings increases the motor's temperature, which reduces efficiency and shortens motor life.

Lubrication

Larger motors require periodic bearing greasing. One problem is over-greasing, which causes increased friction, leading to failure. Excess grease can be forced onto the windings, also causing failure. Clean the fittings before injecting grease in order to avoid contamination.

Vibration

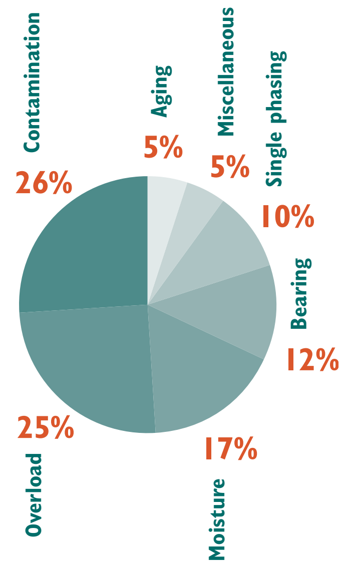
A noticeable increase or change in motor vibration is an indication of a bearing problem, load imbalance, a bent shaft, a coupling misalignment or electrical irregularities. Incorrect belt tension and alignment can increase power consumption and decrease motor life.

Voltage Testing

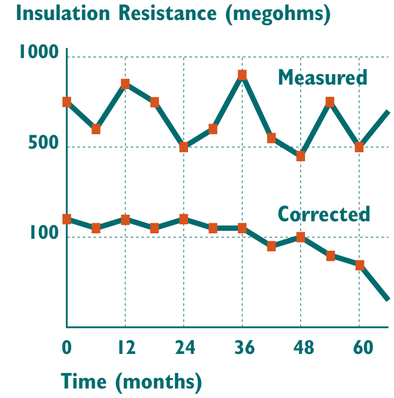
Motors that operate outside a design range of plus or minus 10% of nominal voltage operate at decreased efficiency and have a shorter motor life. Unequal phase voltage can cause extremely large rotor currents, resulting in higher temperatures and dramatically increased motor losses. Measure and log the voltage at the motor's terminals while the machine is loaded. Comparing measurements against established norms can help identify problems.

Insulation Testing

Resistance testing of critical motors on a routine basis is an important predictive test that can reveal degradation of insulation. Readings should be taken once or twice a year. Long-term trending provides a good picture of winding quality. Shown here are measured insulation resistance readings (upper graph), which are corrected to a common temperature base (lower graph), providing an accurate basis for comparison. In this case a significant downward trend occurs at the four-year mark. This motor should be removed from service and sent for a cleaning and "dip and bake" servicing, avoiding a full rewind and at about one third of the cost.



CAUSES OF MOTOR FAILURE



RESISTANCE TESTING ANALYSIS

5 MOTOR SYSTEM MANAGEMENT TECHNIQUES

Major opportunities exist by correctly selecting components to reduce pressure drop

Some general motor system management techniques and options, which can achieve significant energy savings while satisfying all process requirements, are described in the following.

GENERAL TECHNIQUE NO. 1: Speed Modulation

Many systems operate with varying load requirements using throttling methods to control flow. Other methods of control include recirculation, venting and using relief valves. These traditional methods require that the machine run at one constant speed near full load; energy is wasted by dissipating it across control mechanisms. Recirculation wastes energy by maintaining a constant rate of energy consumption while the system provides no useful work to the process.

Speed control offers an excellent opportunity to save energy by matching the speed of the equipment to the actual process requirements. In many fan, pump and compressor systems, power requirements vary with the cube of the flow. Flow varies directly with speed, so a 20% reduction in speed will result in approximately 50% savings in energy.

Speed modulation is accomplished in two ways:

- directly varying the speed of the motor
- using a fixed speed motor with adjustable power transmission systems

Some systems require a wide range of operating points, so selecting an adjustable speed drive may be appropriate. These drives provide a number of advantages in addition to energy savings, including

- precise process control
- increased equipment life
- soft starting
- regenerative braking

Multi-speed motors are commonly used in applications requiring only a few discrete points of operation. They are less expensive than adjustable speed drive motors and are available in two, three and four speeds.

Application Considerations

- Speed modulation is particularly effective in variable torque loads.
- Avoid operating at resonant frequencies and lock out unstable machine operating ranges.
- At slow speeds, external cooling or separate lubrication systems may be required.

GENERAL TECHNIQUE NO. 2: Equipment Sizing

Re-evaluate systems that are operating against partially closed throttling devices. Reduce energy use by resizing the entire machine or retrofitting internals such as impellers and then opening dampers and valves.

Impeller resizing reduces the horsepower requirement of the equipment, resulting in energy savings. Correct trimming of the impeller allows the system to provide all of the process requirements without operating in a throttled condition.

Application Considerations

- Resizing provides a permanent system de-rating.
- Equipment sizing is not suitable if additional capacity is occasionally needed.

GENERAL TECHNIQUE NO. 3: Booster Applications

Systems that need temporary excess capacity can make use of a booster arrangement. A booster is a fan, pump or compressor that supplements systems that serve processes that have infrequent peaks or upset conditions. Primary equipment is sized to operate in the most efficient manner for normal operation; boosters come on line to serve periodic peaks. Frequently, systems encounter peak loads on startup and then, once the process has achieved equilibrium, the loads reduce.

Application Considerations

- Available space and cost may determine viability.
- The booster should run only intermittently.
- Because this control scheme works in steps, it is not as precise or efficient as speed modulation.

GENERAL TECHNIQUE NO. 4: Equipment Upgrade

Upgrading turbomachines may save energy in the following areas:

- Modern, more efficient equipment may be available to replace old designs.
- Processes and system requirements may have radically changed since the equipment was originally specified, requiring the turbomachine to be re-evaluated at the new point of operation.
- The system may benefit from a switch to HEMs.

Application Considerations

- Some higher-efficiency impellers are not suitable for harsh environments.
- Consider replacing motors that are less than 50% loaded or those that have been rewound numerous times.
- Be aware of the possible higher speed of a HEM.

GENERAL TECHNIQUE NO. 5: System Effect Factors

System effect factors are conditions that cause inefficient performance as a result of the system configuration. These conditions alter the machine's performance characteristics so that it no longer performs at maximum efficiency.

Energy is consumed to overcome flow resistance created by filters, dampers, silencers, coils, etc. Reducing the resistance of any component causing a pressure drop will require less power to produce the same flow. Other common factors include improper inlet connections and poorly designed discharge connections. Ensure that components are clean and functioning properly.

GENERAL TECHNIQUE NO. 6: Engine Drives

In some large motor applications, the use of reciprocating engines or gas turbines coupled directly to the load can provide significant benefits. These applications can be successful when there is a constraint on the electrical supply, the heat generated from the engines can be used in the process, and there is a cost-effective fuel source. These engines can also offer variable speed and over-speed capability for peaking loads of short duration. Engine packages offer a wide range of sizes, high-efficiency options and low emissions.

Application Considerations

- allows for a self-powered process and avoids upgrades to the electrical system
- can also be used for emergency backup power if coupled to a generator
- life-cycle analysis should consider fuel cost, capital cost, maintenance and heat value
- constant-duty engines have more robust components for longer life than standby units
- isolation switches should be installed when used in a standby generator application

GENERAL TECHNIQUE NO. 7: Maintenance and Design

- Lubricants – Synthetic lubricants can be used to reduce frictional losses in gearboxes.
- Coatings – Frictional losses can be reduced by the use of various internal coatings and can also repair pitting and cavitation damage, thus further reducing losses.
- Running clearances – Maintaining equipment to specified tight-running clearances reduces leakage and bypass in various systems.

- Gear reducers – Converts a motor’s high-speed, low-torque output to meet the low speed, high torque required by the driven equipment.
  - Worm gears – Inexpensive and simple to maintain. Efficiency varies with the turndown ratio, which can be as high as 94% for a 5:1 ratio and as low as 75% for a 40:1 reducer.
  - Cycloidal gearsets – These have efficiencies higher than worm gears but slightly lower than helical designs. Each stage is capable of large ratios as high as 87:1.
  - Helical gears – Gears have tooth faces on an angle to the shaft, forming a helix. Efficiency depends on the number of stages to achieve desired speed, the type of bearings used, lubrication and quality of gear mesh. A well-designed gear set can have an efficiency of up to 98%.

6 FAN SYSTEMS

Select efficient components and reduce the use of damper controls

Fans provide the means to move air through a system of ductwork. There are two components to optimizing fan system performance:

- fans should be selected to provide the greatest efficiency for a given application
- fan systems should be reviewed to ensure peak operation with a minimum of loss

6.1 SELECTION AND APPLICATION TABLE

	RADIAL	FORWARD-CURVED	BACKWARD-CURVED	AIRFOIL
Application	• erosive environments • used for pneumatic conveying • flat blades resist erosion from the material conveyed • not suitable for HVAC systems or combustion air applications	• used where high outlet velocity is required • used in small air-handling equipment and HVAC units • blades collect deposits if used for anything except clean air	• used in large applications where contaminants foul or erode airfoil blades • used in systems that require low- to high-static pressure; i.e., HVAC systems • custom-designed models can be used in erosive environments	• used in as many areas as possible, even where there is some light dust in the airstream • HVAC systems, dehumidification units, combustion air fans, industrial dryer fans
Principle of Operation	• typically has 6 to 10 blades radiating out from the hub • can be either straight or have a slight curve • may be equipped with removable wear plates • aside from the forward-curved fan, it will be the smallest fan for a particular performance rating	• air leaves the typically 24 to 64 shallow blades at a greater velocity than the tip speed, and mainly kinetic energy is transferred to the air • the fan housing is a scroll design • the tolerance between the inlet cone and the wheel is not critical	• an impeller with typically 9 to 16 blades of uniform thickness is inclined away from the direction of rotation • input horsepower falls off as the flow increases, making it almost impossible to overload • a tight tolerance between the wheel and inlet cone must be maintained	• air leaves the impeller at a velocity less than its tip speed • relatively deep blades result in high strength • to achieve high static-pressure efficiency, a close tolerance between the wheel and the housing inlet cone must be maintained
Static Efficiency	50%–60%	60%–70%	75%–80%	80%–85%

	RADIAL	FORWARD-CURVED	BACKWARD-CURVED	AIRFOIL
Maximum Flow	7 080–14 160 cmm* (250 000–500 000 cfm)	~566 cmm (~20 000 cfm)	14 160–21 240 cmm (500 000–750 000 cfm)	14 160–25 488 cmm (500 000–900 000 cfm)
Maximum Pressure	12–5 kPa (50–20 in. wg.†)	~0.75 kPa (~3 in. wg.)	8–2 kPa (30–9 in. wg.)	8–3 kPa (30–15 in. wg.)
Maximum Power	500–1000 hp	15–30 hp	1000–2000 hp	1000–3000 hp
Advantages	• self-cleaning • can be designed for high structural strength to achieve high speeds and pressures	• quiet • runs at relatively low speed • smaller fan for a given duty		• motor may be sized to cover the complete range of operation • maximum efficiency point allows efficient fan selection

* cubic metres/minute

† inches water gauge

6.2 FAN-SPECIFIC SYSTEM OPPORTUNITIES

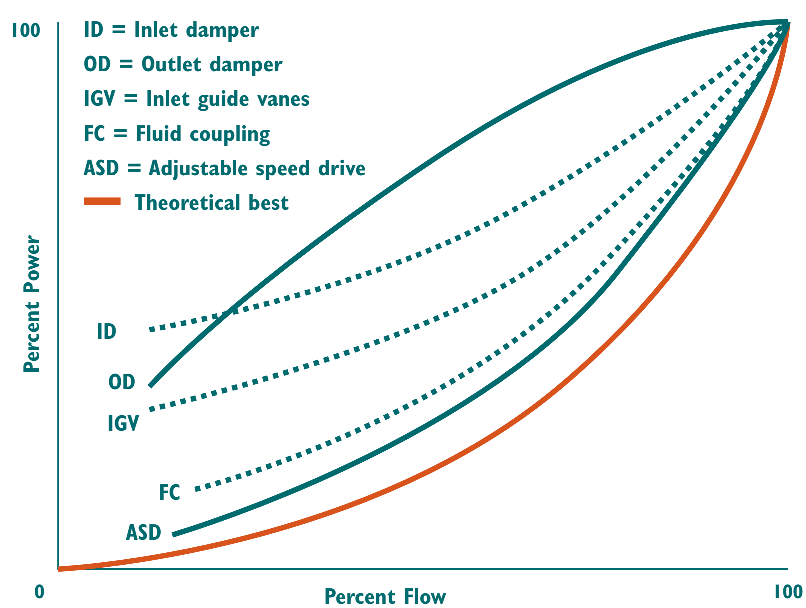
FANS	INEFFICIENT FAN SYSTEMS
Misapplication	• Fans originally purchased based on cheapest initial price can be upgraded or replaced with higher-efficiency models. • Improvements in metallurgy and fan design now allow more efficient models to be used in a wider variety of applications.
Control Methods	• Outlet dampers are an inefficient method of controlling flow. • Butterfly dampers located close to the fan inlet create turbulence and diminish performance.
Guide Vanes	• Variable inlet guide vanes are used to control flow and are generally most efficient in the 85% to 100% flow range (not suitable for harsh environments).

FANS	MAINTENANCE
High System Resistance	• The fan must "fight" resistance created by material buildup on inlet guide vanes or the impeller. • Causes of high system resistance include dirty screens, filters and coils.
Flow Leakage	• Flow that is lost due to leakage is a waste of energy. • Fan systems are susceptible to developing leaks in flexible connections, at loose or distorted flanges and due to deteriorated gaskets. • Another cause of leakage is corrosion or erosion of ductwork.

FANS	SYSTEM EFFECT FACTORS
Intake/Discharge Design	• The most efficient flow of air into a fan is a non-restricted, uniform path. • Elbows located directly on fan inlets increase losses and are to be avoided. • Obstructions at fan inlets and outlets disrupt the flow, causing turbulence. • Flex connections often cause poor transitions that disrupt flow.
Fan Orientation	• Fans should be oriented to ensure smooth airflow, since turbulence is minimized if flow direction is the same as turbomachine rotation.
Turning Vanes	• Turning vanes should be installed to correct inlet or outlet conditions such as when an elbow is too close to an intake.
Elbows	• Round elbows provide lower resistance than square elbows.

6.3 CONTROL SYSTEMS

This graph provides a comparison of horsepower required to provide a given flow for various fan control mechanisms. The difference between power values of the different control systems indicates potential energy savings. Adjustable speed drive (ASD) control provides superior savings over the full range of flow. Between 85% to 100% flow, a number of control options may be evaluated from performance and economic perspectives.



6.4 FAN SYSTEM CHECKLIST

Use fan operation and performance characteristics to identify efficiency opportunities.

System Information – Where and what is the fan used for?

Service/system: ....

System description: .... Annual operation (hours): ....

Fan manufacturer: .... Age (years): ....

❍ Fixed resistance
❍ Fixed resistance/constant pressure
❍ Variable resistance/constant pressure
❍ Variable resistance/constant flow

Optimization Quick Check – More "yes" answers indicate a better opportunity to improve efficiency

❍ Yes ❍ No Is the fan greater than 75 hp?
❍ Yes ❍ No Does the fan operate for more than 4000 hours per year?
❍ Yes ❍ No Are output dampers installed? Is the fan throttled more than 20% of total flow?
❍ Variable torque loads with major energy-saving potential (refer to Section 8)
❍ Constant torque loads with moderate saving potential
❍ Constant horsepower loads with no energy-saving potential

Controls – Inspect fan system controls and indicator mechanisms

❍ Inlet damper: ....% normally open ❍ Auto ❍ Manual ❍ Fixed
❍ Outlet damper: ....% normally open ❍ Auto ❍ Manual ❍ Fixed
❍ Inlet vanes: ....% normally open ❍ Auto ❍ Manual ❍ Fixed
❍ ASD ❍ Eddy current ❍ Wound rotor ....% speed ❍ Hydraulic coupling
❍ Belt drive ❍ Gear reducer ....% ratio ❍ Direct drive

Fan Information

Rated horsepower: .... hp Rated speed: .... rpm
Actual: Flow ....cfm Pressure .... kPa (if available)
Max. (rated): Flow ....cfm Pressure .... kPa
Impeller type: ❍ Radial ❍ Forward-curved ❍ Backward-curved ❍ Airfoil

Motor

Motor manufacturer: .... Model: ....

..................hp ....rpm ....NEMA ....Efficiency ....FLA

Load Duty Cycle – Cost of power ....$/kWh

Average cost = Hours × Power (kW) × ($/kWh)
Three-phase power (kilowatts) = 1.73 × Amp × Volts × Power Factor ÷ 1000 (Section 4.3)

% FLOW	HOURS	MOTOR AMP	MOTOR VOLTS	DAMPER SETTING	FAN RPM	POWER kW	AVERAGE COST

This checklist catalogues important information about equipment operation and its operation specifications. This information when used with the equipment evaluation criteria helps to identify the best candidates for efficiency gains, propose changes to the purchase specification, modify maintenance procedures and optimize equipment operation.

7 PUMP SYSTEMS

Eliminating throttling and recirculation in pump systems saves energy

Pumps provide the force to move a liquid through a piping system in order to overcome differences in elevation and the resistance of the piping or process. There are two main categories of pumps: centrifugal and positive displacement. Centrifugal pumps are widely used because of their relatively simple operation and low cost. They offer the most opportunity for efficiency improvements. Pump efficiency is a function of volumetric efficiency, mechanical efficiency and hydraulic efficiency. Peak efficiency is possible only at one particular flow and pressure. Putting a pump into a system where it is forced to operate at a different point will reduce efficiency.

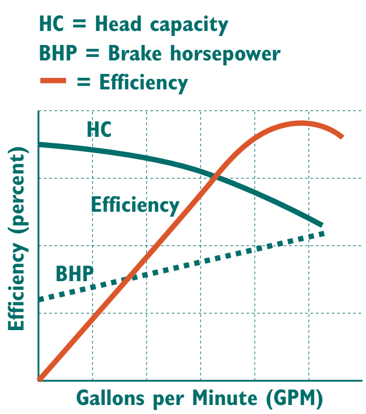
Selecting a pump that is well manufactured is important. Most of the methods that manufacturers use to reduce the price also decrease efficiency. Eliminating diffuser vanes, using undersized impellers, employing open radial-blade impellers, using manufacturing techniques that result in large clearances and rough finishes, all reduce cost and efficiency. The pump system operation can affect efficiency more significantly than design. Operating a pump at low speed, low capacity or at high head all significantly reduce efficiency.

There are three key areas that affect pump system efficiency:

- friction and inertia losses caused by fluid flow in the pipes and fittings
- the difference in elevation between the source and destination location
- the surface pressures at the source and destination locations

Effective utilization of energy by pump systems is affected by several factors:

- configuration of the pumps
- method of control
- inlet and outlet flow conditions
- application of pumps to the requirements of the system
- the efficiencies of the pumps
- sequence of operation in multiple-pump systems



Pump Curves

Centrifugal pumps have a rating curve that defines the relationship between head and flow produced at a particular speed and impeller diameter. Head capacity (HC) and brake horsepower (BHP) are determined by testing a pump, and efficiency is calculated at various capacities. As flow (gallons per minute, or GPM) increases, the HC decreases and BHP increases.

7.1 PUMP-SPECIFIC SYSTEM OPPORTUNITIES

PUMPS	INEFFICIENT PUMP SYSTEMS
Cavitation	• When pressure in the suction line falls below the liquid vapour pressure, vapour forms; these vapour "cavities" collapse when they reach a higher pressure area, causing noise, erosion of components and vibration. • Cavitation will cause impeller and casing pitting, which decrease capacity and reduce efficiency.
Impeller Design	• Wider impellers pump a greater volume of fluid and maintain more constant head pressure at varying flows. • Increasing the pitch of the impeller increases head capacity. • The more vanes an impeller has, the more constant the head capacity. • The capacity of the pump can be increased or decreased by changing the size of the eye of a radial impeller. • As a general rule, enclosed impellers are more efficient; however, they are more expensive and best suited for clean applications.

PUMPS	MAINTENANCE
Tolerances	• Pump efficiency is affected by the amount of leakage past the impeller. • High pressure developed at the impeller discharge can backflow to a lower pressure area. • Erosion by abrasive particles can affect clearances. • Close running clearances must be maintained; some pumps use wear rings between moving and stationary surfaces. • Recirculation must be kept to a minimum for the pump to operate efficiently.
Packing Glands	• Packing glands should be checked periodically for correct adjustment. • Check tightness of the packing by monitoring the rate of dripping; packing must usually leak slightly for lubrication and cooling purposes. • Over-tightening can cause excessive wear at the shaft seal, resulting in mechanical damage and energy loss.
Coatings	• Special coatings can be applied to repair cavities and smooth internal surfaces to reduce friction losses.

PUMPS	SYSTEM EFFECT FACTORS
Design	• The suction inlet design should ensure that flow approaching the inlet is uniform and steady. • A straight run of suction pipe of at least eight diameters in length immediately prior to the pump suction flange is recommended.
Elbows	• Air pockets can form when elbows are positioned in the suction line.

7.2 PUMP SYSTEM CHECKLIST

Use pump operation and performance characteristics to identify efficiency opportunities.

System Information – Where and what is the pump used for?

Service/system: ……………………………………………………

System description: ……………………………… Annual operation (hours): ………………

Pump manufacturer: ……………………………………… Age (years): ………………

- ❍ Constant flow
- ❍ Variable pressure
- ❍ Constant pressure
- ❍ Variable flow

Optimization Quick Check – More "yes" answers indicate a better opportunity to improve efficiency

- ❍ Yes ❍ No Is the pump greater than 75 hp?
- ❍ Yes ❍ No Does the pump operate for more than 4000 hours per year?
- ❍ Yes ❍ No Are throttle valves installed? Does the pump recirculate more than 20% total flow?
- ❍ Variable torque loads with major energy-saving potential (refer to Section 8)
- ❍ Constant torque loads with moderate savings potential
- ❍ Constant horsepower loads with no energy-saving potential

Controls – Inspect pump system controls and indicator mechanisms

- ❍ Outlet throttle valve: ……………% normally open ❍ Auto ❍ Manual ❍ Fixed
- ❍ Recirculation or dump to sump: ………………% flow
- ❍ ASD ❍ Eddy current ❍ Wound rotor ……………% speed ❍ Hydraulic coupling
- ❍ Belt drive ❍ Gear reducer ……………% ratio ❍ Direct drive

Pump Information

Rated horsepower: ……………………… hp Rated speed: ……………… rpm

Actual: Flow …………………… cfm Pressure ………………… kPa (if available)

Max. (rated): Flow …………………… cfm Pressure ………………… kPa

Impeller type: ……………………………………………………

Motor

Motor manufacturer: ……………………………… Model: ………………………………

……………… hp ……………… rpm ……………… NEMA ……………… Efficiency ……………… FLA

Load Duty Cycle – Cost of power ……………$/kWh

Average cost = Hours × Power (kW) × ($/kWh)

Three-phase power (kilowatts) = 1.73 × Amp × Volts × Power Factor ÷ 1000 (Section 4.3)

% FLOW	HOURS	MOTOR AMP	MOTOR VOLTS	DAMPER SETTING	FAN RPM	POWER kW	AVERAGE COST

This checklist catalogues important information about equipment operation and its operation specifications. This information when used with the equipment evaluation criteria helps to identify the best candidates for efficiency gains, propose changes to the purchase specification, modify maintenance procedures and optimize equipment operation.

8 ADJUSTABLE SPEED DRIVES

Adjustable speed drives (ASDs) offer a versatile method of precise speed control over a wide range

Many systems use constant speed motors and mechanically regulate process flow using throttling valves, dampers, fluid couplings or variable inlet vanes. These devices generally do not control flow efficiently because energy is dissipated across the throttling device.

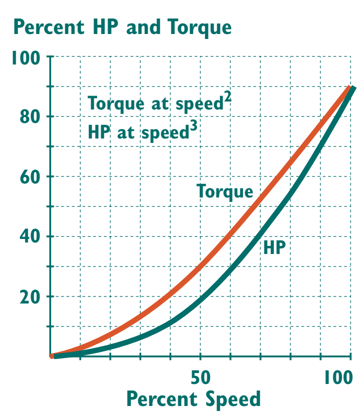
Electronic ASDs provide a cost-effective means of matching system performance to the requirements of the process while saving significant amounts of energy. AC variable frequency drives are used with standard squirrel cage induction motors.

ADVANTAGES	DISADVANTAGES
• precise process control and wide speed range	• increased cost
• reduced maintenance compared with DC systems (brushes and commutators)	• maintenance
• energy savings	• complexity
• soft starting and stopping with controlled acceleration/deceleration	
• reduced noise levels	

Drive applications are categorized with respect to power and torque changes in response to the motor's speed. It is important to understand the type of load presented for a particular application because not all are equally good energy-saving opportunities for the application of an ASD. In fact, if an ASD is used on some loads there will be little or no energy savings.

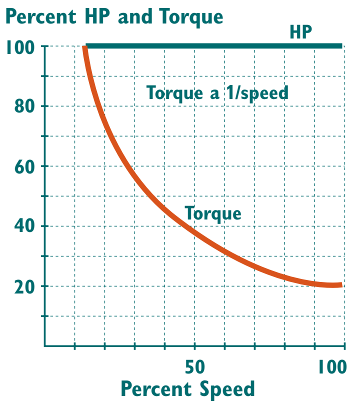
Variable Torque Loads

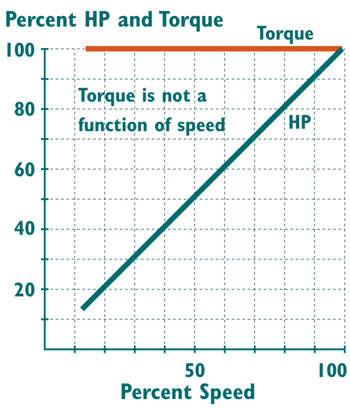
In variable torque load applications, both torque and power change with speed. Torque varies with speed squared, and horsepower varies with speed cubed. This means that at half speed, the horsepower required is approximately one eighth of rated maximum. Common examples of variable torque loads are centrifugal fans, blowers and variable discharge pressure pumps.



The use of an ASD with a variable torque load often returns significant energy savings. In these applications the drive can be used to maintain various process flows while minimizing power consumption. In addition, a drive also offers the benefits of increased process control, which often improves product quality and reduces scrap.

Effective speed ranges are from 50% to 100% of maximum speed and can result in substantial energy savings.





Constant Power Loads

In constant horsepower applications, the power requirement remains constant at all speeds, and the torque requirement varies inversely with speed. One example of this type of load would be a lathe. At low speeds, the machinist takes heavy cuts, using high levels of torque. At high speeds, the operator makes finishing passes that require much less torque. Other examples are drilling and milling machines.

Typically, these applications offer no energy savings at reduced speeds.

Constant Torque Loads

In constant torque loads, the power is directly proportional to the operating speed. Since torque is not a function of speed, it remains constant while the horsepower and speed vary proportionately. Typical examples of constant torque applications include conveyors, extruders, mixers and positive displacement pumps. For constant torque loads, the speed range is typically 10:1.

Usually these applications result in moderate energy savings at lower speeds.

8.1 APPLICATION CONSIDERATIONS

Most ASD installations achieve their objectives of improved process control, energy savings and reduced maintenance. Their proper selection is dependent on many considerations that are unique to each application. The following outlines a number of areas that should be examined.

Control Options

Each turbomachine type will have a somewhat different relationship of flow to power for various flow-control devices. Available power savings are contingent upon the degree of flow reduction. For example, for a fan requiring a small flow reduction from 100% to 85%, the power saving is nearly identical for ASD control or variable inlet vanes, which may be much cheaper. At less than 85% flow, ASD control becomes increasingly more efficient than other methods.

Constant Head Systems

Not all systems with widely varying flow requirements are good candidates for ASDs. Many systems require constant pressure over a wide range of flows or have a minimum head requirement. Even though flow may be substantially reduced, it may be necessary to keep the turbomachine near full speed to meet the system's pressure requirements.

System Suitability

Knowledge of all points of operation of a system is crucial in establishing whether there is an appropriate match of turbomachine performance and variable speeds selected. Operation of a system at unstable speeds may cause damage to the equipment, the system or possibly both.

Surge Conditions

Surge is characterized by strong pulsations that can be quite violent and destructive. For this reason, the surge region of the performance curve is to be avoided. Systems that have a constant static head may have operating points in a surge region when operated under speed control.

Pump Run-Out Conditions

Installation of an ASD on a pumping system frequently involves the elimination of a throttling valve. When the valve is removed and the pump is correspondingly slowed down, it may see very little system resistance. This condition is called run-out and is signified by high vibrations, impeller and seal damage, and piping pulsations.

Shaft Natural Frequencies

Most turbomachines are designed to operate at a speed that is below the first natural frequency of the shaft. In certain cases, high-speed turbomachines are designed to operate between the first and second natural frequencies. A speed reduction for a machine of this type could result in operation at the first critical speed. This would result in high vibration levels and possible failure.

Bearing Problems

Large fans are frequently built with shafts that use sleeve or journal bearings. These fans may have very high breakaway torque requirements, particularly when they have been at rest for an extended period. Selection of the drive and motor should take into consideration this torque requirement to ensure that the necessary requirements can be met.

8.2 ADJUSTABLE SPEED DRIVE CHECKLIST

The following lists information needed to evaluate whether the motor system is a suitable candidate for adjustable speed drives.

❍ Pump ❍ Fan ❍ Compressor ❍ Other: ....

Manufacturer: .... Model: .... Rated power (hp): ....

Temperature Min.: .... Max.: .... Speed (rpm): .... Feedback control: ....

Torque: ❍ Fixed ❍ Variable ❍ Fixed power Design pressure: .... Design flow: ....

Variable controlled: .... Speed/torque requirements: ....

Process requires precise control: ❍ Yes ❍ No Reliability req'd: ❍ Low ❍ Medium ❍ High

Schematic available: ❍ Yes ❍ No Total operating hours: .... Flow tolerance: ....

Pressure tolerance: .... Specific gravity: .... Turn-down ratio: ....

Operating Points (Consult manufacturers' specification for power and speed data)

% FULL LOAD	HOURS	MACHINE RPM SPEED	MOTOR VOLTS	MOTOR AMP	POWER kW	AVERAGE COST

Motor Data Supplier: ....

Manufacturer: .... Serial number: .... Model: ....

Size (hp): .... NEMA type: .... Frequency (Hz): .... Capacitors close: ❍ Yes ❍ No

❍ Clean ❍ Dusty ❍ Acidic Ambient temp.: .... Enclosure type: .... Speed (rpm): ....

Voltage (V): .... FLA: .... Efficiency (%): .... Total operating (hrs.): ....

Monitoring and Control Supplier: ....

Electrical bypass: ❍ Yes ❍ No Max. fault level: ❍ Yes ❍ No

Auto restart: ❍ Yes ❍ No Fault diagnostics: ❍ Yes ❍ No Fused inputs: ❍ Yes ❍ No

Power dip-thru: ❍ Yes ❍ No Adjust acceleration/deceleration: ❍ Yes ❍ No

Harmonics Supplier: ....

Non-linear load: ❍ Less than 20% ❍ Greater than 20% Specify: ....%

ASD on separate circuit: ❍ Yes ❍ No Level of protection required: ❍ Low ❍ Medium ❍ High

Drive protection used: ❍ Reactors ❍ Filters ❍ Isolation transformer

This checklist catalogues important information about equipment operation and its operation specifications. This information when used with the equipment evaluation criteria helps to identify the best candidates for efficiency gains, propose changes to the purchase specification, modify maintenance procedures and optimize equipment operation.

9 COMPRESSORS AND COMPRESSED AIR SYSTEMS

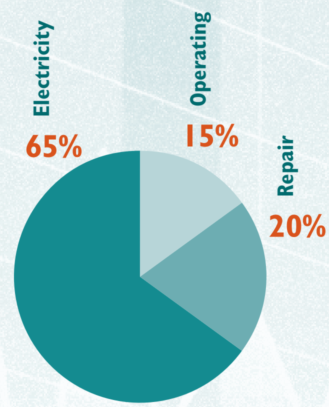
Energy savings through improved design and operation can range from 20% to as much as 50%

Compressed air is distributed throughout a modern facility via a pipe network and is widely used in processes and to operate equipment. Although compressed air is versatile and convenient, it is one of industry's most expensive energy sources.

A typical compressor operating at 100 psi produces about 4 cfm per hp, or about 0.23 kW per cfm. Using an average cost of electricity of $0.06 per kWh, 1 cfm = $0.014/hr.

- 1 cfm over 8000 hours = $112
- 100 hp compressor over 8000 hours = $44,800

Every 2 psi of pressure drop on a 100-hp air system costs approximately $450 more per year.



BREAKDOWN OF COMPRESSOR COSTS

It is important to determine what quality of air is required in terms of minimum pressure and cleanliness from dirt, oil and moisture. The degree of air quality has a significant effect on power consumption from filtration, cooling treatment and compressor capability. Instrumentation requires higher-quality air than hand-operated tools. For example, many filters have a recommended changeout at 8 to 10 psig. Stacking a particulate filter with a coalescing filter to achieve cleaner air than required may result in a pressure drop across the two of 15 psig or more, increasing costs by 7.5%. When selecting components, consider that electricity, maintenance and downtime costs outweigh the initial cost over the life of the equipment.

The two broad categories of air compressors are dynamic and positive displacement machines. Dynamic machines use axial and centrifugal impellers to impart velocity to the air, which is then converted to pressure. The most common positive displacement machines are reciprocating piston, helical rotary screw, sliding vane and lobed. In general, reciprocating compressors are more efficient than rotary types but can be more costly to maintain. Two-stage flooded rotary screw compressors offer significant power savings over single-stage compressors.

Motor Design

Sound-attenuating enclosures can raise ambient temperatures. Ensure adequate ventilation is provided so that ambient temperatures do not exceed 75°C.

9.1 OPPORTUNITIES FOR ENERGY SAVINGS

Relocate Air Intakes Outdoors

Install intakes in locations providing the cleanest, driest and coolest air possible – outdoors if possible. The amount of moisture in air doubles approximately every 65°C. Air density increases as temperatures decrease, raising overall efficiency.

Compressor Controls

Compressors charge the system to the preset pressure and maintain it by various methods, including load/unload, inlet modulation, recirculation, venting, stop/start and speed control with adjustable speed drives. Target a pressure point and bring on compressors as required. Average savings of 35% have been obtained when variable speed drives are used to control air compressors.

Compressed Air Dryers

Atmospheric air entering a compressor always contains water vapour, or humidity. At 24°C and 75% relative humidity, about 3.6 litres of water per hp of compression enters per day. Condensation can create downstream equipment operational problems, lead to corrosion, high-pressure drop, scale and air leakage. Choose filter systems with the lowest pressure drop.

Air and Oil Cooling

It is estimated that compressor cooling is approximately 5% to 7% of overall costs. Compressor systems give off high volumes of low-grade waste heat, which can be used efficiently by some industrial processes, boiler feed water and heating or ventilation systems.

Consider Alternate, More Efficient Methods

Low-pressure applications such as agitation, part ejection, cleaning, cooling and fume removal can be effectively done at greatly reduced cost by blowers or air amplifiers.

Leakage is the Largest Single Waste of Energy Associated with Compressed Air Usage

In a typical plant, air leaks account for 20% of the total air usage, and can be as high as 50%. Tighten connections, replace cracked hoses and install pressure-driven drain valves.

Costs are approximate and are calculated using $0.06 per kWh and 8000 hours.

DIAMETER OF LEAK	COST PER YEAR
0.3 cm (1/8 in.)	$2,000
0.6 cm (1/4 in.)	$8,100
0.9 cm (3/8 in.)	$18,500

Leakage Measurement

An ultrasonic leak detector is recommended as an effective leak detection method. Detect the exact location of leaks by applying a soapy water solution to the joints, valves and fittings and look for bubbles. Overall leakage can be determined by shutting down all loads and measuring the amount of time the compressor operates after the system has been pressurized. Knowing how long the compressor runs and the rate of compressed air produced allows the calculation of the cubic metres of air consumed by leaks per hour.

Use Lowest Pressure Possible

If an application requires air pressure at a much higher level than the rest of the system, consider using a separate compressor or booster that is sized for the function. The lower the pressure delivered to the plant, the lower the leakage rate. Use pressure regulators whenever possible.

Use Adequate Sizing to Reduce Losses

Pipe pressure loss is proportional to pipe length; the square of the compressed air velocity in the pipe is inversely proportional to the pipe diameter. Every 2 psi increase in pressure drop uses 1% additional power. Keep air velocities below 9 m/s.

Reduce Compressor Cycling

Install one gallon of receiver capacity for every cfm of compressor capacity.

10 WEB SITES ON MOTOR SYSTEMS

The **EnerGuide for Industry** Web site, developed by the Office of Energy Efficiency of Natural Resources Canada, provides tips and advice on purchasing energy-efficient industrial equipment, including motors, lighting, transformers, and heating, ventilation and air-conditioning systems. The site helps users select products based on energy efficiency criteria and provides a tool for calculating energy and dollar savings. You can find this site at **oee.nrcan.gc.ca/egi**.

The following Web sites represent a starting point for obtaining unbiased information on energy-efficient industrial equipment. Information about specific brands and products can be found on individual manufacturer and supplier Web sites.

Hydro One Networks

www.hydroonenetworks.com

Go to "Customers" and select "Small Business."

Click on "Energy Efficiency Tips and Tools," select "Commercial Buildings" and then select "Machines, Equipment and Motors."

Air Movement and Control Association International, Inc.

www.amca.org

Go to "Publications."

Electrical Apparatus Service Association, Inc.

www.easa.com

Go to "Other Resources" and select "Directory of Technical Books." Includes information on motors and motor maintenance.

Drives Mag

www.drivesmag.com

Includes various articles and links relating to drives, their selection and installation.

United States Department of Energy's Office of Industrial Technologies

www.oit.doe.gov/bestpractices

Presents information on compressed air, motors, process heating and steam.

Leading Canadians to Energy Efficiency at Home, at Work and on the Road

The Office of Energy Efficiency of Natural Resources Canada
strengthens and expands Canada's commitment to energy efficiency
in order to help address the challenges of climate change.

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