MOTOR CHALLENGE

F A C T S H E E T

a Program of the U.S. Department of Energy

REPLACING AN OVERSIZED AND UNDERLOADED ELECTRIC MOTOR

This fact sheet will assist in decisions regarding replacement of oversized and underloaded motors. It includes a discussion of how the MotorMaster software can be used to conduct motor replacement analyses.

Motors rarely operate at their full-load point. Field tests of 60 motors at four industrial plants indicate that, on average, they operate at 60% of their rated load.[1] Motors that drive supply or return air fans in heating, ventilation and air-conditioning (HVAC) systems generally operate at 70% to 75% of rated load.[2]

A persistent myth is that oversized motors, especially motors operating below 50% of rated load, are not efficient and should be immediately replaced with appropriately sized energy-efficient units. In actuality, several pieces of information are required to complete an accurate assessment of energy savings. They are the load on the motor, the operating efficiency of the motor at that load point, the full-load speed (in revolutions per minute [rpm]) of the motor to be replaced, and the full-load speed of the downsized replacement motor.[3]

Motor Load Estimation Techniques

Operating efficiency and motor load values must be assumed or based on field measurements and motor nameplate information. The motor load is typically derived from a motor's part-load input kW measurements as compared to its full-load value (when kW or voltage, amperage, and power factor readings are available), from a voltage compensated amperage ratio, or from an operating speed to full-load slip relationship.

Equations used to estimate motor load are summarized on page 2. The kilowatt technique should be used whenever input kilowatt measurements are available. Use the slip technique only when strobe tachometer readings are at hand and kilowatt values are not available. The full-load or synchronous speed for the existing motor may be extracted from the nameplate, whereas speed characteristics for new motors are obtained from manufacturers' catalogs.

The energy savings network

Plug into it!

1 Konstantin Lobodovsky, Ramesh Ganeriwal, and Anil Gupta, *Field Measurements and Determination of Electric Motor Efficiency.* Sixth World Energy Engineering Congress, Atlanta, Georgia, December 1, 1983.

2 Jeffrey Jowett and William D. Biesemeyer, *Facts and Fiction of HVAC Motor Measuring for Energy Savings.* American Council for an Energy Efficient Economy Summer Study on Energy Efficiency in Buildings, Volume 5, Asilomar, California, August 28-September 3, 1994.

3 Ramesh Ganeriwal, Anil Gupta, and Konstantin Lobodovsky, *Efficiency Measurement and Economic Evaluation of Conservation Alternatives for Electric Motors.*

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Motor Load Estimation Techniques

kilowatt ratio technique

$$\text{Motor load} = \frac{\text{kW input or volts}_{avg} \times \text{amps}_{avg} \times (\text{power factor} / 100) \times \sqrt{3} / 1000}{(\text{hp rated} \times (.746) / \text{full load efficiency})}$$

voltage compensated slip technique

$$\textit{Motor load} = \frac{rpm_{synch} - rpm_{measured}}{(rpm_{synch} - rpm_{full\ load\ (nameplate)}) \times \left[\frac{\text{rated voltage}}{\text{measured voltage}}\right]^2}$$

The Arizona Department of Commerce Energy Office has recommended against using the slip technique as an indicator of load and suggests that loads be estimated by comparing a motor's true root-mean-square (rms) amperage draw against its full-load or nameplate value. Thus, the load on a motor is defined as:

Amperage ratio technique

$$\textit{Motor load} = \frac{amps_{measured}}{amps_{full\ load,\ nameplate}} \times \left[\frac{volts_{measured}}{volts_{nameplate}}\right]$$

While the amperage of a motor is approximately linear down to 50% load, the relationship is not directly proportional (i.e., at 50% load, current is higher than 50% of full-load current). An improved version of the amperage ratio load estimation technique makes use of a linear interpolation between a motor's full- and half-load current values. The modified equation, useful for estimating loads in the 50% to full-load range, is:

$$\textit{Motor Load} = 0.5 + 0.5 \times \left[\frac{amps_{measured} \times \left[\frac{volts_{measured}}{volts_{nameplate}}\right] - amps_{50\%\ load}}{amps_{full\ load} - amps_{50\%\ load}}\right]$$

The current at 50% load ($amps_{50\%}$) can be found from manufacturer data or MotorMaster.

The accuracy of the amperage ratio methodology is best for motors with outputs exceeding 10 shaft horsepower (hp). Below 50% load, the amperage curve becomes increasingly nonlinear and is therefore not a good indicator of load. Amperage draws at 50% load for motors of different sizes and speeds are given in Figure 1. This figure can be used to approximate current values when specific motor data are not available.

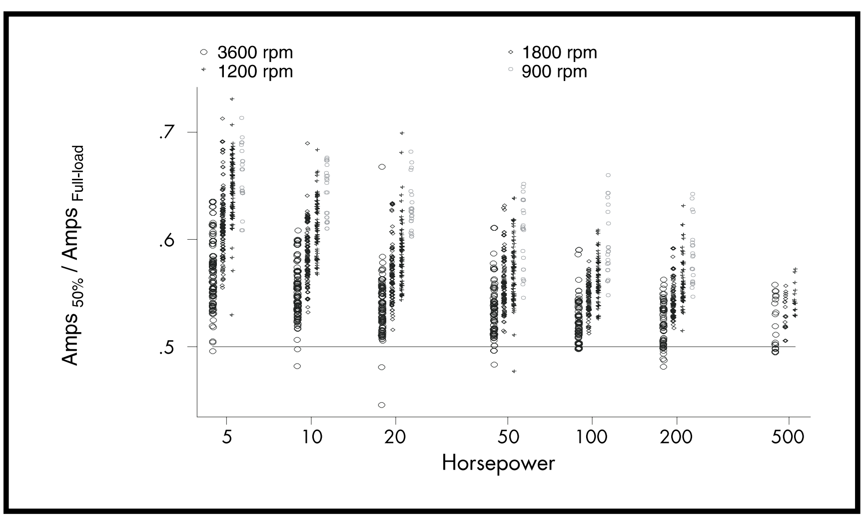

Figure 1

Efficiency versus Motor Load Relationships

The efficiency of both standard and energy-efficient motors typically peaks near 75% of full load and is relatively flat down to the 50% load point. Motors in the larger size ranges can operate with reasonably high efficiency at loads down to 25% of rated load. Efficiency values at partial load points are given in Table 1 for energy-efficient and standard motor models of various sizes.

An inspection of Table 1 indicates two additional trends: (1) larger motors exhibit both higher full- and partial-load efficiency values, and (2) the efficiency decline below the 50% load point occurs more rapidly for the smaller size motors. Thus, a 100-hp standard motor operating at 40% of rated load may operate as efficiently as an energy-efficient 40-hp motor operating at its rated load point. On the other hand, an energy-efficient 5-hp replacement motor could operate with an efficiency as much as five points above that of a standard 10-hp motor operating at its 40% load point.

Table 1
Efficiency at Full and Partial Loads for 1800 RPM, ODP Motors

	Full Load	75% Load	50% Load	25% Load
100 hp				
U.S. Motors - Premium	95.8	96.1	96.1	94.3
Reliance XE	95.4	95.7	95.4	93.2
Magnetek Standard	93.0	94.0	94.0	89.3
U.S. Motors - Standard	92.4	93.8	93.9	91.6
40 hp				
U.S. Motors - Premium	94.5	94.9	94.6	92.0
Reliance XE	94.1	94.1	94.0	91.4
Magnetek Standard	91.0	89.5	92.4	86.5
U.S. Motors - Standard	90.2	88.0	90.8	86.9
20 hp				
U.S. Motors - Premium	93.0	92.7	92.5	89.5
Reliance XE	92.0	93.0	92.0	84.8
Magnetek Standard	88.5	89.5	89.5	84.0
U.S. Motors - Standard	88.0	88.0	86.3	79.9
10 hp				
U.S. Motors - Premium	91.7	90.4	89.8	85.3
Reliance XE	91.7	92.2	91.8	87.8
Magnetek Standard	87.7	89.5	88.5	82.5
U.S. Motors - Standard	86.0	88.0	86.0	80.6
5 hp				
U.S. Motors - Premium	89.5	90.4	89.5	84.3
Reliance XE	89.5	89.7	87.5	82.6
Magnetek Standard	85.5	86.5	85.5	75.0
U.S. Motors - Standard	84.0	84.0	82.0	74.0
Source: MotorMaster database.				

Motor Load and Speed Relationships

The actual operating speed of an induction motor is somewhat less than its synchronous speed. This difference between the synchronous and actual speed is referred to as slip. Many energy-efficient motors tend to operate with a reduced full-load slip or at a slightly higher speed than their standard efficiency counterparts. This small difference can be significant.

For centrifugal fans and pumps, even a minor change in the motor’s operating speed translates into a significant change in imposed load and annual energy consumption. Fan and pump “affinity” laws indicate that the horsepower loading placed upon a motor by centrifugal loads varies as the third power or cube of its rotational speed. A seemingly minor 20 rpm increase in a motor’s rotational speed—from 1740 to 1760 rpm—can result in a 3.5% increase in the load placed upon a motor driving a pump or fan. In contrast, the quantity of air or water delivered varies linearly with speed.

Slip and operating speed are dependent upon applied load, and the loading imposed upon a motor is in turn dependent upon its size. For example, a 25% loaded 100-hp motor could be replaced by a 50-hp motor loaded to approximately 50%; a 62.5% loaded 40-hp motor; an 83% loaded 30-hp motor; or a fully loaded 25-hp motor.

As loads on a motor are progressively increased, it begins to rotate slower until, at the full-load point, operation occurs at the full-load speed. Thus, oversized and lightly loaded motors tend to operate at speeds which approach synchronous. An appropriately sized smaller or fully loaded energy-efficient motor, with a higher full-load rpm than the motor to be replaced, may actually operate at a slower speed than the original oversized motor. This speed and load shift can be significant and must be taken into account when computing both energy and demand savings.

For example, consider a 40% loaded, four-pole, 10-hp Siemens ODP standard efficiency motor which is to be replaced by a 5-hp, energy-efficient, U.S. Motors premium efficiency unit or a Magnetek E-Plus 3 motor. The Siemens motor has a full-load efficiency of 84.0% at a full-load speed of 1720 rpm. The U.S. Motors and Magnetek products both exhibit full-load efficiencies of 89.5% with full-load speeds of 1760 and 1740 rpm, respectively.

The Siemens motor would actually operate at 1768 rpm. The U.S. Motors energy-efficient motor would also rotate at 1768 rpm, while the Magnetek unit would turn at 1753 rpm. Energy savings, assuming 2500 hours per year of operation, are 849 kilowatt-hours (kWh) for the U.S. Motors unit and 1010 kWh for the Magnetek machine. While operating at this reduced speed, the Magnetek unit would provide about 1% less air or water flow. Energy savings and load points for the U.S. Motors and Magnetek motor are given in Table 2, assuming that the full-load speed for the oversized 10-hp motor ranges from 1715 to 1760 rpm.

Table 2
Energy Savings Due to Replacement of an Oversized Motor as a Function of Full-Load Speed

Full-Load rpm of Oversized Motor	Load Imposed on 5-hp 1780 rpm Motor, % of Rated	Annual Energy Savings, kWh*
1715	80.26	823
1720	80.00	849
1730	79.49	902
1740	78.98	955
1750	78.47	1007
1760	77.97	1059
No speed correction: 849 kWh		
Full-Load rpm of Oversized Motor	**Load Imposed on 5-hp 1740 rpm Motor, % of Rated**	**Annual Energy Savings, kWh***
1715	78.25	985
1720	78.01	1010
1730	77.52	1061
1740	77.03	1111
1750	76.55	1161
1760	76.08	1209
No speed correction: 803 kWh		

* Assumes replacement of a standard-efficiency 10-hp, 40% loaded motor with an energy-efficient 1800 rpm 5-hp unit with 2500 hours per year of operation.

Note that, if motor operating speed is ignored, the annual savings given replacement with the 1740 rpm Magnetek motor is 803 kWh. The energy savings could increase to 1209 kWh if the replaced oversized motor happened to have a full-load speed of 1760 rpm. This very real possibility would result in a savings increase of 406 kWh, approximately 50% greater than that predicted if speed correction factors are neglected.

A final word of caution is needed. The National Electrical Manufacturers Association does not require high precision for the nameplate full-load rpm value. An error of plus or minus 20% in slip is allowed. This can represent ±10 rpm for both the existing and replacement 1800 rpm motors. A significant uncertainty is introduced. Greater deviation in full-load rpm can occur if the existing motor has been rewound.

Using MotorMaster to Conduct Analyses of Oversized Motor Replacement Opportunities

MotorMaster software contains a speed/correction algorithm such that when the nameplate full-load speed of the motor to be replaced is entered, the increase or decrease in load for the replacement motor is automatically calculated. Speed change effects are thus used to determine annual energy and dollar savings and the simple payback from investing in a new, energy-efficient motor.

MotorMaster also contains full, 75%, 50%, and 25% load and power factor data for most motors. An oversized motor replacement analysis can readily be made, with MotorMaster interpolating to determine the efficiency at the appropriate internally computed load point for the new downsized motor. Equipment and installation cost data for the replacement motor are automatically entered into the analysis and speed correction is again automatically accounted for.

MotorMaster's Compare Section was specifically created to effectively and correctly conduct analyses of oversized and underloaded motors.

In addition, a Windows-based enhancement to MotorMaster, called MotorMaster+, is available. MotorMaster+ not only facilitates the selection of energy-efficient motors, but can also assist energy coordinators in implementing an effective energy management program. MotorMaster+ has many tools to support energy management activities. These tools include a motor inventory model, a field measurement and operating data storage repository, descriptor search and selective report-writing capability, internal motor load and efficiency estimation capability, MotorMaster database interface, and life-cycle costing analysis.

If you are interested in communicating electronically with other motor system professionals, review the motor-related forums on the Motor Challenge website. The Motor Challenge website can be accessed at http://www.motor.doe.gov.

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About Motor Challenge

Motor Challenge is a partnership program between the U.S. Department of Energy and the nation's industries. The program is committed to increasing the use of energy-efficient, industrial electric motor systems and related technologies.

The program is wholly funded by the U.S. Department of Energy and is dedicated to helping industry increase its competitive edge, while conserving the nation's energy resources and enhancing environmental quality.

BONNEVILLE POWER ADMINISTRATION

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For More Information

Contact the Motor Challenge Information Clearinghouse: 1-800-862-2086. The Motor Challenge Information Clearinghouse is your one-stop resource for objective, reliable, and timely information on electric motor-driven systems.

Access the Motor Challenge website on the Internet at www.motor.doe.gov.

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