REPLACE or REWIND?

The Impact of Rewinding on Motor Efficiency

Originally published by GE Motors, Ft. Wayne, Indiana
#GET-8014

Re-edited by SM Service & Technology, Union, New Jersey,
an Allied Partner, US Dept of Energy, Motor Challenge Program

When a motor fails, the user faces three choices: to rewind to the same efficiency, to rewind to a higher efficiency, or to replace it with a new motor of high efficiency or premium efficiency design. This paper covers the advantages and disadvantages of each approach and the precautions that must be taken to avoid increasing motor losses if rewinding is chosen.

Failed Motors: Rewind or Replace?

When motors fail, the user must decide whether to rewind or replace them. To make the proper decision, the user must consider the relative cost, availability of a replacement, the age of the motor, the type of electrical design, special mechanical features and the urgency of returning the motor to service.

Frequently, putting the driven equipment back in service is the highest priority, and users have made their decisions based on speed. In the past power was very inexpensive, so managers were not concerned if the rewound motor was less efficient and cost more to run.

The Growing Interest in Efficiency

Now U.S. industry is feeling a squeeze on profits due to a rise in power costs. In some industries, the cost of operating motors has actually surpassed the cost of labor as a percentage of sales. So it is no longer practical to view the power bill as a fixed base cost it would not take the effort to reduce. Many companies have hired energy "czars" whose sole purpose is to look for ways to reduce power costs. These managers are finding that because motors and other process components have been ignored for so long, they represent a major potential for cost reduction.

Rising Power Costs

In 1970, electricity cost the average industrial user about one cent per kilowatt-hour. By 1980, it cost four cents: a 400% increase in just ten years. Power costs are already over eight cents in most areas, and in some, over 12 cents per kilowatt-hour. As a result, electricity costs are a major component in the cost of finished goods.

First Cost vs. Operating Cost

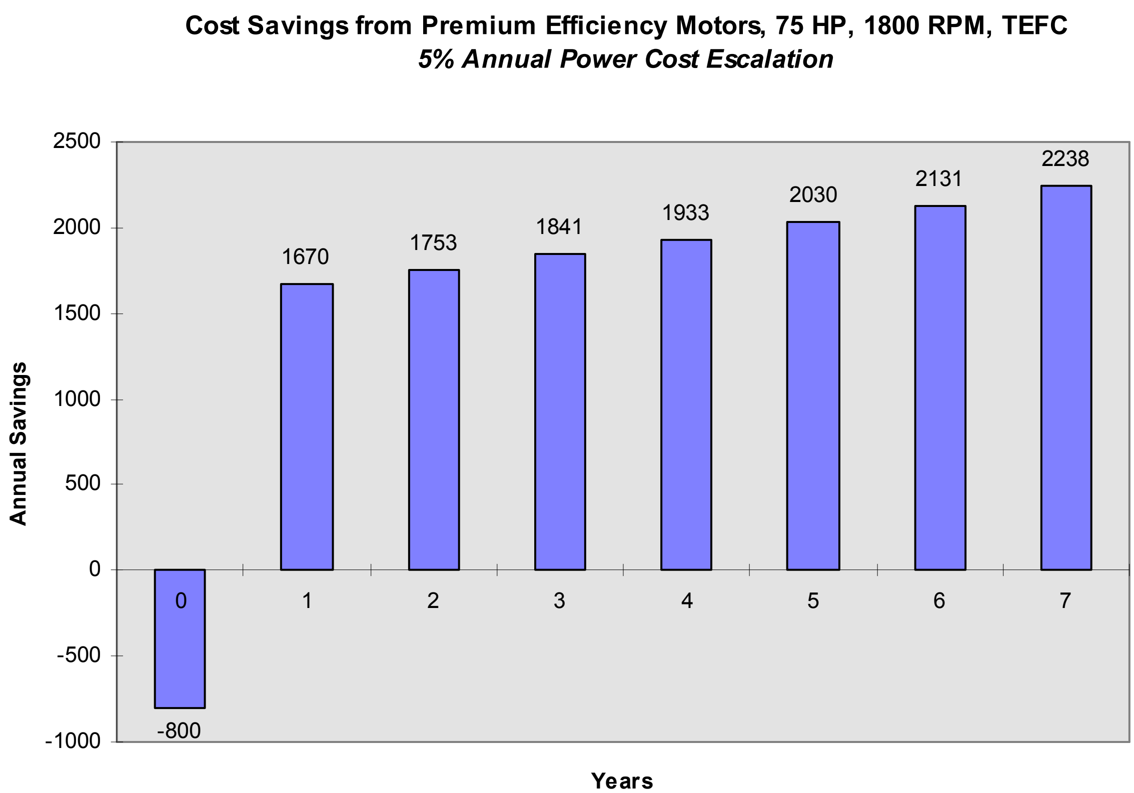
With power costs rising steadily, most users now look at the total cost of owning a motor rather than simply selecting it based on purchase price. Here's an example: a 75 HP, 1800 rpm, TEFC, severe duty motor sells for approximately $4,700, is of high efficiency design, has an efficiency of 91.7% and operates continuously on power that costs $0.08 per kWh. In the first year alone, the operating costs will be $42,270 or 910% of the first cost! Operating cost will equal first cost after only 40 days of operation. Even if the motor is used for only two shifts, (4160 hrs per year), this will occur after 60 days, and if used for only one shift, in just 120 working days. It's no wonder that more users are considering the operating costs in evaluating motor purchases.

An Incorrect Decision Costs Money

Consider the impact on total costs if the user selects a more energy efficient motor. For our example, let's say that a premium-efficiency motor costs about $5,500 or $800 more than the high-efficiency model. For a premium of just 17%, the user would have a motor with an efficiency of 95.4%. This would reduce the operating cost by $1,670 for continuous operation in the first year alone; a savings that would pay for the premium of $800 in roughly six months and continue and increase as the cost of power increases year after year.

Figure 1 shows incremental first cost and annual savings for a seven-year period, assuming an annual power rate increase of 5%. As you can see, by the seventh year the savings have risen to $2,238, an increase of over 30%. And over the total period, the savings amount to $13,596, which would repay the price premium over 16 times. Obviously, choosing a lower-cost, standard motor can be a costly mistake.

Figure 1:



New Factors in the Rewind Decision

With power costs rising and the cost of operating a motor so expensive, the question of how rewinding affects a motor's efficiency has become more important. Some users claim rewound motor is never as efficient as before the rewind; others say that a well-done rewind can be of even greater efficiency than the original design. This wide difference in perception indicates there are many factors involved.

Understanding the factors that affect rewind performance doesn't have to be complicated, however, if one keeps all the variables in mind. Let's examine the various types of motor losses and how they are affected by engineering decisions.

Keep in mind that motor losses may differ between two motors of the same design, depending on how the motor is used. ***Figure 2*** shows how motor losses vary with load. As a motor approaches 100% of rated load, losses increase dramatically, with most of the increase found in the form of rotor and stator losses (I^2R). The age of the motor is also a factor. ***Figure 3*** shows a progression of motor efficiencies through the years and demonstrates that motors have naturally become more efficient as design constraints have improved. (Note that these ratings are for GE motors since 1944; actual efficiencies will vary from manufacturer to manufacturer.)

Also, the distribution of the losses will be different for different designs of motors. Differences in speed, design and enclosure will affect loss distribution, as shown in ***Figure 4***. So the factors that are affected during a rewind depend on the ability of the repair shop to replace the parts that control the losses, such as the stator core, the windings and the rotor.

With all that in mind, let's take a look at losses in a typical 50 HP, 1800 rpm, TEFC, regular high-efficiency design. The distribution of losses is shown in ***Figure 5***. The table in ***Figure 6*** shows how these losses can be reduced. Here are some detailed explanations of the techniques.

Figure 2:

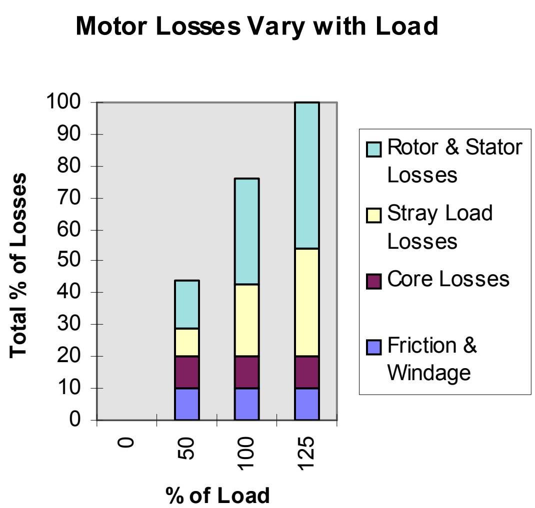


Figure 3:

History of Motor Efficiency, TEFC, 1800 rpm

HP	1944 Design	1955 U-Frame	1965 Normal Eff.	1999 Premium Eff.
7½	84.5%	87.0%	84.0%	91.7%
15	87.0%	89.5%	88.0%	92.4%
25	89.5%	90.5%	89.0%	93.6%
50	90.5%	91.0%	91.5%	94.1%
75	91.0%	90.5%	91.5%	95.4%
100	91.5%	92.0%	92.0%	95.4%

Figure 4:

Types of Motor Losses as a % of Total Losses in Standard Efficiency Designs

Motor Loss Component	3600 rpm	1800 rpm
Non-Load Losses:		
Windage & Friction	30%	11%
Core Losses	18%	22%
Total Non-Load Losses	48%	33%
Load Losses:		
Stator I^2R	34%	47%
Rotor I^2R	8%	9%
Stray Load Losses	10%	11%
Total Load Losses	52%	67%
Total Motor Losses	100%	100%

Figure 5:

Losses in a 50 HP, 1800rpm, TEFC, Standard Efficiency Motor

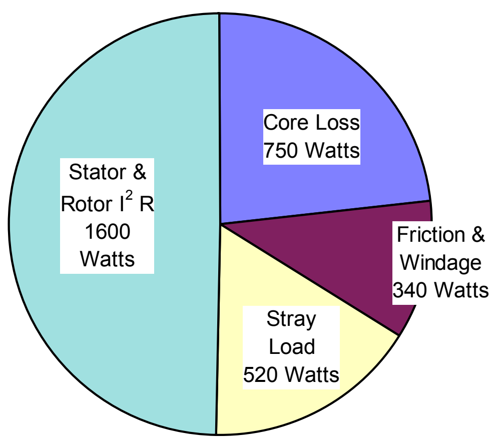


Figure 6:

Possible Methods to Reduce Losses Through Rewinding

MOTOR LOSS	IMPROVEMENT POSSIBILITIES
Stator Loss - I^2R	Increase amount of copper wire in slot Decrease length of coil endturns Decrease turns in stator
Rotor Loss	Decrease turns in stator

Stator Losses

Stator losses are primarily I^2R losses, released in the form of heat as current passes through the stator windings. When rewinding a motor, a smaller diameter wire will increase the resistance and the I^2 R losses; a larger diameter wire will cause the opposite. If the original wire was aluminum, a change to a same-size copper wire will also reduce resistance and loss. Obviously, using a larger diameter copper wire will affect the best reduction.

Another method of reducing stator losses is to reduce the number of wire turns. Use this method with caution. It may increase full-load efficiency, but will also increase starting current and decrease power factor. It also increases starting and maximum torque. A change from ten turns to nine turns would increase the starting current by as much as 23%.

Core Loss

Core loss is the sum of the eddy current and hysteresis loss that occurs while energizing the motor's magnetic field. Motors are insulated between the core laminations to minimize eddy currents, but stripping can destroy this insulation. When stripping a motor for rewinding, insulation burnout must be done at carefully controlled temperatures. Otherwise it is far too easy to overheat the laminations, breaking down the insulation in the core and actually increasing core losses. Not all repair shops use the same insulation burnout techniques. Investigate them thoroughly before deciding where to have a motor rewound.

Rotor Loss

These are I^2R losses, released as heat through the rotor slot and the end rings. If the number of wire turns is reduced in the rewind, flux density goes up, power factor goes down and rotor losses are reduced. Note that in most rewinds the number of turns in the rotor is unchanged.

Efficiency vs. Time

You have undoubtedly heard or read more than once that motor efficiency naturally decreases though the motor's life cycle as a result of "heat aging." The argument says that as the motor starts and stops the core temperature increases and decreases, causing deterioration in the electrical properties of the steel in the core and an increase in internal losses. This is only a problem if an aging type of steel is used in the core. GE motors and most others use non-aging steel that doesn't lose its electrical properties over time.

Rewind vs. a New Motor

Now that you know some of the pitfalls of rewinding, let's reexamine our options in the face of motor failure. Provided the downtime isn't critical, the user has these choices:

1. Rewind the motor to the original efficiency;
2. Rewind the motor to a higher efficiency;
3. Replace with a new motor of the same efficiency;
4. Replace with a premium efficiency motor.

A fifth option that no one would knowingly choose is to rewind the motor to a lower efficiency, but many users unwittingly make that decision. As mentioned above, it is very easy to damage the stator core insulation while stripping out the old winding and increase core losses by *three times* or more.

Figure 7 compares the typical results of each of the choices, with assumptions for the "poor quality rewind' figured at three times the original core loss. The high-fill rewind produces some efficiency gains when larger wire size is used. As would be expected, the greatest efficiencies are realized by retrofitting with new, premium-efficiency motors. ***Figure 8*** shows the annual operating cost difference for each of the four options listed above. Note that the operating cost can be increased by a poor rewind just as much as it can be decreased by a new, premium-efficiency motor. The conclusion is obvious: either replace failed motors with new, premium efficiency motors or exercise extraordinary care in the rewinding process, something that most users have no direct control over, nor knowledge of.

Figure 7:

Efficiency Percent Gain (Loss)
Rewind vs. New Energy Saver

HP	Poor Quality Rewind	Rewind ½ Wire Size	Rewind Full Wire Size	New Energy Saver
10	-6.0	+0.6	+1.1	+4.2
50	-3.7	+0.5	+0.8	+2.8
100	-2.1	+0.4	+0.7	+4.5
200	-1.9	+0.3	+0.6	+2.1

Figure 8:

Annual Operating Cost Difference
Rewind vs. New Energy Saver
Continuous Operation @ .10/kWh

HP	Poor Quality Rewind	Rewind ½ Wire Size	Rewind Full Wire Size	New Energy Saver
10	+$577	-$53	-$97	-$341
50	+$1,500	-$193	-$307	-$1,055
100	+$1,640	-$307	-$536	-$3,334
200	+$3,201	-$446	-$887	-$3,031

Protecting the Stator Core in a Rewind

No single aspect of the rewind process is as important as protecting the electrical integrity of the stator core. Not only can insulation damage increase core losses, but also the resulting rise in motor temperature could cause the motor to fail prematurely. You've probably had at least one motor that operated well for years before failing but failed again shortly after being rewound. The failure is more often the result of temperature rise than of defective materials or faulty workmanship in the new windings.

The obvious question is, "What is a safe insulation burnout temperature?" Unfortunately, there is no simple answer. Manufacturers use a wide variety of materials in building the core. Steel may be supplied with either an organic or inorganic insulation coating, or with no coating at all. If uncoated steel is used, the manufacturer will add an oxide insulation coating during annealing. Each of these lamination insulations has a different limit to the temperature it can take before deteriorating. So it's impossible to name a temperature safe for all motors. But there are some guidelines.

In all cases the stripping operations must control the core temperature to prevent damage to the interlamination insulation. Damage can occur in a low temperature oven when several cores are stacked and fire from burning organic materials results in increased temperature beyond the oven setting.

If the motor has organic lamination insulation, it will begin to deteriorate rapidly at around 500º F and may actually change its chemistry at higher temperatures. Organic insulation can be damaged in any oven hot enough to burn out the winding insulation.

Inorganic insulation can withstand temperatures up to 700º F. The old winding can be safely burned out if the oven temperature is carefully controlled.

Uncoated semi-processed steel laminations will stick together if they get too hot, increasing eddy currents dramatically. Motors with this type of steel should be stripped at oven temperatures of 700º F or below.

Stripping Methods

In the past few years, awareness has grown among users that poor quality motor rewinds can cause an increase in motor losses, so users have begun to demand an end to the practice of burning out the old windings at uncontrolled temperatures. Motor repair shops have kept pace with the technology, switching to temperature-controlled ovens and discontinuing the practice of softening varnish with a hand-held torch. Ask your rewind shop if they can perform these non-injurious stripping techniques:

- Mechanical Stripping
- Chemical Stripping
- High-pressure water jets
- Freezing process
- Ultrasonic Stripping

Regardless of the process used, make sure your rewind shop can follow the motor manufacturer's recommended safe burnout temperature limits. Some do and some don't, which is probably the main reason for one shop's reputation for better quality rewinds than another's. There is really only one way to be sure that losses have not been increased in the process, and that's to perform a qualitative core loss test before and after rewinding. This can also help you screen the motor population to determine if a given motor is even repairable. More and more repair shops are offering this service; ask your repair shop if they can.

Establish a Repair/Replace Policy

In response to the rising cost of electrical power, every company should establish a repair/replace policy to help you make intelligent decisions. Give every motor-driven machine in your plant a repair/replace priority, and consider an investment in spare motors for continuous process machines critical to plant operation. These "critical" machines are excellent candidates for retrofitting with premium-efficiency motors; the existing standard-efficiency motor should not be kept as a spare.

There's a good deal more to comparing relative in-use costs between motors than simple energy usage. Many power companies now offer special rebates to industrial and commercial customers through motor distributors for the purchase of premium-efficiency motors.

To help users make a total evaluation of in-use costs, the U.S. Department of Energy, through its Motor Challenge Program, has prepared software that will take into account all possible repair/replace scenarios and the costs associated with each. This Windows® based software is accessible and/or available free of charge to industrial and commercial customers from Allied Partners of the Motor Challenge Program.

However you arrive at it, if the decision is made to rewind a motor, there should be a full recognition that the motor represents an energy investment as well as an asset investment. Keep watchful eye on the repair shop selected to do the work to be certain they can repair the motor without reducing efficiency and increasing losses.

With today's high power costs and more increases inevitable, it is essential that you be aware of the factors that control motor losses and keep them in mind when making the decision to repair or replace. The decision is no longer a simple one, and repair techniques formerly considered acceptable must now be questioned and improved to meet the efficiency challenge in the years to come.