How hot is that motor?

It depends on where and how you measure the temperature, and according to which standard

By Richard L. Nailen, *EA* Engineering Editor

For a-c motors of any size or type (and no matter how much data has established that most motor failures involve the bearings), the ratings, insulation classes, and ventilation requirements will continue to be based on the winding temperature. Operating conditions, maintenance programs, and control systems are aimed at controlling that temperature. It's only natural, then, that motor users continue to focus their attention on keeping motors cool enough to provide reliable operation for an expected lifetime.

As has been emphasized in these pages, motor "life" is a nebulous term. Some engineers say motor "design life" is 15 years; others say 25 years – but there's neither a standard definition of the term nor any standardized way of calculating a "design life." Individual user experience will dictate an "expected life" based on individual judgment, but it will never be more than an estimate.

Nevertheless, the larger the motor, or the more critical its operation is to uninterrupted facility or process operation, many motor users will want to pay attention to motor winding temperature as one basis for life estimation. Some may use it to monitor motor load. Others may be interested in detecting overheating caused by buildup of contaminants inside the motor. Still others may be seeking guidance for occasional motor overload without risking immediate damage. A sophisticated plant operator may also choose to verify that operating temperature is within standard limits. Whatever the reason, measuring motor winding temperature on the job calls for some knowledge – and some test equipment – that's not always at hand.

The problem, of course, is knowing what the actual load is. Unless the motor terminal voltage can be accurately measured, as well as motor current, no one can be sure how actual shaft load compares with

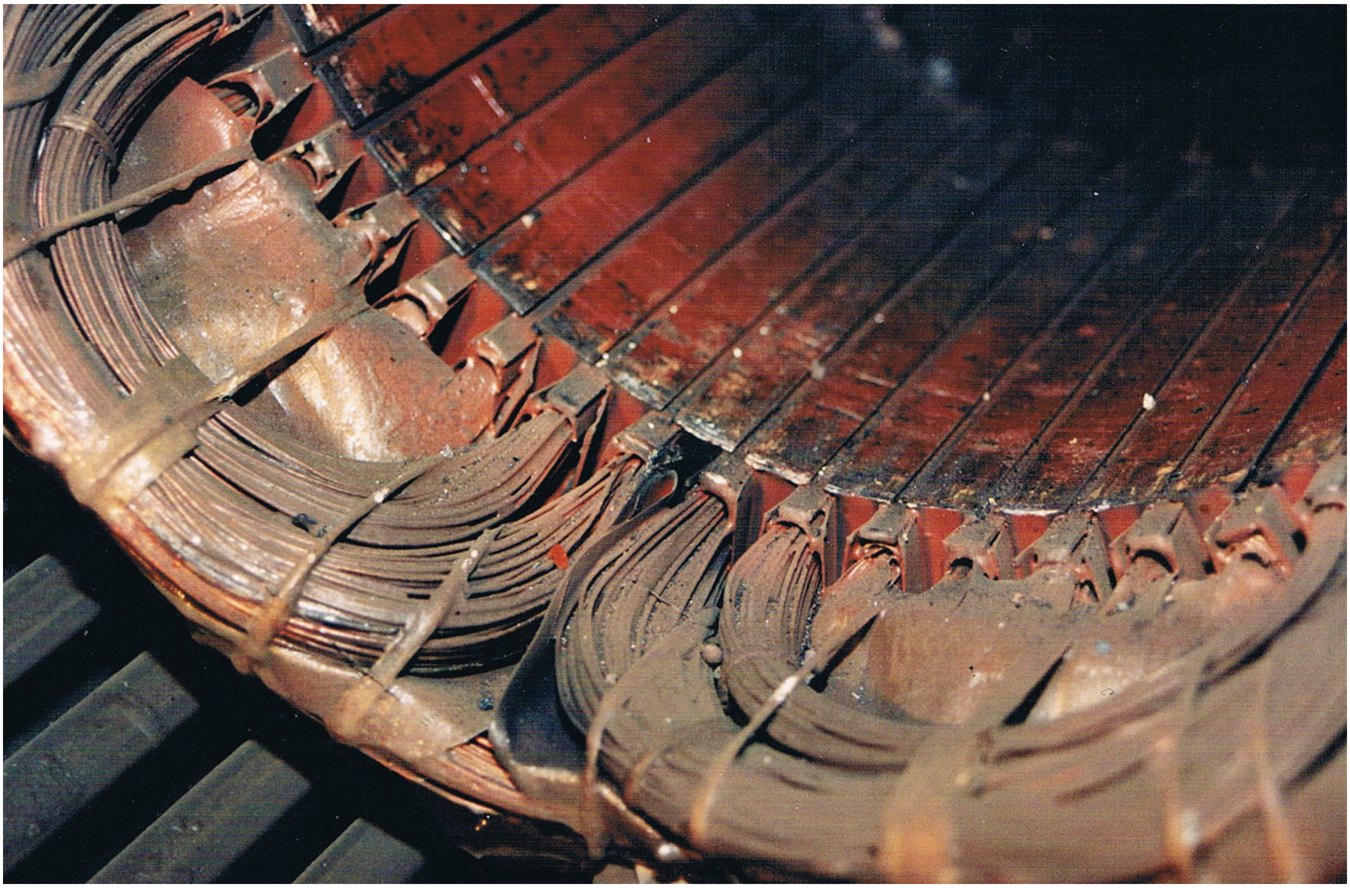

Figure 1. Typical result of winding overheating. Variation in overheating temperature is evident from pattern of discoloration in stator bore.
— *Electrical Apparatus* file photo

what's on the motor nameplate. The motor manufacturer's instrumentation typically allows electrical measurements within ½ percent accuracy – rarely possible in the field. But whatever the measured electrical input may be, the shaft power output is even less readily measured and seldom adjustable. The motor will supply what's demanded, and its temperature will rise accordingly. How is that temperature to be measured?

Temperature variations on the winding

We must recognize that considerable variation will exist among various locations on the winding. End-turn temperature will be lower than in-slot temperature. One end of the winding will often be hotter than the other. Measuring overall temperature by the "rise of resistance" method, which is the usual basis for the motor rating, won't distinguish such differences.

If, however, the motor is equipped with resistance temperature detectors (RTDs) – fairly common only in large machines – they will provide some observation of temperatures that vary around the winding circumference. User and manufacturer will need to agree on whether the range of all detector readings, or their average, is to be considered the "correct" value.

For most industrial motors, however, that's not a concern. They are normally rated and tested based only on an overall winding temperature indicated by the "change of resistance" method involving overall winding resistance. This takes no account of "hot spots" that might be present, neither their number or their size. When more than one "identical" motor is involved, however, we often find that the overall temperature rises are not identical.

One example of that: an order for four 500 hp 6 pole 4160 volt open drip-proof motors, from a user who specified a complete test on each unit. Average temperature rise by resistance for the four motors: 48°C, But the individual motor test values ranged from 42° to 58° – each within the design limit, but hardly "identical." The larger the motor, the more likely there will be only one unit ordered – leaving in doubt what to expect of any future duplicates. Why such variation? To name just a couple: end turn dimensional tolerances in the winding (influencing cooling air flow); lamination steel metallurgy variations.

In factory tests, especially for large motors, standard practice may be to measure winding temperature by thermocouple as well as by change-of-resistance. How those values might differ depends upon thermocouple placement, not only axial location on the winding, but by circumferential position. Variation of 10°C to 20°C is possible. As for the overall change of resistance, that method of measurement unavoidably includes the resistances of coil and phase interconnections.

Variations among tests

In one typical example, temperature rise by resistance averaged 60°C in two tests on the same motor. The readings of thermocouples placed on the stator core averaged 55°; on the end turns of the winding, the average was 47°. Such a pattern is consistent with winding temperature in general being less on the stator core surface than on the coils, and winding end turn temperature being less than in the stator slots because of exposure to ventilating air. What's important to remember is that all direct measurement involves compromise. No single value can be applied to temperatures throughout any machine.

What governs winding insulation life is not temperature rise, but total winding temperature including the surrounding ambient. The "standard" ambient temperature is 40°C. The typical industrial environment will not be that high – but outdoors in a desert environment, the air temperature may be higher. To correctly interpret overall motor winding temperature, then, we must decide what "ambient temperature" means. On the factory test floor, IEEE standard 119 once defined "ambient" measurement quite specifically, based on a number of measurements at different positions and at different distances from the motor on test. But although still available as a "reference," that standard has been officially "withdrawn."

The overall motor test standard IEEE 112 does not go into details of ambient. One motor manufacturer has described ambient as determined by "a thermometer suspended a few feet away from the motor" – hardly a precise definition. Still others define "ambient" as "the temperature of the air

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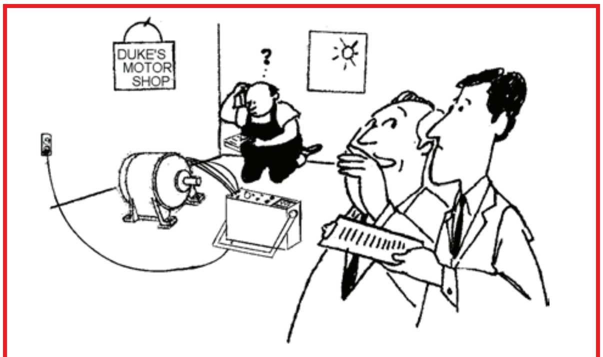


MOTOR TEMPERATURE continued from previous page

immediately surrounding the motor." One motor designer has cautioned: "Don't depend on a thermometer that is hanging on the wall across the room. The motor only cares about the air that it is using to ventilate itself." That seems reasonable – until you consider the group of 400 hp machines driving process machinery that subjected the motors to high radiant heat from that machinery, as well as heat conducted into the motors from the coupled shaft.

A study undertaken by another motor manufacturer once concluded that "tested motor temperature rise cannot count on consistency . . . within 10 percent." Among other things, that meant that "A design modification which appears to offset temperature rise by only . . . 2 or 3 degrees C is not worth making. . . . That variance is well within test inaccuracies." This opinion was based on readings of in-slot temperature detectors. Reasons:

1. Monitoring detector readings using direct-reading instruments meant ½ to 1 percent reading inaccuracy.

2. The angular position of detectors around the winding can result in wide variations in monitored temperatures. The pattern will be quite different for a vertical motor.

3. Measuring temperature by change in resistance means including the resistance of winding interconnections and leads. For a typical horsepower range from 300 through 2500, at 4160 volts, that can add nearly 2 ohms to overall winding resistance. Assume a 2300 volt machine with two cables per lead of No. 0 cable, extending perhaps four feet to the measuring bridge. Total resistance of those leads: 0.0005 ohms. A small number – but test floor metering can offer better than 0.1% accuracy. That "negligible" 5 ten-thousandths of an ohm can be almost one percent of the total resistance being measured.

4. A study undertaken in Germany considered resistance measurements made with a "normal commercial" bridge. The conclusion was that overall measurement error could be as high as ±9%. Reducing that to within ±2% would require measurement accuracy below a rarely achievable 0.3%.

All that becomes much more significant in 460-volt machines, where lead/joint resistances in winding interconnections can be as much as 10 percent of total winding resistance.

Variations among motors

So much for measurement. However accurate that may be, variations from one motor to the next can be more important. For example: temperature rise in some machines is quite sensitive to the contour of air passages around the winding end turns. This varies with winding design and coil pitch, location and size of interconnections, and coil bracing.

What's been said thus far applies to a straightforward "heat run," in which the motor to be tested is coupled to a loading device to supply a measured load while winding temperature is measured directly. The larger the motor, the less readily available is the necessary loading device – typically a dynamometer.

Hence, a number of temperature test methods have been developed without requiring such loading. National and international standards describe several of them, identified as Direct Load, Graphic Method, Back-to -Back, Forward Short Circuit, and Double Frequency Superposition. They vary widely in the auxiliary apparatus required and the accuracy achievable. Such methods may require two identical machines, auxiliary power sources, a special transformer, power supplies at two different frequencies – many variations, each becoming more costly as motor size increases.

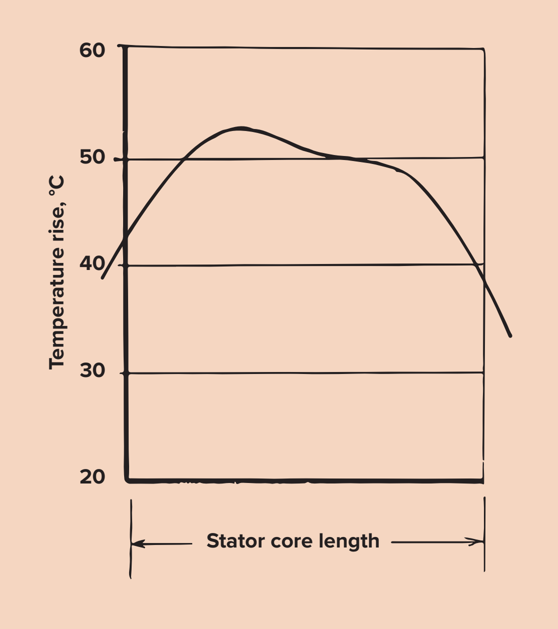


Figure 2. Temperature rise variation from one end of the stator to the other depends upon relative cooling air paths, both axially and radially (depending on whether the stator core itself contains radial vents). Measured "rise by resistance" is an overall average, taking no account of either location or magnitude of the "hottest spot" temperature.

One simulation that can be used when the available dynamometer is too small is the "over-voltage heat run." Operating at less than rated full-load output, the motor is supplied at a voltage much above its rating, resulting in total motor losses estimated to be approximately equal to what they would have been at rated load and voltage – a compromise when nothing else is possible.

In all this, we're not concerned with motor efficiency – only with temperature. Obviously, other things being equal, the lower the motor losses, the lower will be the temperature rise. Conversely, some of the causes of temperature variations can also be responsible for efficiency variations. Not to be overlooked: whatever the observed motor temperature, it will be subject to all these conditions:

1. Time of day. A motor operating at full load 24 hours a day will exhibit long-term temperature excursions quite different from a motor operating only 8 hours a day.

2. Indoor vs. outdoor; ambient temperature never above 30° – or "occasionally" above 40°.

3. Changes in load, whether random or planned.

In summary: the attempt to derive motor longevity based on specific operating conditions necessarily depends on many variables that can seldom be precisely known, as well as the unavoidable differences in performance within any group of "identical" machines. **EA**

A new urgency for utility-scale renewable energy

Utility-scale renewable energy – defined by the **U.S. Dept. of Energy** as wind or solar projects 10 MW and larger – have been steadily gaining favor among U.S. electric utilities, but their expansion has lately gained new momentum.

Behind this new urgency are tightening environmental regulations, increased public spending on renewable energy, and awareness of the vulnerability of oil and gas supplies as the repercussions of war ripple across Europe and the world.

Gains in the use of renewable energy become most apparent when compared with trends in the use of conventional energy sources, some of which are holding steady in use while others are declining.

Consider oil and natural gas. Short-term, we can expect their use to decline while hydropower remains constant and non-hydro renewables continue a gradual but steady increase.

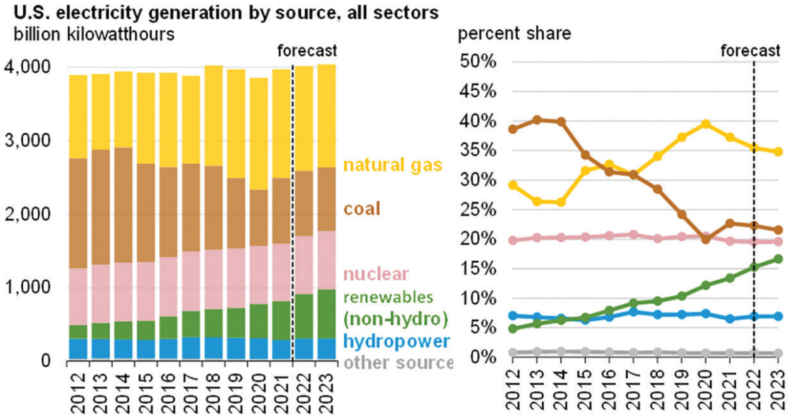
According to the **U.S. Energy Information Administration,** the share of power generated by natural gas in the U.S. is likely to decline from 37% in 2021 to 35% in 2022 and 2023, while the share produced by coal is on track to slip from 23% to 22%. The share of power produced by renewable energy sources, meanwhile, is expected to climb, from 20% to 22%, placing it on a trajectory to surpass coal as a power source within a few years. (See chart.)

Renewable energy's steady uptrend was interrupted last year by congressional stalemates in Washington. According to *Utility Dive,* clean energy installations slipped 3% in 2021 compared with 2020 as the development of new wind and solar installations was stalled by political wrangling over the Infrastructure Act and the failed Build Back Better bill.

And yet, as is evident from the chart at right, this 3% dip barely registers when viewed over a ten-year span. With the Washington stalemate having been somewhat resolved and the details of the Infrastructure Act becoming clearer, utility-scale renewable energy appears to have resumed its upward trend – but this doesn't mean there won't be additional bumps on the road ahead.

According to energy research firm **Rystad Energy,** new utility-scale renewables capacity is set to break records this year, hitting an all-time high of 220 GW worldwide, but a "slowdown of capacity additions could be around the corner as construction start-ups of large-scale projects are expected to stall," Rystad Energy says.

According to Gero Farruggio, head of renewables research at the firm, rising steel prices are constraining the development of new onshore wind projects, "as the cost of steel accounts for almost 70% of the final price of wind installations." These price increases are likely to be somewhat offset, Farruggio said, by increased capacity for the manufacture of polysilicon, a raw material used in the solar photovoltaic supply chain.



Source: U.S. Energy Information Administration, Short-Term Energy Outlook, February 2022

Governments worldwide are taking steps to help renewables fill the looming fossil fuel gap

A huge wild card has been thrown into the game since the results of these studies were released. The Russian invasion of Ukraine has thrown the global oil and gas markets into chaos, as nations around the world have stopped buying Russian commodities in retaliation for Russia's aggression.

Of course, the shutoff of Russian oil and gas will affect different nations differently, depending on how heavily they depend on Russia as an oil and gas source. And yet no nation will be immune to the effects of the war, as the price of oil is set on the international market.

According to a report published by Reuters in early March, Russia supplies more than a third of Europe's natural gas. On a global scale, however, Russian commodities are less significant. According to the **Center for Strategic & International Studies,** "Russia exported about 4.3 million b/d in crude last year, equivalent to 4.5% of global demand, including 2.6 million b/d to Europe via pipeline and seaborne exports." According to a March 7 article in the *Wall Street Journal,* "about 8% of U.S. imports of oil and refined products, or about 672,000 barrels a day, came from Russia last year."

The Russian invasion of Ukraine has made populations around the world, particularly in Europe, acutely aware of the need to become more energy-independent, and many see utility-scale renewable energy as part of the solution. Governments worldwide are taking steps to help renewables fill the looming fossil fuel gap.

The Italian newspaper *Il Giornale,* for example, reported in early March that German economy minister Robert Habeck intends to speed up the passage of the Renewable Energy Sources Act in parliament so that it can take effect by July 1. Habeck said that faster expansion of renewable energy is the key to reducing the dependence of Germany on Russian fossil fuels. "These steps would help renewables account for 80% of Germany's electricity needs by 2030 and all by 2035," the minister was quoted by the newspaper as saying.

The private sector, too, is doing its bit to spur the development of utility-scale renewable energy. The renewable energy market is mature enough that numerous companies experienced in the development of renewable energy projects are prepared to lend a hand.

One of these companies is **Ameresco,** an energy-services company that helps client utilities diversify their energy supplies while "supporting a sustainable energy future." It does this by helping clients navigate and finance new energy-efficiency projects, develop micro-grids and distributed-energy systems, and design, build, operate, and maintain power plants and energy assets. "We are on a mission to help communities and clients become most resilient," the company says.

Resiliency. It's a priority that seems most apt in these days of global uncertainty about energy. – *Kevin Jones* **EA**