ELECTRIC POWER RESEARCH INSTITUTE

TECHNOLOGY INSIGHTS

A Report from EPRI's Innovation Scouts

COPPER-ROTOR MOTOR: IMPROVED EFFICIENCY MOTOR IS NOW AVAILABLE COMMERCIALLY

THE TECHNOLOGY

Electric motors with copper rotors offer significant improvements in efficiency. Thanks to breakthroughs in die casting, this technology is becoming available for a wide variety of industrial and commercial applications.

THE VALUE

Because electric motors are used in almost every industry and account for the largest use of electricity, significant gains in their efficiency could provide benefits to utilities, electricity consumers and society.

EPRI'S FOCUS

With copper rotor technology ready for commercialization EPRI is in a position to monitor the technology's advancement and to drive consideration of copper die cast applications in other electric technologies.

TECHNOLOGY OVERVIEW

Copper-rotor motors substitute a copper rotor for the traditional aluminum rotor in electric motors. Because copper's volumetric electrical conductivity is about 66% higher than that of aluminum (and hence has a lower resistance to electricity flow), waste heat (I2R losses) is reduced, increasing the efficiency of the motor [1]. The primary hurdle to overcome in development of this technology was the challenge of die casting the copper rotor, due to its higher melting point (1083°C or 1981°F) compared to aluminum (660°C or 1221°F) and consequent reduction in tooling life. These challenges have now been overcome due to the efforts of the Copper Development Association Inc. (CDA) and International Copper Association; the former has patented the method it developed to enable economical die casting of copper. CDA licenses the technology to manufacturers—three of which today offer commercially available copper-rotor motors.

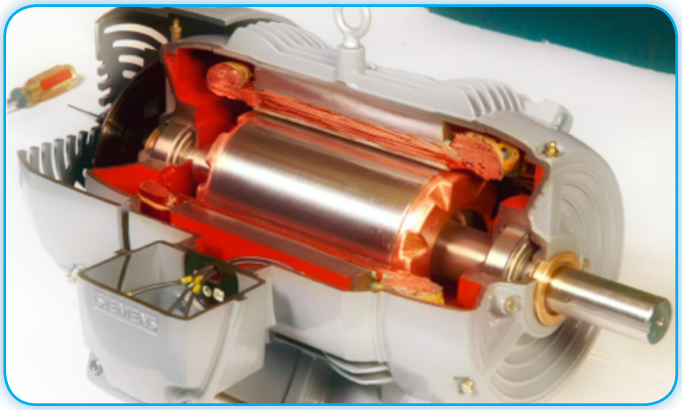

Figure 1 – Cutaway view of a copper-rotor motor (Source: Siemens)

The technology is applicable to electric motors in a variety of applications. These include severe duty applications in paper processing, petrochemical plants, and refineries; conveying and food/beverage production; severe duty trucks; various specialty applications with demanding requirements; and others. The potential impact of this technology is significant in light of the fact that electric motors account for 23% of total U.S. energy use.

BASIC SCIENCE

The stator portion of an ac induction motor accounts for about two-thirds of the electrical losses in the motor. To reduce these I2R losses, motor manufacturers have incorporated copper into the stator. The motor's rotor accounts for about 25% of the motor's overall losses [1]. Yet incorporation of copper into motor rotors has proven to be difficult due to manufacturing challenges. CDA analyzed this problem, developed solutions, and tested the solutions. A CDA computer analysis of the heat transfer in dies showed steep thermal gradients from the die surface when casting a high melting point metal such as copper for rotors. CDA identified suitable high-temperature mold materials, including tungsten alloy Anviloy 1200, forged and solid-solution-strengthened nickel-base alloy INCONEL alloy 617, and Haynes alloy 230. The latter was recommended. The CDA team then showed that operating the dies and shot sleeve at elevated temperatures (625°C–650°C or 1157°F–1202°F) could significantly extend tooling life. They found that surrounding a heated shot sleeve with a thermal wrap was helpful in maintaining heat and reducing thermal fatigue. They also showed that to cast small numbers of copper rotors, a shot-by-shot induction melting method is practical, rather than the method of gas-fired melting in a large-volume furnace that is used to manufacture aluminum rotors. To mass produce these copper rotors, CDA recommended induction melting in enclosed furnaces in a protective nitrogen atmosphere [2].

POTENTIAL IMPACT

Electric motors are pervasive in society, especially in the commercial and industrial sector. They are used in almost every industry and are the single greatest category of electricity use in the United States [3]. They are also increasingly used in vehicles as electric vehicles proliferate. Hence, any advancement in electric motor efficiency would have a huge impact when implemented on a broad scale. This is potentially a disruptive technology in that it may lead to wide-scale replacement of electric motors prior to existing motor failure. The reason is that efficiency paybacks may be relatively short, eliminating the need to replace electric motors only at the end of their life (see the Value to the Industry section that follows for more information).

This technology provides breakthrough potential due to its ability to meet tightening government standards for energy efficiency of buildings. For example, the Energy Policy Act of 2005 (EPAct) requires government agencies to specify only premium efficient motors, which are typically known as NEMA Premium energy-efficiency motors. However, today, copper-rotor motors may exceed the efficiency of NEMA Premium energy-efficiency motors [3].

VALUE TO THE INDUSTRY

Electric motors account for 23% of total U.S. energy use, 40%–50%of commercial energy use, and 67% of energy use [4]. Due to the ubiquitous nature of electric motors, increasing motor efficiency by only 1% in all U.S. electric motors would save 20 billion kWh of electricity per year, at an annual cost savings of about $1.4 billion (assuming an average electricity cost of 7 cents per kWh) [2].

Moreover, the cost of the electricity that an electric motor uses over its life accounts for about 98% of the total cost of ownership (TCO) of the motor; only about 2% is the first cost of the motor. Hence, even if the motor is a bit more expensive to produce, if it can significantly reduce electricity use, it can reduce the TCO [4].

Copper-rotor motors provide various motor design options for various applications. A copper-rotor motor can operate more efficiently at the same motor size, compared to a traditional motor. Alternatively, a copper-rotor motor can provide the same specific energy-efficiency level at a smaller size and possibly weight than a traditional motor. Total manufacturing cost can be reduced at the same efficiency level, compared to a traditional motor. And of course, copper-rotor motors provide the option to achieve very high efficiency levels, where size and weight are not the primary drivers [2].

In one documented example of the cost savings of copper-rotor motors, mineral producer NYCO Minerals, Inc. in New York replaced 150 electric motors in sizes ranging from 1 hp to 20 hp throughout its operation in 2007. NYCO expects that many of the motors will pay for themselves in energy savings in two to three years [1].

STATE OF THE TECHNOLOGY

Copper-rotor motors are at a technology readiness level (TRL) of 9 (commercialization). Today, at least four motor manufacturers produce copper-rotor motors. SEW Eurodrive GmbH and Siemens AG of Munich, Germany (through its U.S. operating company Siemens Energy and Automation Inc.), both produce these motors for the U.S. market; both began offering the devices in 2006. FAVI S.A. of Hallencourt, France, also manufactures die-cast copper rotors for use by motor manufacturers, including ITT/Grundfos in Europe, but does not sell them in the United States. Siemens markets motors in the 1–20 hp range for severe-duty applications such as paper processing, petrochemical plants, and refineries. IndustryWeek named Siemens' motor design one of the technologies of the year in 2006 [5]. SEW Eurodrive offers the motors in the 1–30 hp range, initially in conveying and food and beverage production [6]. Reliance Electric produces 140-hp copper-rotor motors that power U.S. Army severe-duty trucks [7]. COPPER.ORG points out that this technology can also be practical for highly specialized applications, where motors need to operate at high rpm, at high power ratings, very quietly, or at very close tolerances [8].

PUBLIC LITERATURE

This Technology Insights Brief summarizes the public literature on this technology. For more information, see the references.

NEXT MILESTONE

Commercialization (TRL 9) of the copper-rotor motor has been achieved. CDA states that future work can include application of the advanced die-casting technology with copper alloys and other materials to a variety of products other than motors [9].

INDEPENDENT ASSESSMENTS

Dr. Edwin Brush of BBF & Associates in Weston, Massachusetts, conducted a cost study for the CDA. The study compared the cost of existing commercial EPAct/EFF-1-compliant motors (a composite of the motors of six major manufacturers) with copper-rotor motors of similar operating characteristics and efficiencies. This study concluded that 7.5-hp copper-rotor motors cost an average of 18% less to produce and 15-hp copper-rotor motors an average of 14% less to produce than comparable existing motors [10].

CDA purchased several copper-rotor motors from a distributor and submitted them to various laboratories for evaluation according to IEEE/ANSI 112-1996 U.S. test methods. The results of this testing at a nationally accredited independent laboratory (Advanced Energy in Raleigh, North Carolina) showed that the motor exceeded the 91.7% nominal rating for a NEMA Premium motor of this size and type, as well as its nominal nameplate rating, at various rated loads. This testing also showed that the motors' operating temperatures were well within Class B (40°C or 104°F) limits, indicating a high likelihood of a long life [11].

The New York State Energy Research and Development Authority (NYSERDA) evaluated 10-hp and 20-hp Siemens AG copper-rotor motors at a brass mill and water treatment plant in 2006. The program "conclusively showed that ultra-high efficiency, copper-rotor motors can provide substantial energy and cost savings, both over the short and long terms." The evaluation also concluded that incorporating a variable frequency drive improved savings. The study identified "strong indications" that the motor's "lower operating temperatures will result in longer service lifetimes, thereby extending the savings…" [12].

COLLABORATION

CURRENT COLLABORATORS

The Copper Development Association Inc. (CDA) and International Copper Association, both headquartered in New York City, were the primary drivers of copper-rotor motor development. CDA is also active in technology transfer to commercial companies, as well as process demonstration. A variety of information on the technology is publicly available (see the references for more information). CDA sells licenses to the technology to manufacturers.

EPRI ENGAGEMENT

The Electric Power Research Institute (EPRI) continues to monitor the development of copper-rotor motors.

OPPORTUNITIES FOR COLLABORATION

This technology offers a wealth of further opportunities for collaboration, especially in the area of additional applications of copper die casting. A logical collaboration would include joint consideration of possible additional applications in the generation, delivery, and end use of electricity by EPRI and CDA, followed by scoping studies, development, and demonstration.

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