The Evolution of the Die Cast Copper Motor Rotor

The copper industry has been investing in the potential of die cast copper motor rotors for 15 years. As in many research and development activities, the technical focus shifted over time and application opportunities changed. Solving the initial technical challenge was only the beginning; launching this new technology has required persistent effort and the right market conditions.

SEW Eurodrive with Traditional Aluminum Rotor (Left); with a Copper Rotor (Right

The mid-1990s saw great interest in the development of more efficient, lighter, and smaller AC induction motors for use in industry and government sectors. Passage of the U.S. Energy Policy Act of 1992 and similar legislation in Europe reflected a growing awareness of the importance of motor efficiency in the larger arena of energy conservation. Industrial motors consume about 40 percent of global electricity production, so any improvement in efficiency is significant. Industry responded to this legislation with more efficient motors using an increased amount of copper in the stator windings, thereby reducing resistive, or I^2R, losses.

As this project was initiated in the mid-1990s following decades of incremental improvements in induction motor efficiency, few technical opportunities remained to reach significantly higher efficiencies at a reasonable cost. The die cast copper rotor appeared to be the best approach. Copper in the rotor reduced resistive losses in the motor on the order of 40 percent and had the potential to reduce overall losses by 10 - 20 percent, compared with conventional aluminum rotor motors. It was subsequently shown that motors with copper rotors can be made smaller and lighter and can operate at lower temperatures to decrease maintenance requirements. Despite these advantages, existing copper die casting methods were not economical for high-volume production. In addition, motor manufacturers demanded that the copper rotor be fabricated in commercially available pressure die casting equipment.

Pursuing the Opportunity

In 1996, recognizing that a copper rotor was a sound design platform for increasing the efficiency of industrial induction motors, thereby gaining energy and cost savings in motor-driven applications, the International Copper Association Ltd. (ICA) initiated funding for an R&D project to create a practical copper motor rotor suitable for mass production. Led by the U.S. Copper Development Association Inc. (CDA), a consortium of motor manufacturers, die casters and government representatives initiated (and cooperatively funded) the Die Cast Copper Motor Rotor program.

Challenges

Researchers addressed the challenges of reducing processing cost and assuring adequate copper rotor performance. During the high-pressure die casting process, conventional die steels are susceptible to surface cracking (heat checking) due to thermal stress and strain in the die as temperatures cycle from a few hundred degrees to the melting point of copper (about 1085ºC, 1984ºF). Die casting life decreases drastically when casting copper compared to aluminum, which melts at 660ºC and, therefore, induces significantly lower thermal stress and strain in the die. It was also recognized that the design of the rotor and motor should be changed to apply copper more effectively

Solutions

The CDA-led team of industry and academic researchers determined that die cracking could be reduced and die life extended with two changes: replacing critical portions of the steel die with a ductile, heat-resistant, nickel-base super alloy and pre-heating the die to approximately 600ºC (1,100ºF). These actions rendered the copper die casting process economically viable. Motor deign was also investigated. Starting torque is reduced in a high-conductivity rotor conductor, so the shape of the rotor bars, or rotor slots, was modified to further improve the motor's operating characteristics. This was done to incorporate a starting bar to take advantage of copper's high conductivity, allowing the rotor designer to use the "skin effect"—the tendency of alternating current flow to crowd toward the external conductor surfaces. At a given efficiency, a copper rotor uses less lamination steel in the rotor and stator stacks to save material costs, possibly reducing the overall size of the motor.

The Opportunity in Standard Industrial Motors

By spring 2006 one major international motor manufacturer, Siemens, had embraced the new die cast copper rotor technology and brought to market a line of super-efficient industrial motors. Within a year, the motors found widespread commercial acceptance in the U.S. The motors were up to two percentage points more efficient than those meeting NEMA Premium™ standards and offered substantially lower life-cycle costs. While the initial cost of purchasing a copper motor rotor may be higher than an alternative solution, the life-cycle cost for a less efficient motor far exceeds the cost of a copper motor rotor. The initial cost represents only 2 percent of the total cost of ownership. Energy costs, maintenance and other variables make up the other 98 percent of the cost over the lifetime of the motor.

Siemens Super-premium Motor with Die Cast Copper Rotor

The Opportunity in Integral Motors

Several manufacturers of electromechanical system components recognized the value of using a copper motor rotor. They believed the overall size of the motor could be reduced to exactly match the requirements of their equipment. Rather than continue to exclusively use aluminum rotor motors, a leading manufacturer of motor-driven gear-drive systems, SEW Eurodrive, decided to reduce the product variations in their product line and use integral motors with die cast copper rotors in about a third of their product line. This allowed retrofitting existing drives with high-efficiency motors that would fit in the same package. This large scale commercial application signaled that the challenge facing die casting copper rotors had been overcome. Other manufacturers followed. Applications for integral motors include compact, lightweight electro hydraulic systems for aircraft, refrigeration compressors and traction motors.

The Opportunity in Automotive Propulsion

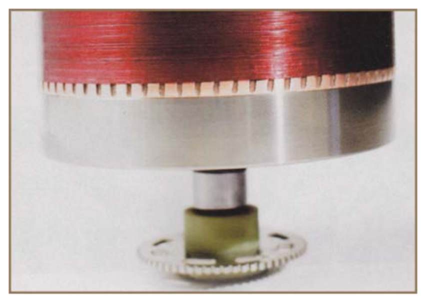
As global interest in electric vehicles increased, automotive engineers recognized that they required special motor designs to meet complex technical, cost and volume production requirements. Interest in using motors with die cast copper rotors increased due to concerns about the availability of rare earth materials such as neodymium and magnet performance at elevated temperatures. Technical studies showed that induction motors could have similar compact, high-power density and higher system efficiency in a parallel hybrid-drive system, generating interest in using die cast copper rotors. With funding from the U.S. government, Baldor Reliance demonstrated a hybrid military vehicle using four fluid-cooled, very high-energy density traction motors with die cast copper rotors.

Hybrid Military Vehicle

In the parallel hybrid traction application, the copper motor rotor offered substantial advantages:

- The ability to redistribute losses to the stator for more effective cooling due to reduced size and weight
- The ability to be de-excited when not producing torque, thereby eliminating no-load rotational and magnetic losses
- The meeting of efficiency requirements across a broader range of loads and speeds
- Better mechanical properties and ruggedness than aluminum-rotor or fabricated copper rotor motors
- Use of readily available copper and steel

Around the same time, Tesla Motors launched their plug-in electric vehicle with a power train that included a motor with a 32.5 cm diameter copper rotor with a maximum operational speed of 13,500 RPM, a power inverter and lithium ion battery packs. (The large amount of copper in the inverter, cables, batteries and motor reduces electrical losses and avoids heating under high-amperage conditions). More automakers are investigating power trains using induction motors for a variety of vehicles with die cast copper rotors. Millions of cars with copper motor rotors at their core will signal success for copper and a substantial contribution to sustainable transportation.



Copper Motor Rotor in Tesla Motor's Powertrain

Continuing Research, Development and Commercialization

The ICA has helped to develop and transfer copper motor rotor die casting technology to manufacturing companies across the world. The capacity to produce die cast rotors for automotive propulsion exists in Germany, France, Japan, Korea, India, Taiwan, China and the U.S.

Research into the vertical die casting process continues at the Non-Ferrous Technology Development Centre (NFTDC) in Hyderabad, India. This work is supported by ICA with co-funding from the U.N. Common Fund for Commodities and the Global Environment Fund (GEF). The technical team at NFTDC has developed sophisticated, cost-effective methods for die casting copper rotors and is now licensing this technology to industry for application in industrial motors and vehicle powertrains.

Beginning in 2006, with the support of the ICA, Yunnan Copper Group and Nanyang Explosion Protection Group established a joint venture company, Yunnan Copper Die Casting Co. Ltd (YCD), to commercialize copper rotor motors in China. In the last five years, based on hundreds experiments and tests, a sophisticated and mature technology base on horizontal press was developed and is already licensed to industry. YCD has produced more than 100 different types of rotors for 18 OEMs.

Cross-section through Rotor Bars and End Ring of Die Cast Copper Motor Rotor

The ICA has supported the Chinese government in developing two national standards for super-efficiency motors including copper rotors. These are the world's first national standards for industrial motors with copper rotors.

Collaborative Technological Projects

The Die Cast Copper Motor Rotor program embodies the principles and objectives of the Copper Applications Technology Roadmap. As a result of well-defined technological needs, industry has organized collaborative effort to fund and implement projects that produce innovative solutions that benefit society at large.

Cross-section through Rotor Bars of Die Cast Copper Motor Rotor

Facts

- Direct ICA funding 1996 - 2010: $2.1 million
- Co-funding from industry and governments: >$10 million
- Die cast copper motor rotors produced: >500,000

Key Business/Technology Learning

- Die casting of copper motor rotors is entirely feasible and commercially viable on horizontal and vertical die casting machines.
- Motor designs and rotor design must be optimized to use die cast copper rotors effectively. Substituting a copper rotor for an aluminum rotor does not achieve maximum benefits.
- The initial focus on high-efficiency, standard industrial motors, which was reasonable in 1996, is still attractive and economically viable. Further improvements in required energy efficiencies and Minimum Energy Performance Standards will assist in further penetration of die cast copper rotors due the fact that other material/design improvements have already been incorporated. The U.S. Department of Energy and regulators in other countries are now studying raising the minimum efficiency standard for industrial motors to a "super super premium" range. An announcement of this U.S. standard is expected in 2012 for adoption in 2015.
- Custom motor designs can benefit from the reduced material use, compact size and lighter weight enabled by a die cast copper motor rotor. The die cast copper motor rotor appears to be well suited to the needs of automotive propulsion systems, which was not a focus of the initial technology development effort.
- Motor-driven systems using die cast copper motor rotors in industrial induction motors is no longer a research priority in the Copper

YCD Die Cast Copper Motor Rotors

Applications Technology Roadmap. This is because attention has shifted from research to application engineering and large-scale commercialization. The challenge of applying die cast rotor motor technology to automotive propulsion systems remains a focus area.