PROJECT DESCRIPTION

APPLICATION OF HIGH TEMPERATURE MOLD MATERIALS

TO DIE CAST THE COPPER MOTOR ROTOR

Introduction

It is well known that incorporation of copper for the conductor bars and end rings of the induction motor in place of aluminum would result in attractive improvements in motor energy efficiency.

Die cast motor rotors are universally produced in aluminum today because of fabrication by pressure die-casting is a well-established and economical method. Only small numbers of very large motors utilize copper in the rotors by fabrication. Such fabrication involves intensive hand labor and therefore is expensive. Die casting, when it can be performed, is widely recognized as a low cost manufacturing process. For these reasons, die-casting has become the fabrication method of choice and aluminum the conductor of choice in all but the largest frame motors. Tool steel molds as used for the aluminum die casting process have proved to be entirely inadequate when casting higher melting point metals including copper. Lack of a durable and cost effective mold material has been the technical barrier preventing manufacture of the “copper cast rotor” (CCR).

An important study sponsored by the Department of Energy found that motors above 1/6 Hp used about 60% of the electricity generated in the United States.(1) Medium horsepower motors, 1-125 Hp, use about 60% of the electricity supplied to all motors. Because of the proliferation of electric motors in this horsepower range, the target of this project, the projected energy savings of the copper rotor motor is a significant national consideration. Efficiency increases (a function of motor size) are projected to result in total energy savings in the year 2010 of 20. 2 E+12 Btu/yr at only 10% market penetration and 143 E+12 Btu/yr at the expected market penetration of 50 to 70% (dependent on motor size). These numbers are equivalent to the yearly output, respectively, of 0.5 to 3.5 600 MW generating plants operating at 75% of capacity.

Problem Statement

Utilizing high temperature, thermal shock resistant materials, design, fabricate and demonstrate molds designed to withstand the copper motor rotor die casting environment for an economically acceptable life, i.e., thousands of casting cycles.

Program Summary

Several candidate die materials have been identified; beryllium-nickel, nickel-based superalloys, and one or more compositions in the tungsten-based composite family produced by a high-speed chemical vapor deposition (CVD) technique by the ThermoTrex Corporation. In the *first* phase of this project, end ring molds of several materials were fabricated and tested on an 800 ton horizontal shot controlled pressure die casting machine located at Formcast in Denver, Colorado. During the second phase of this project, the most promising mold material from Phase I will be fabricated into motor rotor molds and run for an extended number of shots at this same facility. For these runs, motor company partners will supply iron lamination stacks for appropriate motors designed to use copper rotor conductors. The motor partners will test the performance of the copper cast rotors.

Program Partners

The Copper Development Association Inc assembled the consortium of partners for this program during 1995. A DOE-NICE^3 application was submitted in January, 1996 and awarded in May 1996. The contracts were executed September 30, 1996 allowing the project to begin officially October 1, 1996.

Partners in the program are Baldor Motors, Air Conditioning and Refrigeration Technology Institute (ARTI), and Formcast. Each of the motor manufacturers has engineering, rotor stack production and appropriate motor test facilities needed to support this program. Formcast will provide casting experience and will be the site of the mold material evaluation studies.

The Copper Development Association Inc. is managing the project and providing technical expertise on the processing/handling of copper has formed this consortium of partners. The International Copper Association provides copper industry funding.

Background

Recent analysis by two U.S. motor manufacturers shows that the economics of motor operation and manufacture favor the use of copper in all classes of motors if the die life in the pressure die casting process can be extended to the order of 20,000 shots.

Die Cast Copper Rotors (CCR's) can provide advantages to motor manufacture or performance in three ways:

- Improvement in motor energy efficiency in operation
- Reduction in overall manufacturing cost
- Reduction in motor weight

The motor manufacturer can accentuate one of the advantages at the expense of the other two. For example, in the case of a premium 10 Hp motor recently analyzed, the motor efficiency is 91.0%. Three design scenarios using CCR have been analyzed: (1) seeking maximum efficiency improvement; (2) seeking maximum manufacturing cost reduction; and (3) seeking motor weight reduction.

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(1) Classification and Evaluation of Electric Motors and Pumps, DOE/CS-0147, February 1980.

Motors losses result from primary (stator winding) I^2R (usually 34% to 39%), secondary (rotor) I^2R (usually 16% to 29%), iron (core), friction and windage, and stray load.[(2)] In addition to direct reduction in rotor loss with CCR's, designs achieve additional reductions from overall motor re-optimization of iron, strays, etc. CCR-based designs show overall loss reduction from 15% to 20%.

(1) If motor re-design efforts were devoted solely to improving efficiency, it is estimated that the new design with CCR could achieve 92.5% efficiency. This CCR example creates a "super" premium efficiency motor with an efficiency level (i.e., 92.5%) higher than currently available premium efficiency motors.

(2) If motor re-design efforts were devoted solely to reducing manufacturing costs for the current 91.0% efficient premium motor, it is estimated that the new design using CCR could be manufactured at a $36 reduction in overall manufacturing cost (15% of current $240 estimated manufacturing cost), maintaining exactly 91.0% efficiency.

(3) If motor re-design efforts were devoted solely to reducing motor weight, it is estimated that the new design could reduce weight by 5% to as much as 10%.

CCR's can be used in specific motors to achieve a multiplicity of intermediate combinations of these design advantages. For example, where a smaller efficiency increase is required, the CCR could be used to achieve some reduction in manufacturing cost (stator winding, core, etc.) than would otherwise have been the case with traditional aluminum die cast rotor technology.

The problem encountered in attempting to die cast copper motor rotors is thermal shock and thermal fatigue of mold materials. Thermal cycling of the mold surface limits the mold life even in aluminum die-casting. However, cyclic thermal stresses are so severe in copper die casting that in at least one recent instance, a mold-gate-plate made of high strength steel (H-13, a die casting industry standard) being tested at a die machinery manufacturer's facility, fractured in just five casting shots. To be economically feasible, mold life must be measured in thousands of casting cycles.

A problem with common mold materials is that they lose strength at high temperature thus requiring low mean operating (and pre-shot surface) temperatures. A low initial temperature results in a large ΔT at the surface of the die, and thus the stress in the die, on each shot. The high melting temperature, high heat of fusion, substantial latent heat and high thermal conductivity of copper all combine to maximize the thermal shock. The solution to the thermal shock problem lies in the use of high temperature materials. Studies conducted by the International Copper Research Association (INCRA) in the 1970's confirm these expectations.

Motor Company Participation

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(2) Steels for Laminations in Energy Efficient Motors, CMP/EPRI Report 9-11, June 91 Table 2-1

Participation of other motor manufacturers in this program is welcome. The logical point for active participation is to contribute an electric motor and accompanying rotor design for production of the rotor mold and cast copper rotors. The program as funded presently contemplates limited production of cast copper rotors of only two designs. Funds for mold fabrication and rotor casting of other designs would have to be provided by the individual companies. These costs will have to be worked out. We invite motor manufacturer representatives to participate in all meetings and to stay in touch with this project through project update mailings.

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