Die-Cast Copper Motor Rotor Mold Materials and Processing for Cost-Effective Manufacturing

March, 2001

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Die-Cast Copper Motor Rotor

Program Initiation - Background

- Development requested by motor manufacturers
- Program members include:
  - Motor manufacturers
  - Die-Cast equipment manufacturers
  - High-temperature (mold) material suppliers
  - Copper industry technical & financial support
- Members all contributing to process development
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Participants

- ICA—major copper industry support
- US Dept. of Energy—contributed $425,000
- Motor Manufacturers
- Air Conditioning & Refrigeration Tech. Institute
- CDA members – alloy testing suggestions
- ThermoTrex—CVC Tungsten-coated Molybdenum
- Formcast—die casting technology capability
- CDA—program management & technical direction
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Objectives

- Development of Mold (Die) Materials and Processing for Cost-Effective Copper Motor Rotor Manufacturing
- Electrical Energy Efficiency Improvement
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Background

- Multiple analyses show additional 15% to 20% reduction in motor losses (input/output method) achievable with copper rotor compared to same motor design using aluminum
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Advantages to Motor Performance - Scenarios for Manufacturers and Users

- Improvement in motor electrical energy efficiency to reduce user operating costs
- Reduction in overall motor manufacturing cost if maintaining existing efficiency
- Reduction in motor weight
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Options for Improvement in Motor Energy Efficiency

- Create a “Super” premium efficiency motor product line
- Improve existing motor efficiency without major re-engineering by replacing current aluminum with copper rotor
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The Die Casting Process
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System Design at Formcast test facility

- 660 metric ton Buhler SC (independent computer controlled - closure & shot)
- Induction melting (15 kg of copper in 9 minutes for rotors – earlier design used 4 kg of copper per 2 minute cycle for material testing)
- High-temperature mold (die) materials and handling to achieve long life in service
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Phase I - Activities Completed

- “Test cavity” design for Die Materials testing Program — 1kg Cu through gate
- Extensive thermal modeling conducted
- Mold (Die) material analyses/run results:
  - H-13 (base case) — 750+ shots: severe heat checking after 20 shots
  - TZM/Anviloy/Tungsten — 980 shots
  - Inconels - 601, 617, 625, 754, 956 — 950 shots
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Test Cavity Design and Copper Die Casting
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Major Program Innovation: Phase I Findings

- Multiple high-temperature mold (die) materials may perform adequately in various die locations—depending upon thermal stresses/load requirements
- Mold (die) material handling—preheat requirements are critical—to reduce thermal stresses and assure long die-life in-service
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Problem With Common Mold Materials:

- High temperature
- Substantial latent heat
- Thermal shock
- Thermal fatigue
- High operating temperature: Loss of strength
- In previous studies: steel molds lasted only a few shots
# Die-Cast Copper Motor Rotor

## Conductivity

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<tr>
<th>Shot Number</th>
<th>% IACS</th>
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<tr>
<td>9</td>
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<tr>
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<td>800</td>
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**Average:** 98.8
Phase II: Prototype Motor Rotor Production

- Initial rotors produced December 1999
- Mold (die) inserts machined - 35 small copper rotors produced (April 2000): motor test results confirm loss reductions achievable as estimated
- 14 large copper rotors produced (May 2000)
- Designed die inserts for Air-Conditioning and Refrigeration Technical Institute’s hermetic motors - die-cast 37 medium sized rotors (January 2001)
- Die-cast 35 smaller rotors (January 2001)
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Large Die Set for Casting Rotors

- Middle Section
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Master Die on Pallet
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Die Cavity—Gates and Runner
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Arbor (Mandrel)
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Core stack being assembled
Die-Cast Copper Motor Rotor

Assembled Core Stacks
Die-Cast Copper Motor Rotor

Compressing Laminations
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Inserting Laminations (Core Stack)
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Inductotherm (Induction Melting) Furnace
Die-Cast Copper Motor Rotor

Copper Pellets in the Crucible
Die-Cast Copper Motor Rotor

Removing Molten Copper Crucible from Furnace
Die-Cast Copper Motor Rotor

Pouring Copper
Die-Cast Copper Motor Rotor

Furnace Controls
Die-Cast Copper Motor Rotor

Programming Die-Caster Computer Control
Die-Cast Copper Motor Rotor

Ejecting Rotor and Runner
Die-Cast Copper Motor Rotor

Extracting Rotor
Die-Cast Copper Motor Rotor

Quenching Rotor
Die-Cast Copper Motor Rotor

Fin Detail/Complete Fill on a Large Rotor
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Cross-section of a Rotor
Conclusions - Phase I - Test Cavity

- Trials Completed
- To Date: Inconel Alloy 617 Best Candidate
- Must Run Dies as Hot as Possible
- Copper Microstructure Exhibited Minor Defects
- Conductivity Very Good; Elimination of Iron in System Should Improve Conductivity
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Market Targets – Near Term – High Duty Cycle

- General Industrial & Commercial
- Air Cond. & Refrigeration – Hermetic & Fan
- Pump, Fan, Compressor – Ind. & Comm.
- Household Refrigerator, Machine Tools, Conveyors, & Other Fractional hp
- Aerospace (incl. Weight Reductions)
- Current High Efficiency Motors (including Manufacturing Cost Reductions)
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Copper Usage Annual Market Potential

- Worldwide – 30,000 tons Near Term;
  125,000 tons Longer Term
Copper Individual Motor Rotor Perspective

- Copper Usage in the Die-Cast Rotor for Individual Motors Evaluated Ranges from Approximately 40% to 55% of the Copper Magnet Wire Usage in Each Motor

- For Example – 15hp (~11kW) Uses 6.4 kg of Copper in Die-Cast Rotor (Replacing 2.8 kg of Al), and Contains 12.3 kg Copper in the Magnet Wire Windings
IEEE Test Results to Date

- 15% to 23% Reduction in Losses vs Al Die-Cast Rotor, Primarily in Rotor $i^2R$, Stray Load, & Friction/Windage
- Operating Temperatures Reduced Over 5 Degrees
- Torques also Reduced – Bar/Slot Redesign Required to Re-optimize for Maximum Benefit from Copper
**Status of Phase II - Rotor prototypes**

- Rotor Die Casting Trials for 4 motor companies completed
- Evaluation of Prototype Motor Performance: first results confirm energy efficiency improvements, as projected. Die-casting process proves to be robust
- Run of 200 to 500 Rotors for Production Motors planned
- Technology Transfer in 2001