International Copper Association, Ltd.

Die-Cast Copper Motor Rotor Mold Materials and Processing for Cost-Effective Manufacturing March, 2001

Dr. John G. Cowie

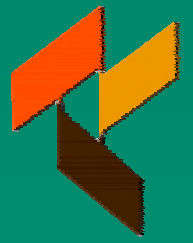
Copper Development Association Inc.

Dr. Dale T. Peters

Consultant, Copper Development Association Inc.

Dr. Edwin F. Brush

Consultant, International Copper Association, Ltd.



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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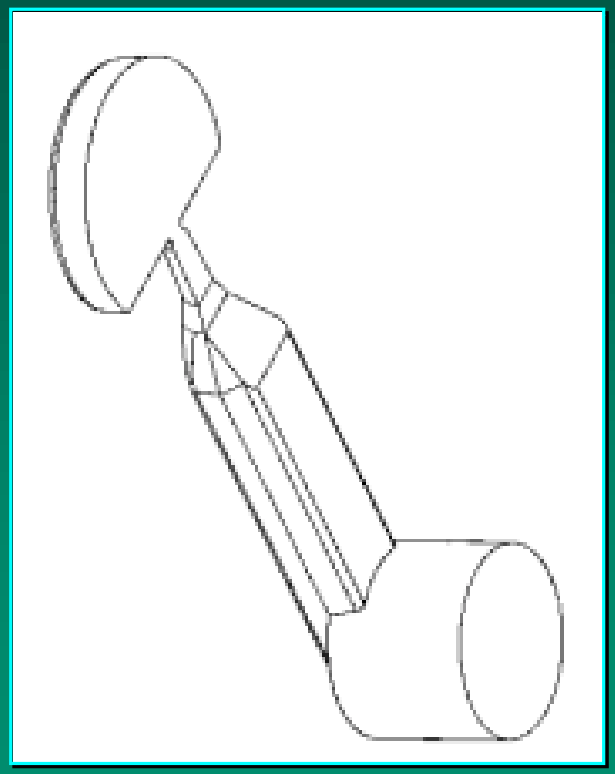
Test Cavity Design and Copper Die Casting



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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

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Conductivity

Shot Number	Average % IACS
9	97.8
11	95.2
438	96.8
600	99.7
800	99.4
Average	98.8

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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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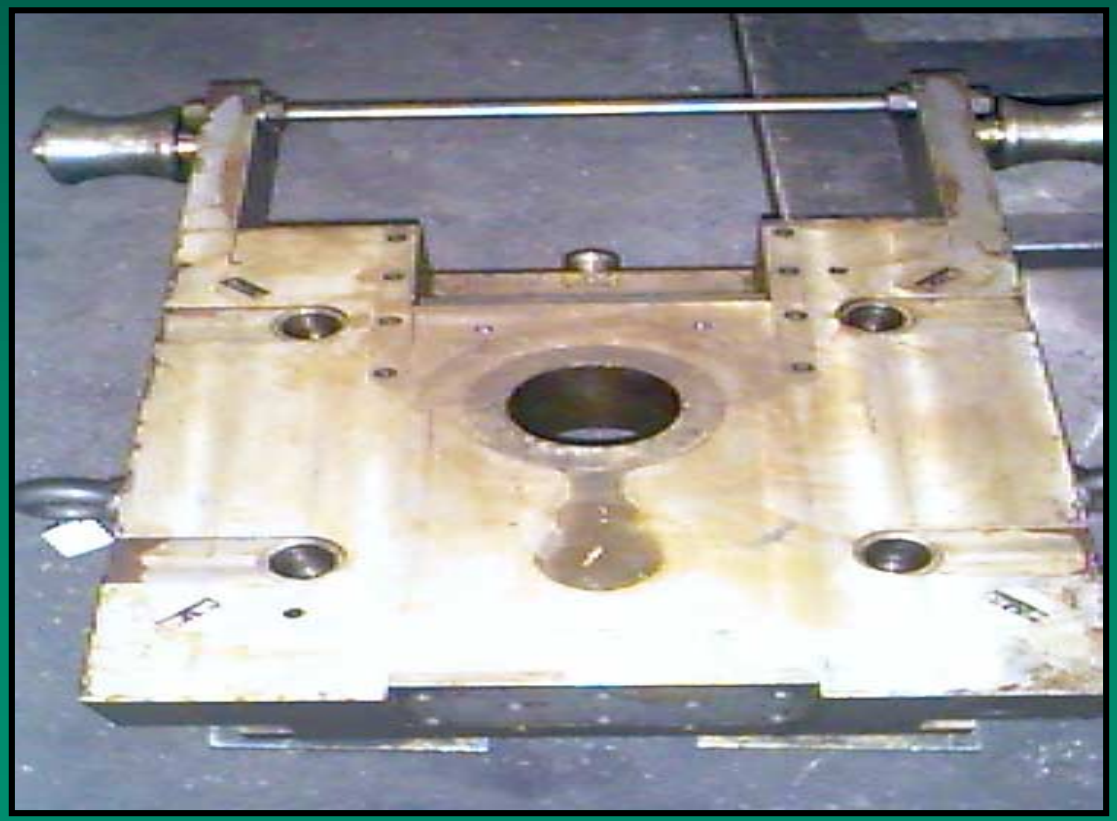
Large Die Set for Casting Rotors

- Middle Section



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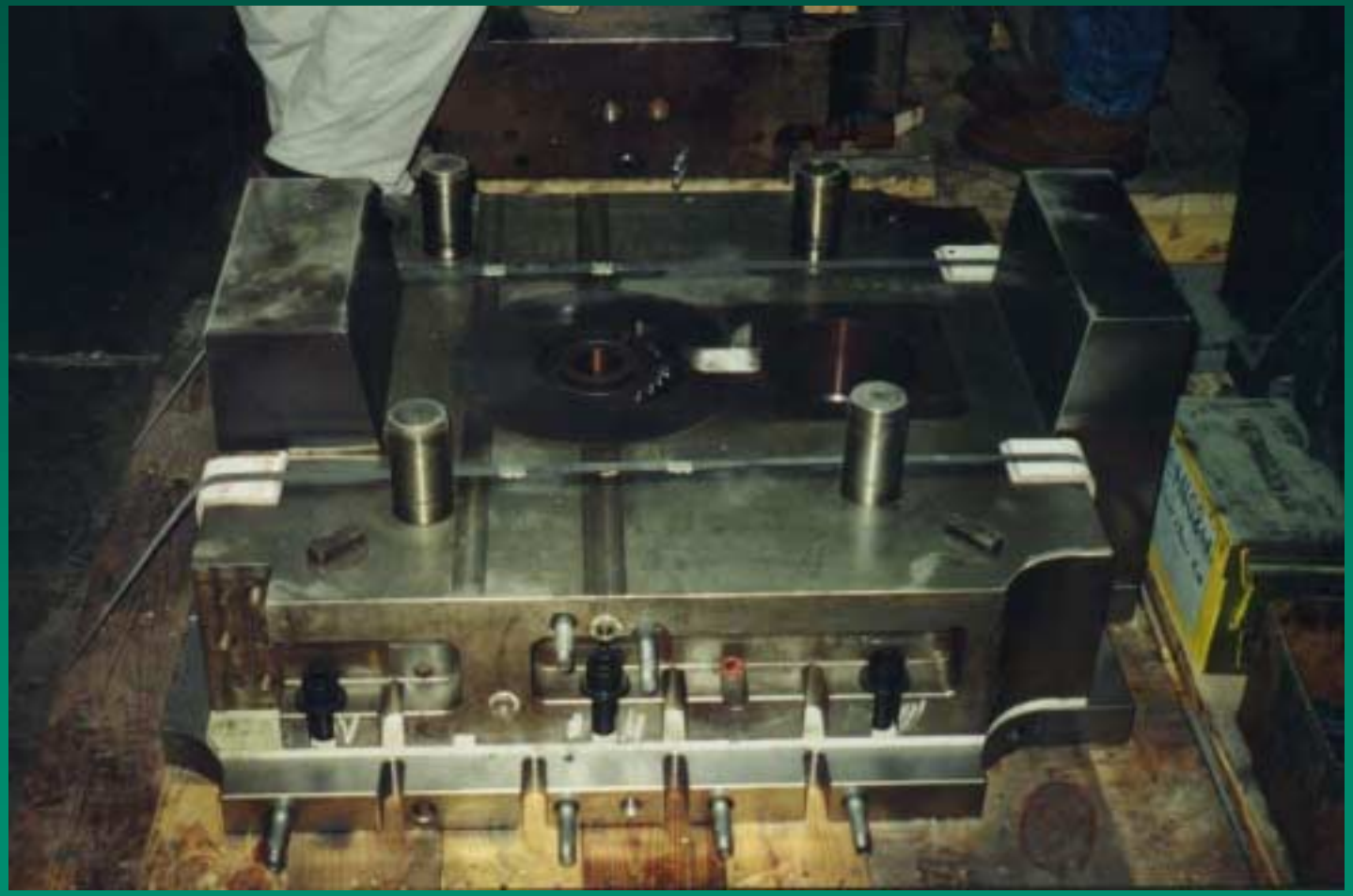
Master Die on Pallet



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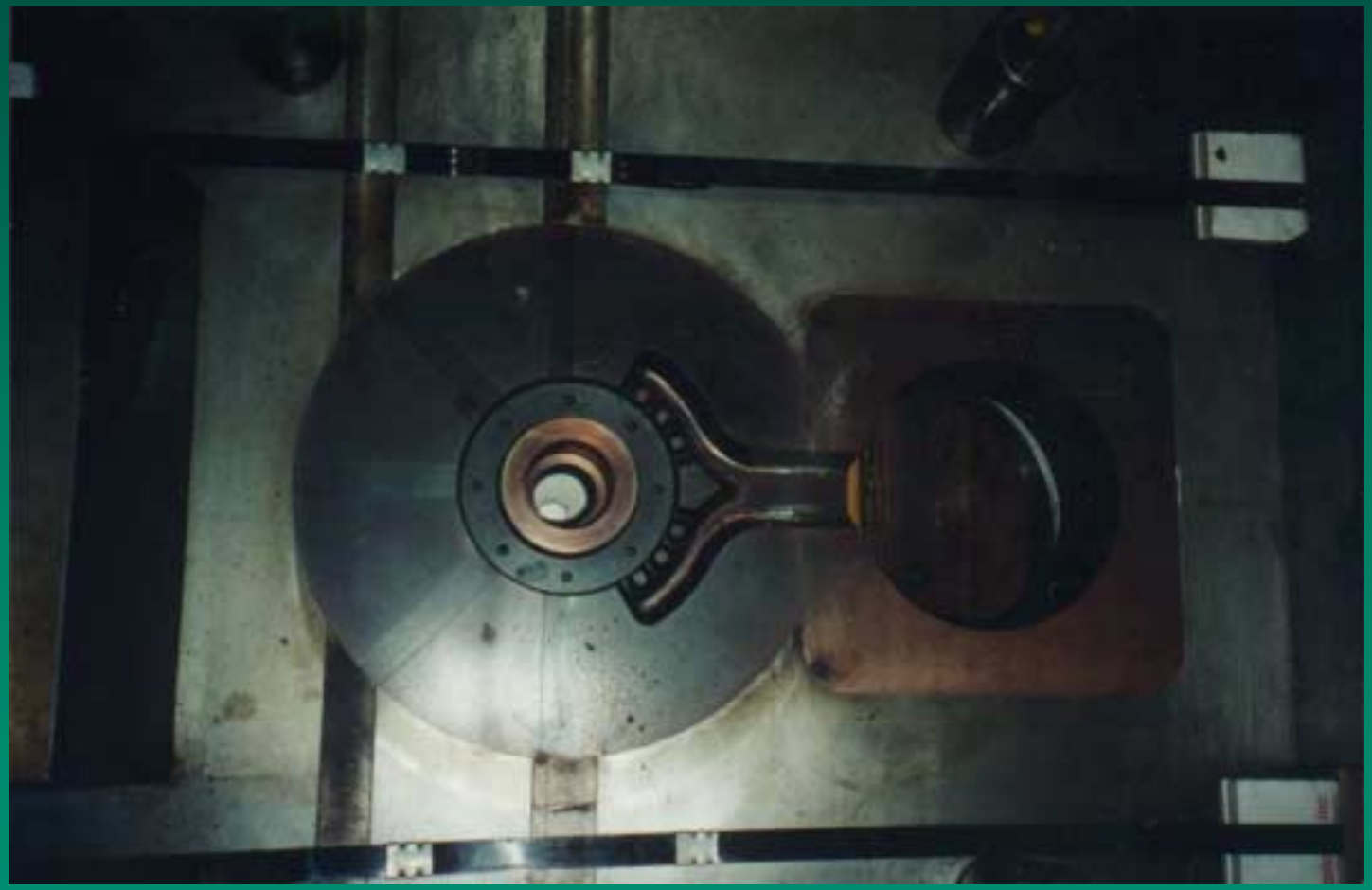
Die Cavity—Gates and Runner



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Arbor (Mandrel)

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Core stack being assembled

Die-Cast Copper Motor Rotor

Assembled Core Stacks

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Compressing Laminations

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Inserting Laminations (Core Stack)

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Inductotherm (Induction Melting) Furnace

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Copper Pellets in the Crucible

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Removing Molten Copper Crucible from Furnace

Die-Cast Copper Motor Rotor

Pouring Copper

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Furnace Controls

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Programming Die-Caster Computer Control

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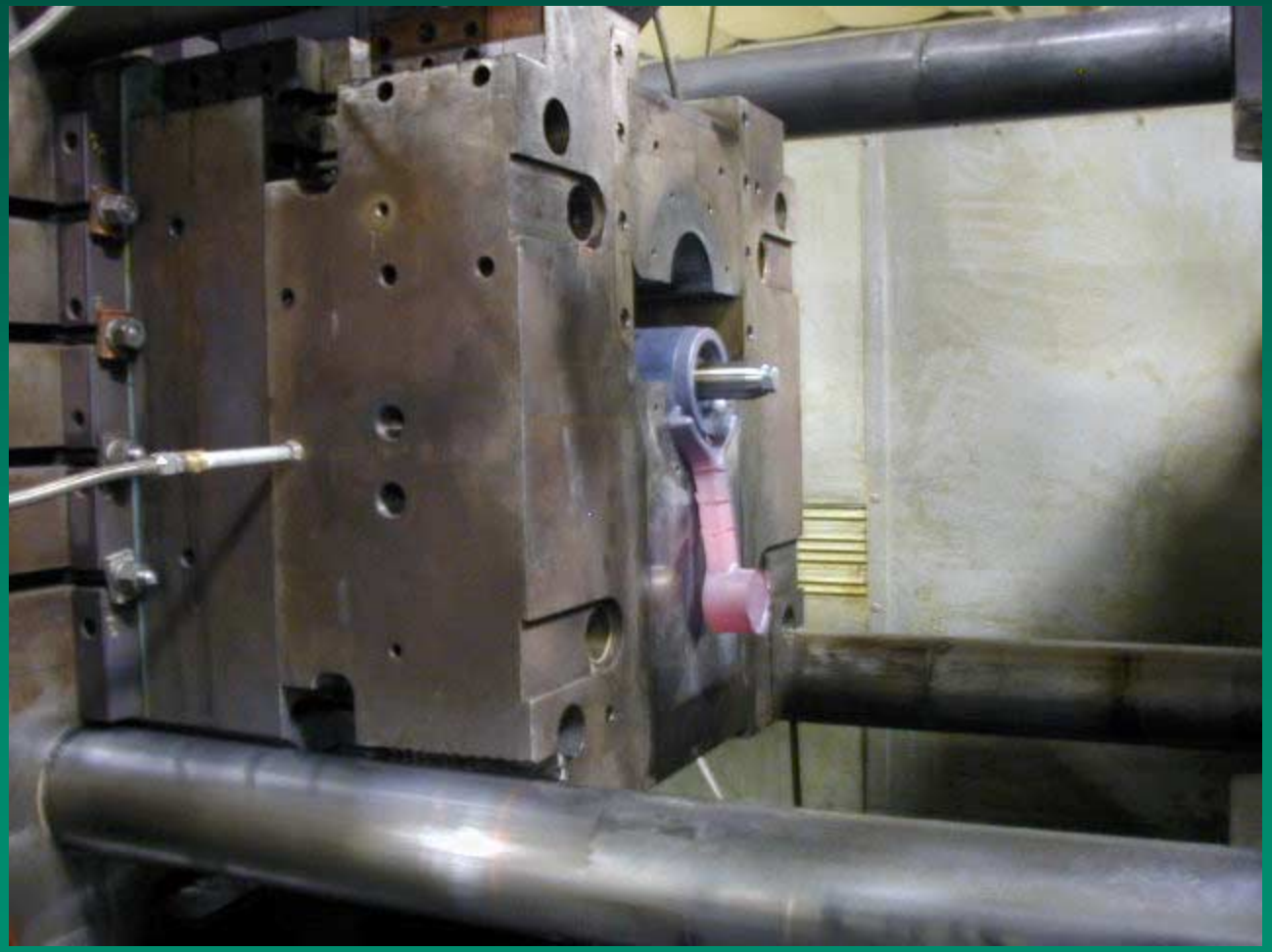
Ejecting Rotor and Runner



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Extracting Rotor

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Quenching Rotor

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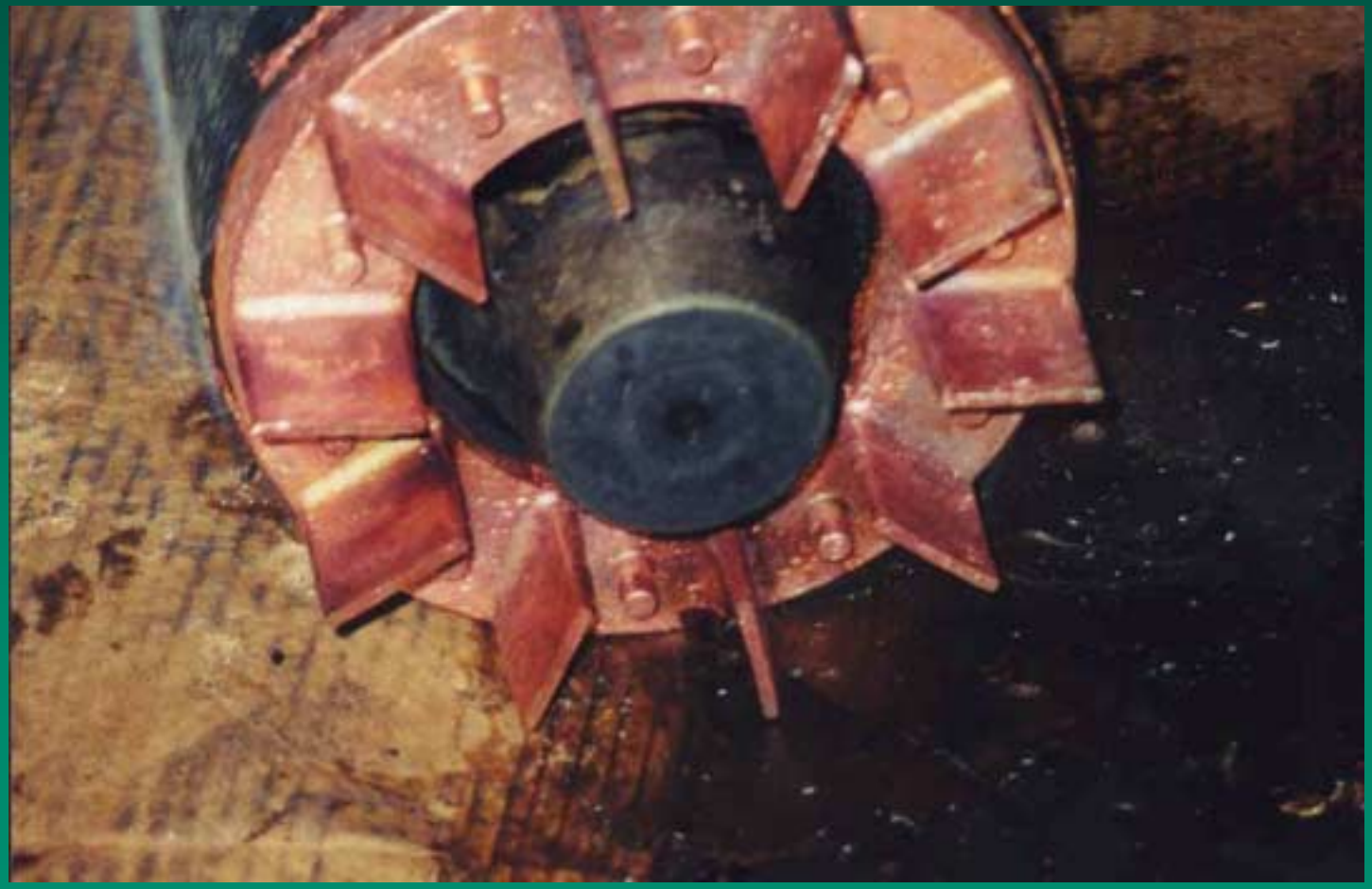
Fin Detail/Complete Fill on a Large Rotor



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Cross-section of a Rotor

Die-Cast Copper Motor 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

Die-Cast Copper Motor Rotor

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**

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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

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IEEE Test Results to Date

- 15% to 23% Reduction in Losses vs Al Die-Cast Rotor, Primarily in Rotor i2R, 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

Die-Cast Copper Motor Rotor

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