Recognizing and Eliminating Flux Concentrator Failures

Mr. Robert Ruffini
President
Overview

- What are the failure modes of a flux concentrator?
- How do we improve the design to prevent the failure in the future?
- Examples of coil lifetime improvement by proper use of flux concentrators
Common Flux Concentrator Failure Modes

• There are three common things that can lead to flux concentrator failure:
  – Mechanical Damage
  – Excessive Temperature
  – Electrical Break

• The failure modes may be different depending upon flux concentrator type

Rusted laminations beginning to separate at the ends of the stack on a crankshaft coil
Mechanical Damage

• Inductors oftentimes operate under relatively harsh conditions in heat treating applications

• Mechanical flux concentrator failure is generally caused by one of the following:
  – Coil/concentrator impact with the part or a part of the machine
  – Coil is dropped/damaged outside of the machine
  – Coil movement due to electrodynamic forces
  – Coil movement due to thermal expansion of the copper
Mechanical Damage Due to Impact with Part

- Clamshell side-shield impacted by counterweight of crankshaft
Concentrator Breakage Due to Thermal Expansion of Copper Tube

- Common Failure Mode in applications where inductor profile has a small nose for concentration of power in a radius
- Copper has very high current density, leading to high power density, which heats copper
- Concentrator has a thin profile, which is not strong and breaks on expansion
- Due to concentrator breakage, current concentration is not as strong in nose and pattern is compromised

Concentrator often looks darkened, but source of temperature is coil copper, not radiation!
Coil Movement Due to Thermal Expansion of the Copper

Insufficient water cooling of the copper caused copper to expand vertically, breaking off sections of the flux concentrator.
Excessive Temperature

• Inductors oftentimes operate under relatively harsh conditions in heat treating applications
• Thermal flux concentrator failure is generally caused by one of the following:
  – Too high coil copper temperature causes oxidation of concentrator
  – Large gaps between concentrator and copper
  – Low thermal conductivity of adhesive
  – Poor application of adhesive
  – Exposure to 3-D fields (especially for laminations)
• Thermal failure in heat treating applications is very, very rarely caused by radiation from the part
Proper Design & Glue Adhesion

Proper Air Gap Design and Gluing Allowances

Proper Concentrator Design (No Pointed Ends)
Good Clearance Gap (.18MM - .30MM)
Complete Glue Cover (All Contacting Surfaces)

Improper Concentrator Design (Pointed Ends)
Poor Clearance Gap (.40MM - .60MM+)
Partial Glue Cover (Only Some Surfaces)

Good Gluing Technique

Poor Gluing Technique
Black on rest of the concentrator oil from the part heating
Glue layer too thick, which caused formation of air pockets and local overheating

Thermal conductivity of epoxies much lower than for Fluxtrol materials and much, much lower than for copper. Air pockets, have almost no thermal conductivity, which cause local buildup of heat where they are present. This area of big air bubbles caused the concentrator to overheat, crack and separate from the glue. Other sections of the inductor had no issues.
Non-Water Cooled Inductor for High Temperature Melting Application

Temperature of susceptor around 1000 C for 1 hour, but concentrator cool to touch

Radiation in Heat Treating is not the cause of concentrator overheating!
Electrical Break

• Flux concentrators are not true dielectrics. When exposed directly to high electric potential, a break could occur.

• The areas of concern are as follows:
  – Turn to turn breakdown on multi-turn coils
  – Breakdown in the leads area
  – Coil to cooling plate or structural component
  – Conductive dust, debris or scale is present

• Electrical breaks are a greater concern for high frequency and large diameter, multi-turn coils.
Arced Laminations

- Turn to turn arc on laminations on the leads side caused by overheating due to 3-D fields and subsequent oxidation of lams leading to a bridge between turns.
Improving the Design

• Different Failure Modes Require Different Solutions to Resolve
• Some Good Design Practices will Be Provided to Prevent Failures from Occurring
• Case Stories of Implemented Solutions will be Provided
Preventing Mechanical Damage from Impact

- Part Guides/Concentrator Protectors
  - Non-Magnetic Stainless Steel/Brass
  - Fiber Reinforced Plastic (G-11 or similar)
  - Ceramic or Carbide (shoes on crankshaft coils)
  - Potting in plastic or casting in ceramic
Resolving Issues Associated with Coil Movement from Electrodynamic Forces

- Electrodynamic forces cause cyclic vibrations of the inductors during the process
- The main solution is to segment the concentrator into shorter segments
- Also, retainer rings are used to limit coil deflection and hold concentrator in place
- This can extend concentrator lifetime by an order of magnitude

Crankshaft coil with segmented concentrator to allow the coil to flex during the process
Case Story of Solving Thermal Problem

• Customer had coil lifetime problems with heating of a stem of a CVJ
• After a certain number of parts, the nose of the concentrator would break off and pattern would be lost
• Customer blamed the concentrator for the failure.
Head Design Improvement to Reduce Copper Temperature

- Excessive copper temperature was the cause of the failures
- By redesigning the copper nose and cooling pocket, copper temperature was reduced 25%
- This increased the coil lifetime from 25,000 to 100,000 pieces without changing the pattern
Case Story of Overheating of Laminations Due to 3-D Fields

- Application at 3 kHz for heating of off-highway component
- Laminations overheating due to 3-D field and actually pushing copper keepers over until they arced with the part or pattern lost in fillets
- Coil lifetime around 13,000 parts
- Replaced laminations with Fluxtrol LRM without keepers.
- Result was lifetime of around 50,000 pieces and improved heat treat pattern
Case story for Electric Breaks on Cold Crucible Melting Coil

- Two types of arcs were occurring
  - Turn to turn arcs from the stud, through the concentrator, to the stud
  - Stud to stud arcs from the stud, through the concentrator, through the faraday ring, through the concentrator, through the stud
- Application was for making powder metal, so large amounts of conductive powder present
Solutions to Arcing Problem

Use of stud insulators and concentrator split

Elimination of studs on concentrators
Conclusions

• Magnetic Flux Controllers are a very important component of the induction heat treating coil design
• Magnetic Flux Controllers have a beneficial effect on many types of inductors
• Flux Concentrator failures are often resolved by very minor design changes, which can have a drastic effect on the coil lifetime
• If you run into an issue with insufficient coil lifetime, do not hesitate to contact your Fluxtrol representative
More Information

More information about magnetic flux control, controllers and application technique may be found on www.fluxtrol.com

Thank you!