by Valery I. Rudnev • Inductoheat Group

Systematic analysis of induction coil failures

PART 1: INTRODUCTION

This multipart column presents portions of an in-depth analysis of induction coil failures, which included identifying and understanding coil failure modes and developing ways to improve coil life by building "healthy" coils. The study was initiated by Inductoheat's Aftermarket Department and was conducted over a period of several years by the company's R&D staff. The report cannot be published in its entirety because it contains much proprietary know-how and trade secrets related to the design and fabrication of long-lasting coils. However, the information presented in this and subsequent installments will give readers an understanding of a broad spectrum of interrelated factors and phenomena that can help them identify the potential causes of a particular induction coil failure.

This series of columns is believed to be the first attempt at providing heat treaters with a systematic scientific/engineering analysis of coil failures. Much of the information has not been previously published.

Professor Induction welcomes comments, questions, and suggestions for future columns. Since 1993, Dr. Valery Rudnev has been on the staff of Inductoheat Group, where he currently serves as group director – science and technology. In the past, he was an associate professor at several universitie. His expertise is in materials science, heat treating, applied electromagnetics, computer modeling, and process development. He has 28 years of experience in induction heating. Credits include 16 patents and 128 scientific and engineering publications.

Contact Dr. Rudnev at Inductoheat Group
32251 North Avis Drive
Madison Heights, MI 48071
tel: 248/585-9393; fax: 248/589-1062
e-mail: rudnev@inductoheat.com
Web: www.inductoheat.com

The induction coil is the most critical component of an induction heating system. It also is often considered the "weakest link" — the least dependable of the components that significantly affect system reliability and repeatability, up-time, and maintenance cost, as well as the quality of heat treated parts.

An inductor or induction coil is an electrical device positioned in close proximity to the workpiece.[1] Alternating current flowing in the inductor generates a time-varying magnetic field that provides an electromagnetic link between the inductor and workpiece resulting in contact-less heating of the entire workpiece or selected areas of it.

Figure 1 shows a small sample of a virtually endless number of coil designs. A particular coil configuration depends upon specifics of the application that include but are not limited to geometry of the workpiece, heating mode, production rate, required heating profile, and available power/frequency.[1] Coils for such popular applications as through hardening, selective hardening, tempering, and stress relieving can be divided into these major categories: scanning, progressive, single-shot, and special inductors.[1] Often, a given type of induction coil is prone to a particular failure mode.

Coils Are Made of Copper

Induction coil failure is a very complex subject because typically there is no single factor responsible for the failure but rather a combination of interrelated factors. At minimum, a coil failure analyst must have knowledge of electromagnetics, metallurgy, materials science, mechanics, heat transfer, and chemistry.

Although different inductors often

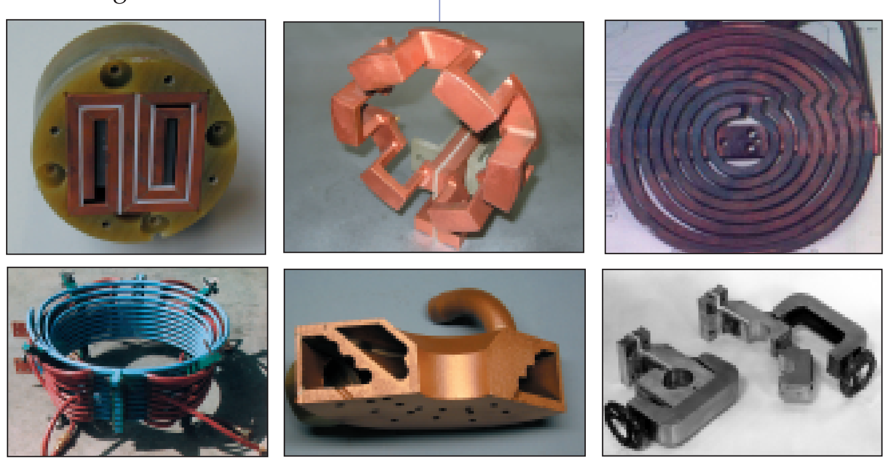

Fig. 1 — A small sample of the wide variety of induction coil designs. A given type of coil may be prone to a particular failure mode.

have a different primary cause of failure, the secondary cause is typically related to localized excessive coil current density. Thus, it is important to keep in mind during a coil failure analysis the possible chain of events that could result in the specific mode of failure.

Coil material: Induction coils are fabricated from copper because of its unique properties, including, among others, good electrical and thermal conductivities, inherent corrosion resistance, and superior cold and hot workability.[2] Copper's availability, and it's mechanical properties and cost are other important factors that make it the material of choice for induction coils.

Coils for hardening are typically CNC (computerized numerical control) machined from a solid copper bar, which makes them very rigid, durable, and repeatable. In other cases, a copper tube (rectangular or round cross section) may be used (examples are shown in Fig. 1), while in some low-coil-current/low-workpiece-temperature applications Litz wire can be successfully used. (Litz wire derives its name from the German word *litzendraht*, meaning woven wire. It consists of a number of individually insulated magnet wires twisted or braided into a uniform pattern, so that each strand tends to take all possible positions in the cross-section of the entire multistrand conductor.[3] Litz wire eliminates the skin effect leading to an increase in current-carrying area, reduced coil resistance, and coil losses.)

The majority of factors related to a premature coil failure can be conveniently categorized into four groups (Fig. 2). These factors will be discussed in subsequent columns in this series. A "fish-bone" diagram useful for troubleshooting coil failures also will be included.

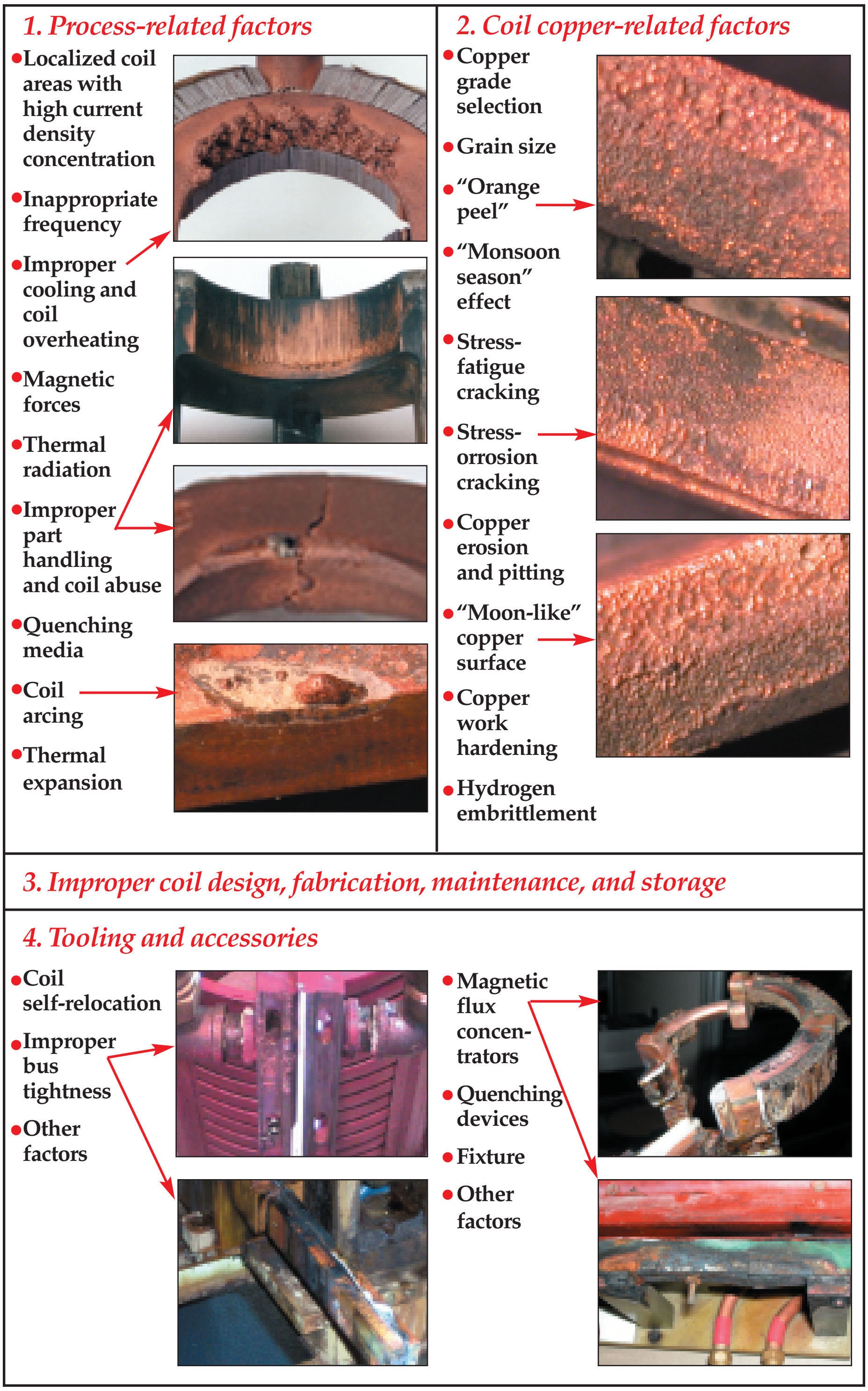

Fig. 2 — The majority of factors related to premature induction coil failure can be categorized into these four groups. The various factors will be discussed in subsequent columns.

Next: Effect of Coil Current

Before beginning a discussion of specific coil failures and their analysis it is important to review the principle phenomena of induction heating as they relate to coil failure. Part 2 will discuss the effect of current flow on crack propagation in a copper induction coil.

References

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3. "What is Litzwire?": www.litz-wire.com/applications.html, website of HM Wire International Inc., Canton, Ohio.

Note: Illustrations courtesy Inductoheat, an Inductotherm Group company.