by Dr. Valery I. Rudnev, FASM, Inductoheat Group

Systematic analysis of induction coil failures

PART 12: INDUCTORS FOR HEATING INTERNAL SURFACES

Entries in the "Systematic analysis of induction coil failures" series alternate with those in the "Metallurgical insights for induction heat treaters" series.

Induction heating of the internal surfaces of a workpiece can be used for applications such as hardening, tempering, annealing, shrink fitting, stress relieving, and brazing. Figure 1 shows a variety of different inductor styles for heating internal surfaces including solenoid-type cylindrical single-turn and multiturn coils and hairpin inductors. Specifics of designing internal inductors as well as the peculiarity of the selection of process parameters are discussed in Ref. 1 and 2.

Single-turn and multiturn solenoids are the most popular inductors for heating internal surfaces. Such inductors are called as ID coils or internal coils. Internal coils are typically made of copper tubing that is spiral wrapped the same way a solenoid is wrapped. In some cases, the head of the internal inductor is machined from a solid copper bar. This not only provides a rigid, robust coil, but also it allows profiling of the coil face to match specific part geometry and minimize the end effect of coil helix.

The main restriction to using internal coils is the difficulty of heating small-diameter holes. Since the return leg of the inductor usually goes through the center of the coil, the smallest outside diameter of solenoid-type ID coils is usually limited to about 0.625 in. (16 mm), but 0.75 in. (19 mm) is more typical.

If the inside diameter of the heated part is smaller than 0.75 in., hairpin inductors can be used. (The name of hairpin-type inductors is derived from the resemblance of the inductor's loop shape to a lady's hairpin.) Such inductors are usually formed of bent or brazed copper tubing. The workpiece must be rotated during heating when using hairpin-type inductors.

Typical Failure Modes of Internal Inductors

Failure mode #1. In contrast to inductors used to heat external surfaces or outside diameters, the effectiveness of an internal coil depends to a much greater extent on the coil-to-workpiece gap. Electrical efficiency of internal coils rapidly decreases with an increase in the coil-to-workpiece coupling gap, particularly when heating nonmagnetic metals or carbon steels above the Curie temperature. Reduction in coil electrical efficiency directly relates to an appreciable increase of coil copper losses. Therefore, it is important to remember that an increase in coupling gap while using internal inductors results in much greater increase in copper losses compared with similar inductors for heating outside surfaces. This, in turn, makes it necessary to appreciably increase water-cooling requirements to prevent the copper coil from overheating.

Fig. 1 — Variety of inductors for heating internal surfaces.

Coil-calculation techniques based on the Baker or Williamson methods widely used in the past should not be used to determine copper losses due to the mathematical restrictions and poor accuracy of both

Professor Induction welcomes comments, questions, and suggestions for future columns. Since 1993, Dr. Rudnev has been on the staff of Inductoheat Group, where he currently serves as group director – science and technology. He has 28 years of experience in induction heating. His expertise is in materials science, metallurgy, electromagnetics, heat treating, computer modeling, and process development. Credits include 18 patents and 146 publications. Contact Dr. Rudnev at Inductoheat Group 32251 North Avis Drive Madison Heights, MI 48071; tel: 248/629-5055; fax: 248/589-1062; e-mail: rudnev@inductoheat.com; www.inductoheat.com.

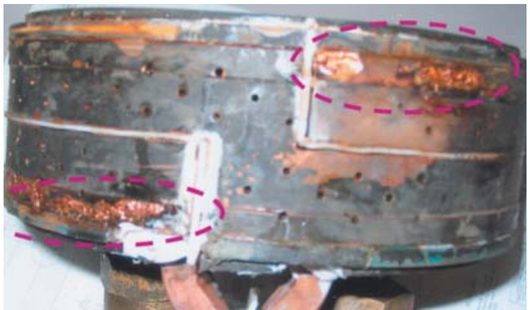

Fig. 2 — A desire to have small coil-to-part gaps is associated with a danger of arc development.

techniques for calculating internal inductors. Numerical computer modeling using finite element or boundary element methods are more suitable for such calculations.

Failure mode #2. Depending on the application, attempting to keep the coil-to-workpiece coupling gap as small as possible results in having air gaps in the range of 0.125 to 0.0625 in. (3.2 to 1.6 mm), and in some cases, air gaps are even as small as 0.03125 in. (0.8 mm). A desire to have such small clearances is accompanied with the danger of arc development (Fig. 2) and/or potential coil abuse due to improper part/coil handling when the inductor can accidentally touch the part (Fig. 3). The use of an appropriate fixture that provides robust, reliable loading/unloading operation is essential for ID coils.

The use of a thin layer of ceramic coating or an electrical insulator such as Kapton tape can help prevent arc development between the coil and heated part.

Failure mode #3. Installation of a magnetic flux concentrator inside of the internal inductor is frequently mandatory to increase coil efficiency and reduce coil current, particularly for heating internal surfaces of small to moderate diameters. The flux concentrator has a substantially stronger effect on coil current distributin than electromagnetic "ring" effect [1] and forces the coil current to be shifted toward the coil outside area to be positioned closer to the surface of the heated workpiece. This increases magnetic field strength and heat intensity at workpiece internal surfaces[1,3-4].

Fig. 3 — Evidence of coil abuse due tp improper part/coil handling when inductor can accidentaly touch the part.

The use of magnetic flux concentrators on internal coils provides noticeable reductions in required coil current and power, reduces coil water-cooling requirements, and often simplifies load matching of the induction coil and inverter[1,3-4].

However, a magnetic flux concentrator is frequently considered to be the weakest link of induction heating system. It is particular true for ID inductors[1,5]. This is due to a danger of a possible magnetic saturation of the flux concentrator material and subsequent overheating, which could result in premature degradation of the inductor and shortens its service life. Careful evaluation of process parameters and computer modeling help in selecting proper parameters, long-lasting design, and prevent premature failure of the flux concentrator.

Failure mode #4. Water-leakage of brazed joints represents the forth most typical coil failure mode. Some coil builders fabricate coils that have numerous brazed joints. The presence of electromagnetic forces in combination with greater coil copper losses make inductor joints vulnerable for weakening. As discussed in Ref. 6, elimination of or significantly reducing the number of braze joints, particularly in current carrying areas, is a key to fabricating durable, reliable, and repeatable long-lasting inductors. **HTP**

Kapton is a registered trademark of Dupont.

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