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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. In the past, he was an associate professor at several universities. His expertise is in materials science, metallurgy, heat treating, applied electromagnetics, computer modeling, and process development. Dr. Rudnev is a member of the editorial boards of several journals, including *Microstructure and Materials Properties* and *Materials and Product Technology*. He has 28 years of experience in induction heating. Credits include 16 patents and 128 scientific and engineering publications.

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Systematic analysis of induction coil failures

PART 10: CONTACTLESS INDUCTORS

This multipart column presents portions of an in-depth analysis of induction coil failures. 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 information presented in this series 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.

Parts 1–9 appeared in the August, September/October, and November/December 2005; January/February, March/April, May/June, September/October, and November/December 2006; and January/February 2007 issues.

The previous entry in this series discussed split or clamshell inductors used for hardening irregular shapes that do not allow an inductor to encircle the part.[1] Examples include the eccentric journals of some crankshafts or the lobes of certain camshafts that have large bearings, sharp "noses," and moderate "base circles."

At the same time, in other applications such as strip or plate heat treating and coating (galvanizing, galvannealing, Galvaluming, nonmetallic coating, and paint drying, for example), the ability to move the induction coil from the heating position to an off-line position is considered an important system requirement. Solenoid induction heaters with water-cooled "doors" were commonly used in the past for such applications (Fig. 1). Inductors having doors are actually very similar to split or clamshell coils.

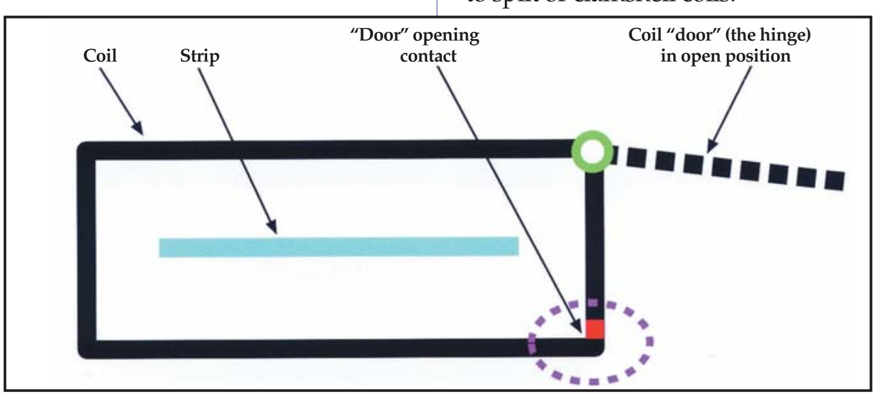

Fig. 1 — Transverse section of a solenoid-type induction strip heater with a "door."

The contact area with its inherent need to break the electrical current path represents the "weakest link" of both clamshell coils and coils with doors. Drawbacks to these coils are discussed in Ref. 1 and 2. They include a short life, poor reliability, and high maintenance costs.

To substantially mitigate these disadvantages, induction heating equipment manufacturers have developed advanced contactless coils that are alternatives to clamshell coils and inductors with doors. This column focuses on two of these approaches.

Doorless strip heating coil

The so-called doorless induction coil was developed to increase coil life and to eliminate the maintenance problems associated with high-frequency current interrupting a doored coil.[2,3]

The uniform heating and high efficiency provided by solenoid coils tend to make them the inductor of choice in most strip heating applications. The doorless coil is a clever adaptation of this existing technology. Two coils are connected in series, and the interconnection bus is rotated so that one coil is over the other (Fig. 2). The strip passes through both coils for heating to final temperature. The gap between the interconnecting buses allows passage of the strip without the need to have a door.

Removing the door eliminates the

need to make and break electrical connections each time the induction heating unit is moved off line. By eliminating these high-current-carrying electrical connections, reliability is increased dramatically and maintainability is improved significantly.

To move the doorless coil off line, air cylinders installed on each side of the interconnection bus are used to slightly spring it 2.5 in. (65 mm) in each direction, providing a 5 in. (125 mm) gap that is typically sufficient for strip to pass through. However, it's easy to provide a much greater gap if necessary.

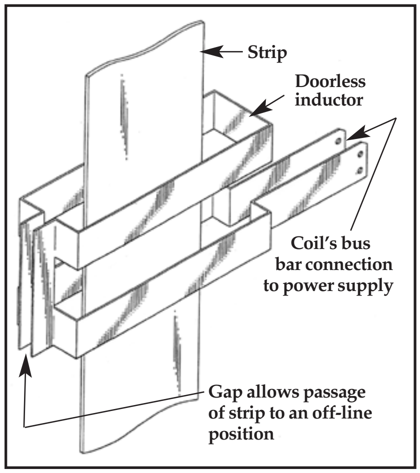

Fig. 2 — Sketch of the doorless coil for strip heating applications. Ref. 3.

Crankshaft, camshaft coil

The Stationary Hardening Process for Crankshafts and Camshafts (SHarP-C technology) also eliminates high-current contacts when using encircling clamshell coils.[2,4] Use of the technology improves coil reliability and life and does away with the need to rotate the part being hardened.

In the process (Fig. 3), the inductor consists of two coils: a top (passive) coil and bottom (active) coil. The bottom, active coil is connected to a medium- or high-frequency power supply, while the top, passive coil represents a short circuit (a loop). The bottom coil is stationary, while the top coil can be opened and closed. Each coil has two semicircular areas where part features will be located.

Thanks to a lamination pack that serves as a magnetic flux concentrator, both coils can be tightly coupled electromagnetically. After loading a part (a crankshaft or camshaft) into the heating position, the top coil moves into a "closed" position and power is applied to the bottom coil. Current starts to flow in the bottom coil. Because the bottom coil is electromagnetically coupled to the top coil, a current flowing in it will cause eddy currents to flow in the top coil. Those induced currents will be oriented in a direction opposite to the source current. If design parameters have been chosen correctly, the difference between the source current flowing in the bottom, active coil and the current induced in the top, passive coil will be essentially negligible (less then 3%).

Any feature of the part being heat treated "sees" the SHarP-C inductors (Fig. 4) as classical encircling cylindrical coils with an induced eddy current flow along the circumference of the feature. Therefore, heating is efficient and symmetric, and the hardness profile is consistent, including the so-called "fish-tail" area (or split region of the coil). In traditional induction heating systems there is a distortion of the electromagnetic field in the fish-tail area due to current cancellation phenomena. Several electromagnetic solutions have helped to dramatically reduce these undesirable phenomena.[2]

Future columns: In response to requests from readers of *Heat Treating Progress*, the next Professor Induction column will be the first in a new series devoted to "Metallurgical Insights Into Induction Hardening." Entries in this series of columns will alternate with those in the "Systematic Analysis of Induction Coil Failures" series.

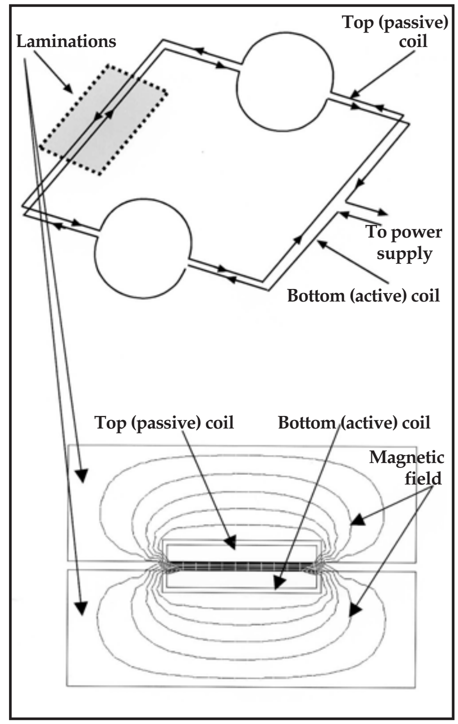

Fig. 3 — Top: Sketch of a SHarP-C coil circuit for crankshaft and camshaft hardening. Bottom: Magnetic coupling of the top and bottom coils.

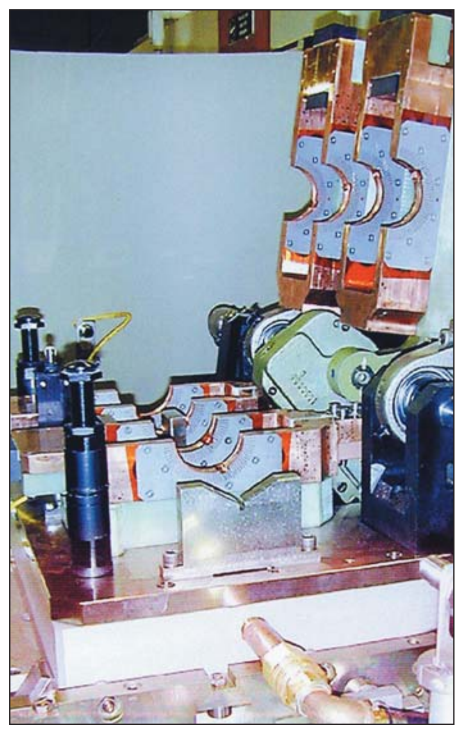

Fig. 4 — SHarP-C coils in the open position. Top coils are passive; bottom coils, active. Ref. 2.

References

1. "Systematic Analysis of Induction Coil Failures, Part 9: Clamshell Inductors," by Valery I. Rudnev: Professor Induction, *Heat Treating Progress*, Vol. 7, No. 1, January/February 2007, p. 17–18.
2. *Handbook of Induction Heating*, by V. Rudnev, D. Loveless, R. Cook, and M. Black: Marcel Dekker Inc., New York, 2003, 800 p.
3. "Continuous Strip Material Induction Heating Coil," U.S. Patent 5,495,094: awarded to H. Rowan, J. Mortimer, and D. Loveless, Feb. 27, 1996.
4. "Induction Heat Treatment of Complex-Shaped Workpieces," U.S. Patent 6,274,857: awarded to D. Loveless, V. Rudnev, L. Lankford, and G. Desmier, Aug. 31, 2000.