

Figure 1 — High-power single shot and scanning type inductors.

HOW TO IMPROVE INDUCTOR LIFE

Inductors used in induction heating applications operate in a harsh environment including rapid thermal cycling from high temperatures to room temperature and exposure to cooling fluids and process quenchants. Optimizing inductor life under these conditions requires good system preventative maintenance.

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mong the many types of inductors used in induction heat treating are single shot and scanning inductors (Fig. 1), which are extensively used in high energy, high production applications. Inductors operate at high frequency and high power in a harsh industrial environment including high temperatures, rapid thermal cycling and contact with various fluids. Getting the most out of an inductor in this environment requires close attention to good system maintenance. Three areas that can have a significant impact on inductor life discussed in this article are electrical contact maintenance, inductor cooling, and quench maintenance.

Electrical Contact Maintenance

The initial point of electrical contact in the system is where power is introduced to the inductor from the output transformer. Often, the inductor is bolted directly to the transformer. Sometimes bus extensions and inductor adapters are used, which involves several additional points of electrical contact. Each of these contacts must be kept clean and properly bolted to prevent damage to the contact area. Figure 2 is an example of what can happen to an improperly bolted contact. Arcing caused by a damaged insulator (seen at the right side of the photo) occurred across dirt accumulated over time. The resultant arcing caused extensive damage not only to the contact, but also to the transformer mounting foot, requiring replacement of the transformer.

Inductor contacts can be cleaned using a nonabrasive pad (e.g., such as those used in the kitchen), soap, and water, then silver plated, which prevents oxidization. Steel wool pads should not be used because steel residue from the pad may cause arcing. Contacts should be plated when the inductor is replaced.



Figure 2 — Arced contacts due to improper or loose bolts (left) and an accumulation of dirt (right)



Figure 3 — Clean, silver plated transformer and inductor contacts



Figure 4 — Break-away bolts and washers

Figure 3 shows well-maintained inductor contacts.

Properly bolted contacts require the use of both a proper bolt and washer (Fig. 4). Threaded inserts in the foot should be inspected for damage before installation to the transformer foot. Tapped holes in the transformer foot often are not drilled through, therefore the threaded hole depth should be measured using a pencil point. Using this measurement, the bolt must be shorter than the sum of the contact thickness and the total hole depth. The bolt must fully engage the threaded insert (usually 0.375 to 0.5 in., or approx. 10 to 13 mm) and tightened to 155 or 178 N (35 or 40 ft. lb.)Because over-tightening can cause damage to the threaded insert, special break-away bolts are available, which are designed to snap the head at 245 N (55 ft. lb.) preventing thread damage and allowing easy removal of the remaining stud. Special thick washers (shown at the right of Fig. 4) work with the bolt to protect the copper by distributing the compressive load. Further protection is provided over slots by means of specially designed integrated washers. Steel bolts and washers should never be used in an electromagnetic circuit.

Preventative electrical contact maintenance is further achieved by isolating the power transformer from quench fluids, oil, smoke and dirt. This can be accomplished by moving the transformer back and out of working environment (if possible). Figure 5 shows the installation of a new panel with an inductor



Figure 5 — Transformer is kept out of the working environment of the induction heating process using an interconnecting bus bar.



Figure 6 — Blown axle inductor caused by steam barrier failure

mounting foot and a short bus back to the repositioned transformer. The benefit is two-fold: 1) damage to the mounting foot on the panel can be immediately repaired or replaced using inexpensive parts; and 2) it eliminates the possibility of a costly transformer breakdown caused by quench fluid and dirt contamination.

Inductor Cooling

Water cooling is the life blood of the system. High-production, highpower single shot and scanning inductors need efficient cooling for long life. This is accomplished using a good pump and a clean cold water supply together with a precise inductor cooling chamber design.

Three distinct failures linked to cooling (i.e., steam barrier, vapor lock, and no cooling) are discussed to help you identify the cause of a blown inductor.

Figure 6 shows a blown inductor in a wheel axle spindle due to a steam barrier failure. Fillet and flange heating require intense energy (exceeding the current limit of the copper conductor) for short periods. In this case, a cooling water pressure boost to 200 psi (14 bar) directly into the cooling chamber could not prevent a steam vapor barrier from forming. There is an intense current flow within the copper closest to the steel part being heated due to the proximity effect. The intensity of current causes the cooling water to immediately vaporize along the current path inside the water chamber, causing the formation of a thin steam

vapor barrier, which does not permit the copper to cool. The cooling water simply flows over the boiling vapor surface, resulting in a rapid increase in electrical resistance, causing the copper to heat and expand locally. These localized hot spots expand, contract, and oxidize during each cycle leading to failure. Flux intensifiers, although essential to the process, aggravate this condition.

Inductor life can be improved by forcing cold (50 to 70°F, or 10 to 20°C) water into the cooling passages. The electrical resistance of the copper is kept low for a period just long enough for these short cycle (usually 5 seconds or less) heating applications by cooling the copper and replenishing it at 180 to 200 psi (12 to 14 bar). Internal vaporization is delayed within the cool mass of the inductor.

Many inductors are connected directly to the same system that cools the power supply. Modern power supplies require deionized distilled water for cooling, sometimes containing a cooling additive. The cooling temperature is specified above the local dew point (90°F, or 32.2°C) to prevent condensation within the unit. For a problem inductor, this temperature is too high, and the inductor should be removed from this cooling system. A dedicated cooling supply to the inductor using cold, filtered system water could be installed with a properly sized, commonly available pressure boost pump. The dew point is of no consequence at the inductor, which is usu-



Figure 7 — Blown wheel bearing inductor caused by vapor lock failure



Figure 8 — Blown bore liner inductor due to absence of cooling

ally drenched in quench fluid. Furthermore, a deionized distilled water system is not necessary to cool an inductor of this type. A separate system injecting pressurized cold water has proved to be successful in extending the inductor life cycle.

Figure 7 shows a blown inductor in a wheel bearing inductor due to *vapor lock failure*. The inductor is split in half, usually at a braze joint, which is the weakest link because the melting point of the joint material is lower than that of copper. A vapor lock occurs when cooling water boils within the cooling chamber, where it quickly expands and completely blocks the flow of cooling water. Re-



Figure 9 — Arcing (arrows) at the inductor through the quench fluid



Figure 10 — Single-shot type inductors eroded to failure



Figure 11 — Inductor coated with magnetic steel particles

sistance heating within the steam pocket melts the inductor at a weak point. Insufficient pressure to properly cool the inductor is the problem. Assuming the pumping system is working properly, a supply valve may be partly closed or a blockage may be restricting the system. It is also possible that the pressure differential is not low enough to provide adequate cooling flow. Pressure gages should be installed on the water supply and return of the inductor cooling circuit. The cooling system should be inspected before installing a spare or repaired inductor.

Figure 8 shows a blown inductor in a partially disassembled bore liner inductor due to *absence of cooling*. The copper inductor instantly vaporized when a 450 kHz power supply was turned on because the cooling valves to the inductor were closed. Melting occurred so quickly that the flux intensifier material surrounding the tube remained intact. A flow sensor in the inductor cooling line would have prevented the failure.

Quench Maintenance

The quench system is the heart of a induction heat treating process. Often neglected (sometimes due to budget constraints), the quench system can become polluted. A wellmaintained filter system helps control the conditions, but polymer quenchants break down over time and the system must be drained, at which time quench tanks, as well as filter housings and plumbing should be pressure washed to remove scale and scum. While this maintenance is expensive, it is absolutely necessary to produce a consistent product.

Quench-induced arcing is also something of which to be wary. Inductors usually work well in a clean environment, but will suffer if a quench system is dirty. Dissolved solids precipitate out of the quench and coat the inductor, and if allowed to accumulate, these solids will arc and damage or destroy the inductor under the right conditions.

Arcing initiating through the quench fluid when the induction power is on is even more dangerous. Many applications require quenching a steel part immediately after heating it (single shot). The next steel part is positioned within the inductor, which is coated with quenchant fluid dripping from the inductor. Because the electrical circuit of the inductor is isolated and operating at a voltage potential to ground, small arcs discharge from the inductor through the dripping quenchant to the heating part (Fig. 9). Arcing continues as parts are processed, removing copper from the area where the arcs occur and eventually eroding the inductor to failure (Fig. 10). This situation often is wrongly blamed on poor cooling or inferior copper.

The cause of this type of arcing is contamination of the quenchant with fine metal particles of about the consistency of copy toner. The particles enter the induction hardening environment clinging to the slightly magnetic steel parts. The particles electromagnetically jump from the steel part to the inductor when the inductor is powered (Fig. 11). Most are washed off during the quench process, passing through the filters and suspended in the quenchant, accumulating until the voltage potential is right and arcing begins.

Inductor life can be improved under this condition by aggressive parts washing prior to induction heating. Installing a magnetic particle separator in the quench system also is helpful; drum type magnets that work continuously are the best. Magnets in the filter housing work well as long as they are cleaned daily. A simple, large, strong plastic coated permanent magnet suspended in the quench tank also will work in a pinch.

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