Taking the Crank Out of Crankshaft Hardening

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Induction heat treatment is traditionally a popular choice for hardening and tempering of quality crankshafts. This article will explain how continuous process improvement makes a good process even better.

Crankshafts are widely used in internal combustion engines, pumps, compressors, etc. and belong to the group of the most critical auto components typically weighing between 30-85 pounds depending upon the engine. At the same time, the weight of some crankshafts (ships and power generators) exceeds 2,000 pounds.

A crankshaft, typically cast or forged, comprises a series of crankpins (pins) and main journals (mains) interconnected by webs/counterweights (Fig. 1). Steel forgings, nodular-iron castings, micro-alloy forgings and austempered ductile-iron castings are among the materials most frequently used for crankshafts.[1] High strength and elasticity, good wear resistance, light weight, low vibration, geometrical accuracy, short length and low cost are some of the most important crankshaft requirements. Most of these attributes are augmented by the induction-hardening process.

Fig. 1. A crankshaft comprises a series of crankpins (pins) and main journals (mains) interconnected by webs/counterweights

Induction Technologies of the Past

Inasmuch as the diameters of a crank's journals (mains and pins) are much smaller compared to the external dimensions of the counterweights (webs), the conventional encircling-type coils could not freely pass from one heat-treated journal to another. This feature dictates having a specific inductor design.

Clamshell or Split Inductors

Specially designed clamshell or split inductors (Fig. 2) were developed and extensively used for induction hardening of crankshafts in the 1950s. No rotation of the crankshaft was required. Short coil life, poor reliability and low production rate of the clamshell coils are some of the main drawbacks of these inductors.[2] The short coil life resulted from inherent necessity of breaking the current pass by having the high-current contacts.

Fig. 2. Clamshell or split inductors

When the inductor is closed, it must be clamped with sufficient pressure to ensure that good electrical contact is made between the movable parts. Realistically, there are no contact surfaces of a coil that are perfectly smooth.

Regardless of the amount of contact-surface polishing and cleaning, air pockets and contaminated islands of the contact area will force the coil current to flow through the localized solid-to-solid contact points.[2] What results is the appearance of a localized increase of current density and an increase in electrical resistance of the contact area compared with solid copper areas of the coil because electrical resistance of the contact surfaces is usually more than tenfold that of solid copper, and heat generation is directly proportional to change in electrical resistance.

The clamping area of the coil also contributed to short inductor life due to wear and contaminants, which led to excessive overheating and even arcing and, ultimately, to premature coil failure. The quality of the electrical contact degrades appreciably after multiple openings and closings of the coil in a production environment. Contaminants quickly build up on contact surfaces, which further increase electrical resistance of the contact area.

These factors caused an increase of the electrical resistance of transitional areas between contact surfaces to continuously change during coil operation, resulting in poor reliability and variation in the power induced within the heated part. Heat treaters often were required to increase the contact pressure to compensate for a clamshell coil surface deterioration with time. This practice resulted in coil copper deformation in clamping areas, unpredictable coil performance and its premature failure.

U-Shaped Inductors

From the 1960s to the year 2000, the majority of existing induction crankshaft-hardening machines utilized U-shaped inductors, which rode on while a crankshaft rotated during heating. According to that process, each crankpin and main journal was heated by bringing a U-shaped inductor close to the pin or main bearing surface while the crank was rotated about its main axis. Since the pins' axes were offset radially from the main axis, the pins orbited the main axis. The circular orbital motion of such a heavy system should be maintained quite precisely with a special control tracking system providing a power modulation for each heated crank's feature during its rotation (Fig. 3 A,B).

There are several obvious drawbacks associated with this technology, including:

- High maintenance cost
- Bulky and noisy system design
- Poor pattern repeatability, high system sensitivity and short tooling life
- Appreciable equipment downtime (short coil life and wear out of flexible cables)
- Safety concerns due to the presence of multiple moving heavy machine parts and cables

More detailed shortcomings related to use of the U-shape inductors include:

- Carbide guides (locators) are required. Carbides "ride" on the pin/main surface at high temperature. The process demanded having critically small "journal-to-coil" air gap (0.25-0.4 mm) making it difficult to monitor the wear of the carbide. The small gap requires time-consuming setup training and experience in the proper adjustment of the locators, and it still allows for human error. Due to the small air gap and uncontrollable wear of carbide guides (locators), the U-shaped coil often accidentally touches a rotating crank surface. This results in coil water leaks and premature coil failure and negatively affects the quality of heat-treated journals (i.e., pattern shifting, an appearance of "soft" spots on as-hardened surface). Besides, each locator is simply one more part that can go wrong.
- The necessity of having critically small "journal-to-coil" air gap in combination with appreciable amount of heat radiated from the journal surface and a moist working environment accelerates coil copper deterioration due to stress-corrosion and stress-fatigue failure modes.
- U-shaped coils are fabricated using one of two techniques: copper banded or brazed. In both cases, precision and repeatability of fabrication of complex-geometry coils (Fig. 3 C,D) is always a concern.
- U-shaped coils produce a non-symmetric heating pattern at any given time because heat is applied to less than half portion of the crankshaft journal (Fig. 3 B). The rest of the pin/main undergoes a "soaking-cooling" mode. The non-symmetrical heating nature of U-shaped inductors can result in non-uniform hardness profiles and requires having relatively prolonged heat times (7-20 seconds), which in turn leads to heating appreciable metal masses, resulting in excessive shape distortion.

Better Technology – SHarP-C

In order to utilize induction hardening while not having to rotate the crankshaft, a patented non-rotational technology, SHarP-C, was introduced in early 2000. Since first appearance, this technology was further "fine-tuned" to become a proven advanced process that eliminates

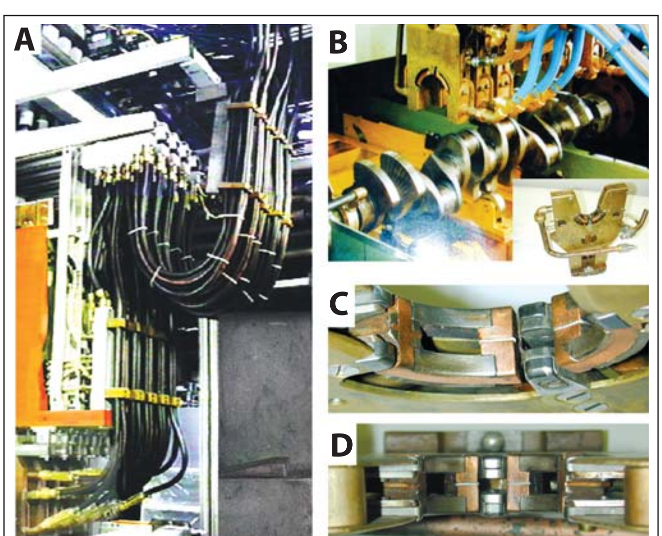

Fig. 3. Rotational hardening process utilizes a number of U-shaped inductors. Note: Carbide guides (locators) are required.

Fig. 4. CrankPro machine implements Inductoheat's patented non-rotational crankshaft hardening and tempering technology

the need to rotate the crankshaft during heating and quenching cycles while at the same time eliminating drawbacks of high-current contacts associated with clamp-type coils. Figure 4 shows a CrankPro machine, which implements SHarP-C technology, providing high-production hardening and tempering of crankshafts.

According to a patented non-rotational hardening process, an inductor consists of two coils (Fig. 5) – a top (passive) coil and a bottom (active) coil. The bottom coil, being active, is connected to a medium- or high-frequency power supply, while the top coil (passive) represents a short circuit (a loop). The bottom coil is a stationary coil, while the top coil can be opened and closed. Each coil has two semicircular areas where the crankshaft's features will be located.

Following robot loading of a crankshaft into the heating position, the top coil pivots into a "closed" position, and the power is applied from the power supply to the bottom (active) coil. The current starts to flow in the top coil. Being electromagnetically coupled to a top coil, a current flowing in the bottom coil will induce the eddy currents that start to flow in the top coil. Those induced currents will be oriented in the opposite direction compared to a source current similar to a transformer effect. Any heated feature of the crankshaft "sees" the SHarP-C inductor as a classical fully encircling coil[1-4] having a very discrete heat pattern possible.

This patented non-rotation induction-hardening and tempering technology provides several principle benefits such as simple operation, superior reliability, quality, maintainability and cost reduction. Other benefits:

- Heat patterns are "locked in place" and very repeatable since neither the crankshaft nor the coils are moving. The same pattern is achieved over many cycles.
- Induction coils are much more robust, rigid and repeatable, being CNC-machined from solid copper without any brazed or banded parts. This eliminates inductor distortion and hardness-pattern drift. There are far fewer components involved in the patented coil design, meaning higher reliability because of the smaller number of parts that can go wrong.
- No wearing of the locators/guides involved. The SHarP-C process utilizes inductors, which do not require contact guides or complex and expensive non-contact coil-positioning tracking systems of any kind.
- On average, required heat time has been reduced fourfold – being in the range of 2-4 seconds – providing several principal benefits, including energy reduction and improving shape/size distortion. Reduction of total indicated runout

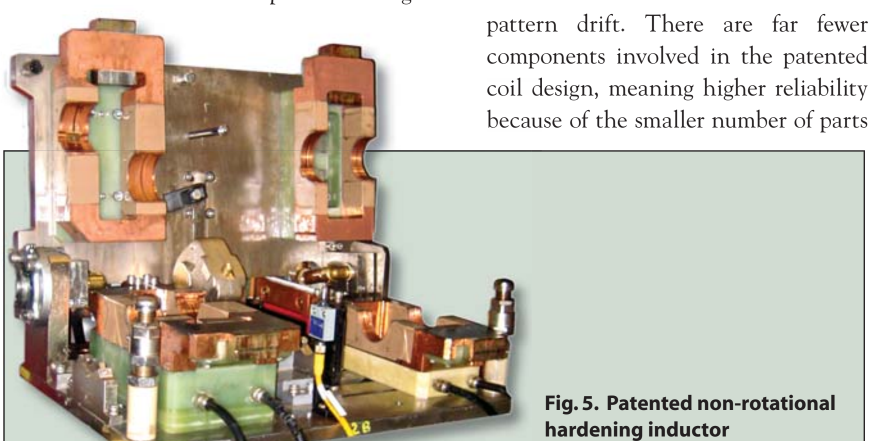

Fig. 5. Patented non-rotational hardening inductor

Fig. 6. Non-rotational hardening process provides crankshaft pins and mains with superior microstructural properties

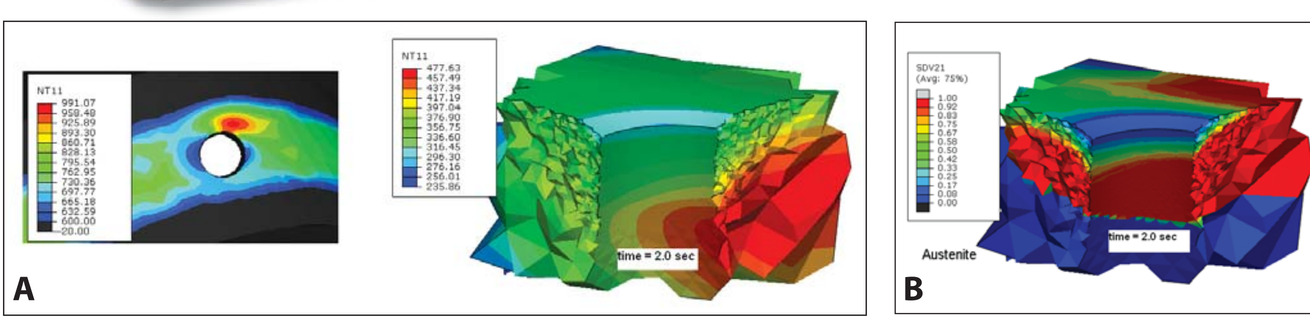

Fig. 7. Computer modeling of temperature profiles during spray quenching of crankshaft journal (A) and prediction of austenite transformation (B). Courtesy of Deformation Control Technology, Inc.

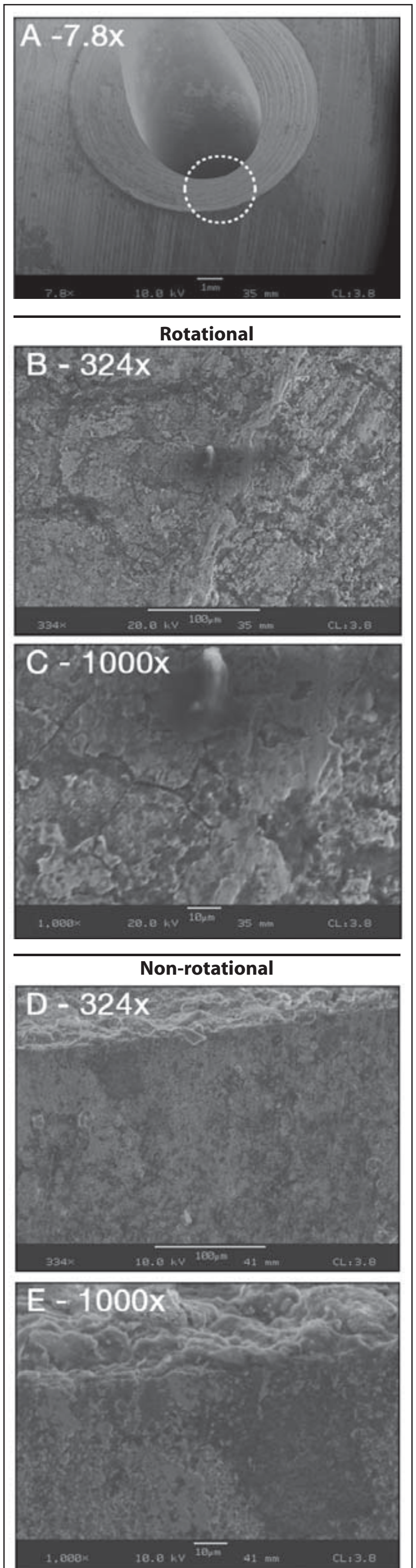

Fig. 8. The results of SEM analysis of similar regions near oil hole using rotational and non-rotational technology. Note: There is indication of a grain-boundary liquation with rotational hardening process.

(TIR) distortion is traditionally one of the most important factors in the heat treating of crankshafts. It directly affects the amount of metal required to grind. One of the most important factors that has a pronounced effect on distortion is the amount of heat generated within the crankshaft body. The greater the amount of heated metal, the greater the metal's expansion, which in turn causes greater distortion. Appreciable reduction of the heat time associated with this patented process leads to only a small mass of metal being heated. The heat-affected zone is minimized, resulting in correspondent reduction of metal expansion and, obviously, a minimization of size and shape distortion (typically distortion is less than 25 microns).

- Crankshaft pins and mains have superior microstructural properties. These include the noticeable reduction of grain growth, decarburization and oxidation of the pin/main surface. The hardened zone is clearly defined and "crisp" (Fig. 6) without the "fuzzy transition zone" that is present when longer heat times are employed. The case depth consists of a fine-grain martensitic microstructure with a negligible amount of retained austenite and without any traces of free ferrites. Essential surface compressive stresses obtained when applying SHarP-C technology are imperative for prevention of any surface-crack development. Intensive theoretical and computer-modeling studies have been conducted in cooperation with leading world experts such as Dr. Lynn Ferguson of Deformation Control Technology, Inc. to provide an ideal distribution of transitional and residual stresses in heat-treated cranks (Fig. 7).
- The necessity of having the surface of crankshaft journals at high temperature for prolonged times, as required by rotational technology, is often associated with such an undesirable metallurgical phenomenon – grain boundary liquation. This phenomenon substantially increases brittleness and sensitivity to intergranular cracking, in particular of the oil-hole area. Thanks to process features of non-rotational technology and continuous improvement, this undesirable phenomenon has been eliminated. Figure 8 shows the results of SEM analysis of similar regions located in close proximity to an oil hole using rotational and non-rotational technology.
- The SHarP-C coil-to-journal air gap is noticeably larger compared to air gaps required by the rotational crankshaft-hardening process. This creates a favorable condition to reduce stress-corrosion and stress-fatigue induction-coil copper failures and allows tooling life to be dramatically increased.
- Accurate CNC coil shaping and utilization of a "quick-change" pallet approach guarantee that coils are automatically aligned with respect to the crankshaft after coil replacement. No time-consuming process adjustments are required to "tweak" each coil after replacement. Unitized construction allows quick, error free, production-ready factory installation and start-up, substantially reducing downtime.
- Since there is no rotation of a crankshaft required, it is not necessary to move heavy structures often weighing over 2,000 pounds through the orbital path during heating. There are no high-current electrical contacts or flexible cables to wear out. There is only "open-close" action. All of which improve the safety of operating equipment.

Conclusion

In addition to superior production improvements, SHarP-C technology offers crankshaft designers more flexibility to optimize hardness and wear properties where needed and not where formerly limited by other processes. **IH**

References available online only.

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