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Advanced Non-Rotational Induction Crankshaft Hardening Technology Introduced to Automotive Industry

A revolutionary new induction heating system is being introduced to the automotive industry for the heat treatment of crankshafts. This technology involves heat treating the crankshaft journals using stationary inductors rather than the cumbersome methods of conventional crankshaft hardening processes. In conventional methods, the inductors must follow the offset rotation of the connecting rod journals, requiring the movement of massive induction fixtures as the crankshaft rotates. In the method described here, both the crankshaft and inductors remain stationary, resulting in improved hardness patterns and a significant reduction in floor space requirements for the equipment.

"Well, times have changed and things are modern," said one user after an evaluation of a newly developed non-rotational induction crankshaft hardening machine. He later added "A non-rotational approach makes sense from all perspectives. It is somewhat similar to simply pushing a remote control button to start your car compared to using a manual crank as in the good old days."

Crankshafts are widely used in internal combustion engines, pumps, compressors, etc., and are among the most critical auto components. A crankshaft, typically cast or forged, comprises a series of crankpins and main journals interconnected by webs/counterweights (Fig. 1). High strength, good wear resistance, geometrical accuracy and low cost are among some of the crankshaft requirements.

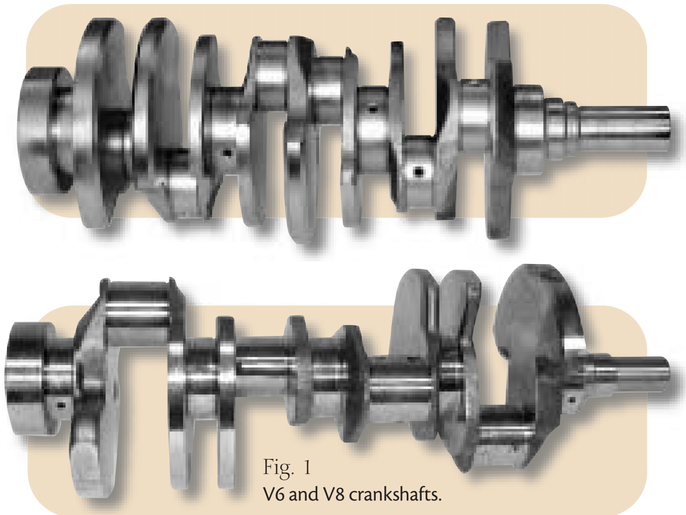

Fig. 1
V6 and V8 crankshafts.

CONVENTIONAL TECHNOLOGY

A majority of the existing induction crankshaft hardening machines require the crankshaft rotation during heating. Each crankpin and main journal is heated by bringing a "U-shaped" inductor close to the crankpin or main bearing surface while the crankshaft is rotated about its main axis. Since the crankpin axis is offset radially from the main axis, the crankpin will orbit around the main axis. The crankshaft's rotational speed varies between 24 and 32 rpm; consequently, the "U-shaped" inductor, as well as other massive components of the induction hardening machine including output transformer of power supply, busswork, cables, etc. (which often weight over 2,000 lbs), must travel with the orbital motion of the crankpins.[1] The circular orbital motion of such a heavy system must be maintained precisely, resulting in the complex, sensitive, bulky, noisy and costly design of the conventional induction hardening machines.

Equipment maintainability, reliability and harden pattern repeatability are among other concerns expressed by users of the existing technology. In particular, the short coil life was a dilemma. There are several factors that led to short coil life while using conventional crankshaft hardening technology:

- Traditional technology is required to have a small air gap (in some cases less than 0.5 mm) between the coil and surface of the heat treated feature. The combination of small air gaps, relatively prolonged heat time (7 sec to 12 sec), crankshaft surface temperature (1750°F plus) and a moist working environment provide a favorable condition for stress corrosion in the coil copper;

- On the other hand, complex brazed coil geometries with numerous joints in combination with significant heat exposure and the existence of electromagnetic forces create a favorable condition for stress fatigue coil failure and crack development;
- Due to small air gaps, the uncontrollable wear of carbide guides (locators), or to an error of the non-contact coil position tracking system, the coil often makes accidental physical contact with a rotating crank surface (a coil "rides" on the crankshaft feature). This sometimes results in physical damage to the coil and often leads to premature coil failure.

STATIONARY HARDENING PROCESS FOR CRANKSHAFTS

To improve on the above mentioned drawbacks of the conventional induction crankshaft hardening systems, a new, non-rotational technology has been introduced by Inductoheat, Inc., Madison Heights, MI. The Stationary Hardening Process for Crankshafts (SHarP-C Technology) eliminates the need to rotate or move either the inductor or the crankshaft during heating and quenching while at the same time eliminating high current contacts required when using encircling clamp-type coils.

The first machine has been built for one of the world's leading automotive manufacturers and a second machine is under construction. The advantages of the non-rotational system over the conventional hardening systems were recognized immediately by the customer's materials, manufacturing and quality engineers. Some of these features include:

- The stationary method of heating without crankshaft rotation provides several practical benefits such as simple operation, reliability, maintainability, compactness (using only 20 percent of the floor space required by a conventional method), horizontal or vertical handling, and cost reduction (Figs. 2 and 3).
- Reduction of shape/size distortion - one of the most important factors in the heat treating of crankshafts is the amount of heat generated within the crankshaft body (including mains, pins and counterweights). The greater the amount of heated metal, the greater the metal's expansion, which in turn causes greater distortion. The non-rotational technology requires a shorter heating time (typically in the range of 1.5 to 4 seconds) than that required conventional machines (7 to 12 seconds). This results in less residual heat build-up in the crankshaft (allowing for the elimination of special cooling systems that are typically required for conventional systems) and less metal expansion to minimize size and shape distortion (typically less than 0.025 mm).
- Short heating time improves the metallurgical properties of the hardened zone by reducing grain growth, decarburization and oxidation of the pin/main surface. The hardened zone is clearly defined without the "fuzzy transition zone" that is present when longer heat times are employed. The case depth consists of fine grain martensitic micro-structure with a negligible amount of retained austenite without any traces of free ferrites.
- Short pulse induction heating can also lead to "super hardening," a phenomenon where hardness is increased by 2 to 4 points HRC over the normal maximum

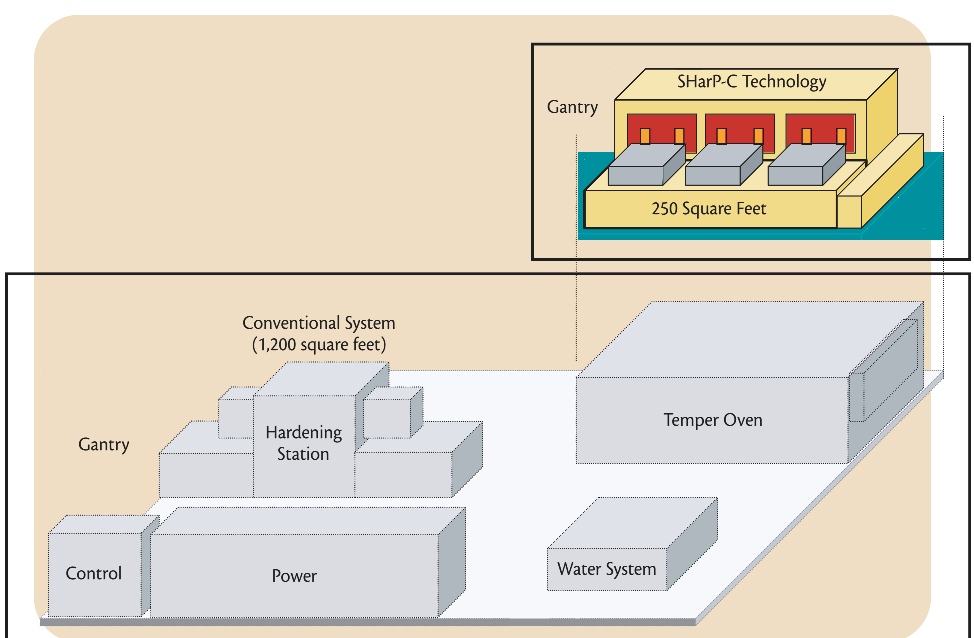

Fig. 2 The stationary crankshaft hardening technology requires only 20% of the floor space required by a conventional crankshaft hardening systems.

Fig. 3 Photograph of the non-rotational (SHarp-C)crankshaft induction hardening unit.

hardness for a given grade of steel. This may allow a user to apply a lower steel grade without sacrificing surface hardness.

- With regard to electromagnetics, any heated feature of the crankshaft (main, pin, oil seal) "sees" the stationary inductor as an encircling "closed form" coil with induced eddy current flow along the circumference of the heat treated feature. Using the conventional induction coil design ap-proach, the heat sources are limited to local eddy current loops only, resulting in reduced coil efficiency, especially above the Curie temperature. The electrical efficiency (or coil power factor) of stationary coils is therefore higher than "U-shaped" coils and electromagnetic field exposure (external to coil) is negligible.

- Since the features of the crankshaft (main, pin, oil seal) are exposed to symmetrical heating patterns through the stationary hardening coils, the hardness profiles are more consistent (Fig. 4). When applying a "U-shaped" coil, there is a non-symmetrical heat mode. At any given time, heat is applied to only one half of the crankshaft feature (i.e., main or pin). The second half of the pin or main under goes a "soaking-cooling" mode. The non-symmetrical nature of conventional inductors can result in non-uniform hardness profiles and possibly egg-shaped distortion of pins or main journals.

- The stationary induction hardening process is not very sensitive to the irregular shape of pin/main adjacent masses (webs/counterweights). Coil design combines a number of innovative electromagnetic solutions, which makes the technology insensitive to differences in adjacent masses. The hardness pattern shown in Fig. 4 illustrates this feature.

- The controllability of the stationary hardening process is excellent. It is possible to modify the hardness profile along the circumference of the pins and the mains as well as across the width of the heat treated feature. This controllability can also be used to prevent localized underheating or overheating. For example, where an oil hole is angled relative to the surface, there is less metal mass on one side of the hole than on the other; thus, a need to induce different amounts of heat within those areas exists. Also, when the counterweight to the left of a journal is not identical to that on the right, the heating can be controlled to prevent pattern drift from one side to the other.

- "Top-to-bottom" and "left-to-right" cross-sections can also be controlled. This includes the so called "fishtail" area (or "split region" of the coil) where in traditional induction systems there is a distortion of the electromagnetic field due to a current cancellation phenomena. As a result of this phenomenon, a soft spot or "necking" of harden pattern could appear. As seen in Fig. 4, there are no soft spots or hardness pattern "necking" evident in the stationary hardening process. In addition no "double-hoop" pattern is seen using the stationary hardening process (Fig. 5).

- Some conventional "U-shaped" inductors use carbide guides (locators) requiring specific setup training and experience in the proper adjustment of the locators allowing for human error.

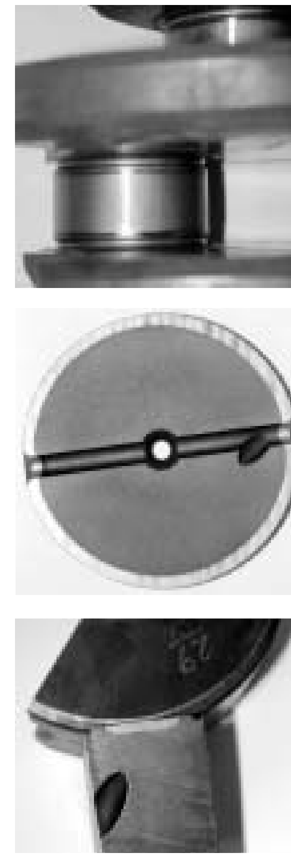

Fig. 4 The hardness pattern on a V6 crankshaft journal resulting from the stationary hardening process.

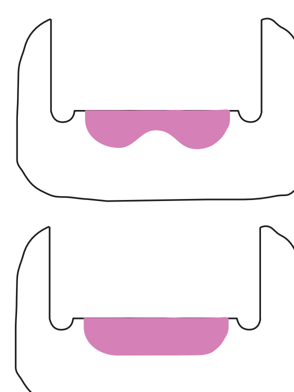

Fig. 5 Schematic diagrams representing the hardness patterns on crankshaft journals. The "double-hoop" pattern in the top diagram is typical for conventional crankshaft hardening methods. The pattern in the lower diagram is typical of the stationary crankshaft induction hardening process.

These carbide guides ride on the surface of the part being treated at high temperature and can introduce inclusions into the pin/main surfaces creating stress risers (this particular factor can be dismissed if final grinding is used). It is necessary to monitor the wear of these carbides and their location. Otherwise, the hardened pattern can be shifted or the induction coil can rub the crankshaft surface, which shortens the coil life.

- To achieve electrical efficiency in an inductor, the existing technology must apply a variety of lamination packs in close proximity to the heated surface (air gap between heated surface and surface of the laminations is often less than 0.5 mm). The combination of radiation and convection heat exposure from the hot crankshaft surface, along with the inherent thermal cycling, can shorten the life of these lamination packs. With the advanced stationary coil design, these laminations are unnecessary. These advanced coils utilize special flux concentrators that are much more durable, have less chance of magnetic saturation, and are not exposed to as much heat or magnetic forces as the laminations used by conventional methods.

SUMMARY

In general, the stationary hardening process for crankshaft hardening and tempering is quality oriented and more reliable because (1) there is no rotation of the crankshaft and thus, no requirement to move heavy structures through the orbital path during heating; (2) coil/inductor design is more robust meaning higher reliability with a lesser number of parts; (3) no wearing of locators or guides since the inductors do not require contact guides or complex coil positioning tracking systems of any kind; and (4) crankshaft pins and mains have superior microstructural properties as compared to conventional crankshaft induction hardening processes.

The SHarP-C is a cost effective technology. This novel crankshaft hardening/tempering process is designed with ergonomics in mind, including compact designs with reduced floor space requirements down to 20%. Machines are easier to maintain and operate with significant reduction of industrial noise and a major improvement in coil life. The use of cellular approach (coil nests) allows for simple and quick changeover. IH

REFERENCE

[1] J. Lewis, "Advanced controls eliminate case-hardening contact," Design News, 01 May 2000, pp. 59-61.