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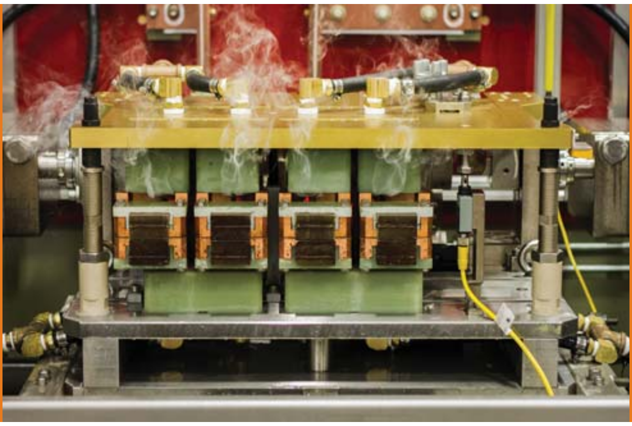
New Technology Straightens Out Camshaft Distortion



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Induction heat treatment is a common method for heat treating different automotive components, including camshafts, which belong to the group of critical engine/powertrain components. Now a new approach makes it possible to induction harden camshafts with almost undetectable distortion.

An engine's camshaft controls the timing and the speed of the opening and closing of the intake and exhaust valves. It consists of several sets of cam lobes and bearings (Fig. 1). The number of lobes, their size, profile, positioning and orientation are dependent upon the camshaft type and engine specifics. Figure 2 shows some examples of a variety of cam lobe shapes. Gray and nodular cast irons as well as medium-carbon steels are used to fabricate camshafts.[1]

During its operation, the cam may run millions of cycles and experience considerable wear and contact stresses. A good combination of wear resistance and strength is essential for cam lobes, which require induction hardening of the working surfaces. In addition to strength and wear resistance, camshafts need to be straight to offer quiet and vibration-free performance.

Induction Heat Treatment of Camshafts

Depending on the camshaft's geometry and production requirements, the shafts may be induction heat treated using scan hardening of a single lobe or static (single-shot) hardening of a single lobe or multiple lobes.

Both vertical and horizontal induction hardening designs were used by different manufacturers. Heat times are in the 3-8 second range depending on type of material, prior microstructure and geometry. Shorter heat times were required for quenched-and-tempered and normalized prior microstructures. Frequencies of 3-40 kHz are typically used, depending on required case depth and camshaft geometry.

Scan Hardening

Scan hardening is typically used for relatively low production rates and somewhat wide lobes. Depending on the process specifics, lobes can be rotated during heat treating. When lobes are scan hardened without rotation, the inductor heating face can be machined to better accommodate lobe geometry and properly compensate electromagnetic proximity effects. In this case, measures should be taken to provide an appropriate lobe orientation with respect to an inductor.

Scan inductors offer the greatest flexibility by hardening lobes of various lengths/widths applying a minimum

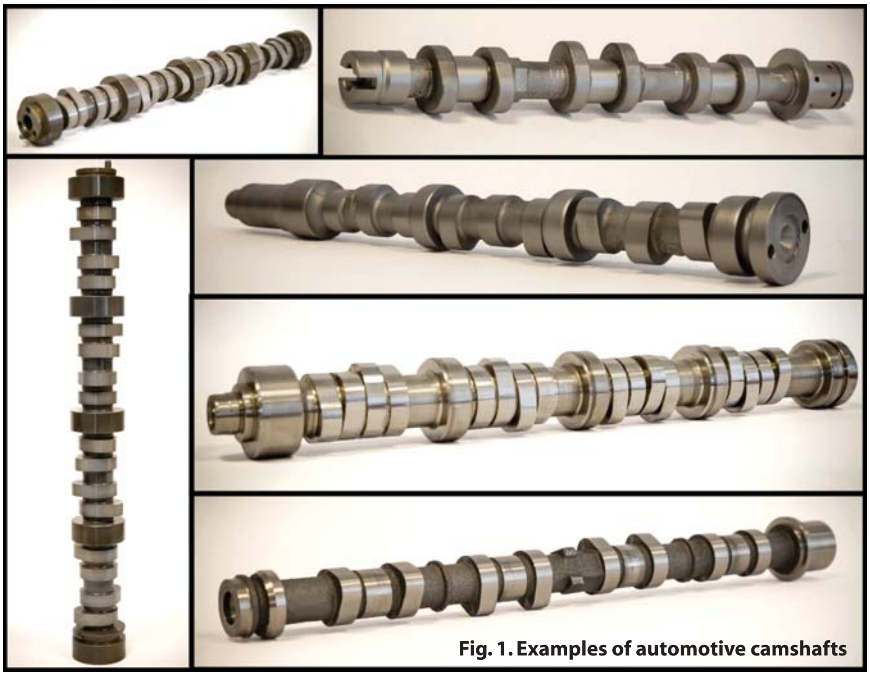

Fig. 1. Examples of automotive camshafts

amount of power since only a portion of the single lobe is heated using an inductor with a relatively narrow copper face. This process is often used for hardening large lobes (e.g., ship and train cams). A complex algorithm to control power versus scan rate and inductor positioning is typically required to compensate for end effects.

The main limitations of applying scan hardening to automotive camshafts is related to low production rates due to single-lobe processing and some difficulty in obtaining the required hardness pattern of closely positioned lobes. Quench back splash and undesirable localized tempering soak back are additional issues.

Single-Shot Hardening

In contrast to a scan hardening, single-shot heating of multiple lobes is commonly used when surface hardening small- and medium-size camshafts with lobes of similar size and shape and having the same or very similar axial gaps between them.

Camshafts are rotated during induction hardening. In order to increase the output, multiple lobes are heat treated simultaneously. A corresponding number of single-turn inductors are connected electrically in a series, which provides the required heating of multiple lobes. Coil copper is often profiled in axial direction to obtain desirable power-density distribution. This also takes into consideration an electromagnetic interaction between neighboring turns, which properly controls end effects and addresses specifics of the cam-lobe geometry. Quenching can be incorporated into an inductor design, or it can be done out of place after completing the heating cycle.

Single-shot hardening with camshaft rotation is usually associated with noticeably deeper case depth in the nose compared to a base circle (the heel) area, because the nose of the cam lobe has closer electromagnetic coupling with an inside diameter of the coil copper.

Single-shot hardening usually necessitates having greater inverter power compared to scan hardening. It is required to austenitize an entire surface of multiple lobes to a desirable depth in order to achieve the required hardness pattern upon subsequent quenching.

Static (Non-Rotational) Induction Hardening

With static hardening, both the inductor and camshaft are motionless during heating and quenching stages. Several inductor designs were used over the years to statically harden cam lobes. Many of those designs were very similar to designs used for hardening crankshafts.

Conventional Single-Turn Static Inductors

Conventional single-turn coils were one of the earliest inductors used to surface harden cam lobes. The nose of the cam lobe was typically positioned in the inductor area, where copper busses that transmit electrical current from a power source are connected to the induction coil. In this region, a magnetic field is formed by incoming and outgoing electrical currents oriented in opposite directions. This causes a flux-fringing effect.

An attempt has been made to apply this effect to reduce the surplus heat generation in the lobe nose area, which occurs due to the electromagnetic proximity effect. In addition, magnetic flux concentrators were applied in the lobe base circle area in an attempt to compensate the deficit of the heat sources that appeared due to a larger coil-to-lobe gap. Unfortunately, this coil design resulted in poor controllability of the hardness pattern, low heating efficiency and high distortion. As a result, its use is extremely rare.

Clamshell or Split Inductors

Specially designed clamshell or split inductors are also used for hardening camshafts. No rotation of the camshaft is required. Coil copper is profiled to accommodate the shape of the cam lobe.

Clamshell inductors are so named because they are typically hinged on one side so that the camshaft's journal can be loaded in the correct heating position while maintaining a uniform air gap between heating face and lobe surface. This helps to minimize lobe distortion, apply short heat times and produce a contour-like hardened pattern. Unfortunately, short coil life, poor reliability and maintainability, and low production rates are some of the main drawbacks associated with the use of clamshell inductors due to electrical contact issues.[1]

Fig. 2. Cam-lobe geometries[1]

New Technological Approach

Patented non-rotational technology (SHarP-C™) that was developed for hardening crankshafts has recently been effectively expanded for producing true contour hardening of camshafts. The inductor consists of a top (passive) inductor and a bottom (active) inductor (Fig. 3). The bottom inductor (being active and connected to a power supply) is stationary, while the top (passive) inductor can be opened and closed during camshaft loading and unloading. Each inductor has profiled areas where the cam lobes, which need to be heat treated, can be located while the top inductor is in its open position. Due to the

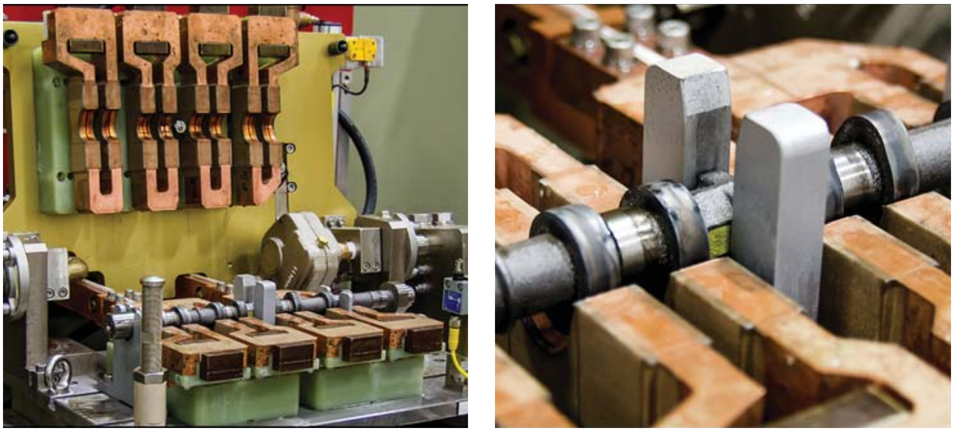

Fig. 3. **CamPro™ machine utilizes patented non-rotational hardening technology (SHarP-C™ technology)**

Fig. 4. **Uniformly distributed true contour-harden patterns produced by CamPro™ machine** *(courtesy of Inductoheat Inc.)*

active/passive approach, electrical contact issues associated with clamshell coils are not a problem.

Following loading of the camshaft into the heating position, the top inductor pivots into a closed position, and the power is applied from the power supply to the bottom (active) inductor. Electrical current flowing in the bottom coil will instantly induce the eddy currents that start flowing in the top inductor. This is due to a lamination pack that serves as a magnetic flux coupler, which electromagnetically couples top and bottom sections similar to a transformer effect. Therefore, cam lobes "see" the non-rotational inductor as a classical encircling and highly electrically efficient induction system with a uniform lobe-to-inductor gap.

As expected, the heating face of such inductors can be easily profiled to achieve the desirable hardness pattern. Specially designed quench slots are used to accomplish the process of quenching as well as coil copper cooling.

Non-rotational induction hardening technology provides several principle benefits such as dramatically reduced distortion, simple operation, better quality, superior reliability and equipment maintainability as well as life-cycle cost reduction. SHarP-C inductors are robust, rigid and repeatable, being CNC machined from solid copper block. All brazed or banded components in manufacturing inductors are eliminated. This, in turn, dramatically reduces the possibility of inductor distortion during its fabrication and eliminates the associated hardness-pattern drift.

This novel process lends itself for hardening several lobes (Fig. 3). Therefore, high production rates can be achieved by statically heat treating multiple cam lobes simultaneously.

Dramatic Reduction of Camshaft Distortion

A measurable advantage of recent installations that have implemented this novel process is the ability to harden camshafts with practically undetectable distortion. In some cases, this potentially eliminates the entire camshaft straightening operation.

There are several factors that affect distortion of heat-treated components, including type of material, its prior microstructure, geometry, hardness profile, etc. Camshafts have relatively complex geometry with a lack of symmetry. One of the critical factors affecting distortion is the amount of heat generation. The greater the amount of heated metal, the larger the expansion, which causes greater distortion.

One of the most attractive features of this technology is its ability to produce uniformly distributed true-contour hardening patterns (Fig. 4) regardless of the fact that the camshafts belong to a group of geometrically irregular components. If required, the heat-affected zone (HAZ) can be minimized, which further reduces metal expansion and, obviously, minimizes shape distortion by putting less energy into the camshaft. The core of the journal, acting as a shape stabilizer, remains relatively cold during the entire heating cycle. Heat patterns are locked in place and very repeatable since neither the camshaft nor the inductors are moving during heating. The same pattern is achieved over many cycles.

In contrast to alternative processes, where axial pressure is applied to rotate a camshaft, no axial force is applied during heat treating because the camshaft is being rested on V-shaped blocks (Fig. 3).

Accurate CNC coil shaping and utilization of a quick-change pallet design guarantee that coils are automatically aligned with respect to the camshaft

Testimonial

Ignacio Castro from Arbomex SA de CV commented, "The SHarP-C hardening machine helped us reduce camshaft distortion to 3-5 microns and we have been able to eliminate the entire straightening operation. So, our savings on elimination the straightening operation alone is about $40,000 per year. On top of that there has been substantial improvement of the quality of the hardened camshafts, and our scrap was reduced about 1.5%."

after inductor replacement. By simply disconnecting two hoses and loosening a few clamps, the inoperative pallet can be easily removed from the machine. A functioning pallet is then put in its place in just minutes. Unitized construction allows quick, error-free, production-ready factory installation and start-up, which substantially reduces downtime compared to alternative processes. This also allows a conversion of the machine to process a variety of different parts.

Post Heat-Treating Operations

Heat treating of the camshafts is followed by grinding/polishing. Final grinding of the camshaft working surfaces is needed to minimize surface roughness and ensure dimensional accuracy of lobes and journals. Complex and interrelated thermo-mechanical and chemical processes take place during surface grinding. Several grinding conditions can be used: gentle, normal or severe.

Excessive heat generated due to inappropriate grinding conditions can negatively affect the camshaft's performance. Wear resistance of bearing surfaces is compromised by altering the microstructure, which decreases beneficial compressive residual stresses and even reverses a desirable residual-stress distribution.

As would be expected, the required amount of grinding is a function of the amount of stock left on the part and the component's distortion. Therefore, being able to obtain a true contour-hardening pattern allows a substantially reduced amount of grinding. Better camshafts are the result. (Note: The amount of grinding stock that is removed from the hardened case directly affects the life of the cutting tool, overall process robustness and cost effectiveness.)

Conclusion

Compound benefits of this patented technology include the following three major points:

1. Neither the part nor the inductor moves during heat treating, preventing misalignment, wear or electrical short-circuit potential.
2. The inductor is CNC machined, ensuring exact dimensional accuracy.
3. Utilizing SHarP-C™ technology in recent installations has proven to produce superior camshaft straightness along with excellent hardening characteristics right off the production line. **IH**

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Reference

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