New developments in part handling tooling in the field of cam lobe hardening allow achieving uniform case depth hardening using conventional heat treating equipment and accelerated austenitizing techniques.

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Early approaches to camshaft hardening involved single lobe and multiple lobe hardening using relatively low power densities and long heat cycles. Power density was in the range of 4 to 5 kW/in.² and heat time was in the range of 27 to 30 seconds for multi-lobe hardening of 16 lobes at a time. Power density and heat time for single cam lobe hardening was approximately 8 kW/in.² with a 10-second heat time. Figure 1 illustrates the multilobe hardening process. The end result was a deep case of about 0.25 in. (6 mm) in the lobe base circle or heal area and up to 0.5 in. (13 mm) in the lobe. Figure 2 illustrates the hardness pattern of this processing method.

The result of this deep case processing method was high distortion, especially noticeable if the case depth goes into the shaft of stick area. Also evident with this process is an overheated metallurgical structure in the lobe area creating tension stress and, in some cases, subsequent radial cracks.

Crack detection methods were used as part of the metallurgical quality control evaluation. In the multilobe processing technique, metallurgical evaluation was compounded by the need to examine each lobe, as each lobe varied in case depth and microstructure due to the uneven heating, which was the result of mutual inductance caused by the multiple loops used in the process. Essentially, each loop was machined to discrete dimensions to compensate for the effects of overlapping electromagnetic fields. In some cases, flux concentrators were necessary to distort and shield the mutual inductance. Heavy grinding was needed to correct for distortion and to remove the surface material in the lobe area, which was high in retained austenite from the over-heating condition. Heavy grinding resulted in microcracking, which proved later in the evolution of valve train design to be detrimental to roller lifter technology.

Alternative technology
Static, or nonrotational, single lobe heating using a frequency range of 10 to 25 kHz with up to 50 kW/in.² and heat times of 1 to 1.5 seconds resulted in case depths of approximately 0.080 in. (20 mm) in the base circle and lobe areas. Figure 3 illustrates the hardness pattern of this process. The process calls for the lobe
nose to be positioned at the split in the inductor, which is where the weakest area of the electromagnetic field is located. Flux intensifiers are spaced accordingly to increase the field in the loosely coupled areas and decrease the field in the closely coupled area at the nose.

Directional quench impingement points are also used to improve quench uniformity in the cam lobe and ramp areas. This becomes very important when nonrotational quenching is used. Distortion is minimal, and with proper contouring of the inductor face, surface crowning could be controlled to a point where finish grinding after hardening was not necessary. This approach was not inexpensive though; it required a complex fully machined inductor together with a very precise part-handling machine having axial and radial positioning, requiring almost machine-tool accuracy. In addition, the use of high power densities in this process led to premature inductor failures due to fatigue stress cracks in high mechanical fatigue areas caused by the flexing of the single loop inductor during the expanding and collapsing electromagnetic fields. Increased inductor life was realized by stress relieving the inductor after assembly.

Shallower case depths have also been developed using high frequencies above 200 kHz and power densities of at least 25 kW/in.² with heat times in the area of 0.2 seconds, resulting in case depths in the range of 0.030 to 0.040 in. (0.76 to 1 mm). This process involves the use of an integral quench, contoured split or clamshell inductor, shaped in the profile of the cam lobe. Coupling distances are usually held at about 0.040 in. This inductor is designed to open and close in a scissor-like motion to allow for axial and radial positioning from one lobe to the next. Figure 4 illustrates the shallow, uniform pattern obtained.

This method is more costly from a tooling standpoint due to its high complexity and higher maintenance due to wear on moving parts and period replacement of electrical contact inserts. The additional mechanical motions of the inductor results in increased cycle time compared with a stationary inductor. Consequently, this inductor design is not used in high production applications usually found in the automotive industry.

Simultaneous dual frequency heating
Cam lobe hardening development work has also involved using simultaneous dual frequency (SDF) heating. One of these process was used with a loosely coupled, tube fabricated production inductor. The normal production operating parameters required preheating, a delay, and then a final heat cycle having an overall heat cycle time of 3.5 seconds, producing a relatively uniform pattern. However, there was a deeper case depth in the lobe area.

Using the same inductor, a heat time of 0.22 seconds with 192 kW of medium frequency and 106 kW of high frequency was used for a total of 298 kW. The result is a case depth of 0.082 in. at the nose and 0.063 in. at the heal of the cam lobe (2.1 and 1.6 mm) as shown in Fig. 5. The fully transformed microstructure is very similar to the production
samples, with the only difference being a very narrow, almost non-existent transition zone, which is typical of Electroheat’s Accelerated Austenitizing technology using high frequency power densities at or above 50 kW/in.². Even though the heat cycle was dramatically decreased, the variations in heal-to-lobe case depth do not show any significant improvement using the SDF process. This process is more applicable to gear hardening and other tooth profile configurations.

New process solves problems
In the cases discussed above, the cam lobe hardening processes used part-holding tooling that either rotated or held the part concentric with the shaft or stick diameter of the camshaft. A recently patented process simplifies the method of uniformly case hardening a cam lobe while using conventional induction heating equipment and tooling, which can be close coupled machined or loosely coupled formed tube inductors.

The tooling involves an eccentric locator that has its center or rotation at equal distances from the base circle to the apex of the lobe (Fig. 6). The rotation of the eccentric locator allows for uniform coupling with the inductor, so more uniform heating occurs that approximates heating seen in a profiled split inductor or a static heating inductor without having all the complexities or production penalties. A sample part was produced using an eccentric locator, which produced a pattern having a uniform case depth of 0.092 in. (2.3 mm) in the heal and nose and 0.088 in. (2.2 mm) in the ramp areas (Fig. 7). Part-to-inductor coupling distance is shown in Fig. 8. This process lends itself well to hardening single cam lobes that are subsequently fixed to a hollow shaft, such as a composite or assembled camshaft. Conventional solid shaft camshafts require a synchronized, adjustable locator at each end of the camshaft to provide the eccentric axis of rotation for each cam lobe, as one lobe is hardened at a time.

The benefits of having an eccentric locator to obtain a base circle or heal-to-nose coupling uniformity include:

- Consistent metallurgy in heal to nose and ramp areas
- Elimination of tension condition in lobe apex and ramp areas caused by excessive case depths
- Minimal distortion
- Capable of using Accelerated Austenitizing to reduce heat time for increased production
- Conventional machined or less costly formed tube inductors may be used
- Conventional single, medium to high frequency power supplies can be used
- Conventional part handling equipment such as lift and rotate or dial indexing machine

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