Crankshafts in internal combustion engines control the sequencing of movements of the inlet and outlet valves. They are composed of an extremely varied arrangement of cams and bearing surfaces. The number of cams, their size, profile, positioning and orientation depends on the design and engine-power class of the internal combustion engine in question (Fig. 1). Crankshafts are made both from grey cast iron and medium carbon low alloy steels. During the course of their working life, a camshaft often undergoes several million cycles of use and experiences a significant amount of wear and compressive stress. A combination of wear resistance and fatigue strength on the surface of the cam is therefore extremely important for trouble-free and reliable operation. In addition, workpiece distortion must be limited to a minimum if quiet, vibration-free operation is to be achieved. The mechanical properties on the entire workpiece and in specific locations can be adjusted by a heat treatment process. Localized optimization of the mechanical properties is often initiated by an inductive hardening process.

Depending on the geometry of the workpiece and the constraints of the manufacturing process, inductive hardening is carried out in the feed or by a localized heating of the entire surface when stationary. In this process both the individual cam and also several pairs of cams are treated at the same time in either the horizontal or vertical plane. The average heating times vary here in the range from 2–8 seconds depending on the material used and the existing grain structure. The shorter heating times are feasible if QT or normalized structures are present. The operating frequency of the process is normally in the range from 3–40 kHz.

In many cases, a scan hardening process is used for inductive heat treatment of camshafts. This process is advantageous for lower manufacturing rates or larger cams. The process is also characterized by excellent flexibility. Thus, various lengths of the cams can be processed with a single inductor by a simple adjustment to the hardening programme. In addition, because of the local heating of an individual cam, or in many cases only parts of a cam, the power requirement of equipment of this nature is very low in comparison with competing processes. This requires a more complex algorithm to phase power, feed rate and inductor positioning with each other to compensate for parasitic inductor end effects. The disadvantages of this process are the significantly lower throughput of parts, the potential reciprocal interaction of the hardening processes from cam to cam resulting from the unwanted inductive tempering of a location which has already been hardened when the subsequent cam is hardened.

Unlike moving inductive processes, with standard rotational processes (also known as “single shot” processes) several cams can often be hardened at the same time in annular inductors. This is possible for small and medium dimensions if all cams have a similar geometry and dimensions and the cams are equidistant from each other. Cams which are hardened by the usual stationary rotating methods normally exhibit a significantly greater hardness depth in the region of the centre. The heat source density in the centre is usually greater than in the foot due to the better electromagnetic coupling. Compensation for this is possible if the interaction gap between the inductor and the cam is uniform. Such cases are often called “single shot shaped inductors”. The contoured shape of the inductor surface creates a uniformity of the induced heat sources and consequently a uniformly distributed hardening profile. Individual cams can be positioned in a corresponding alignment inside a shaped inductor. This positioning is difficult if individual cams are situated on a shaft and this shaft has bearing surfaces at its ends, the diameter of which exceeds that of the cams. If this is the case, it is impossible for the inductor to move from the outside area of the camshaft over a bearing surface and then onwards over the cams.

**Fig. 1:** Overview of the varied arrangement of inductive hardened camshafts
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A new, patented process, originally developed for the inductive hardening of crankshafts, and known under the brand name of SHarP-C is able to overcome this problem and offers an attractive and clever solution for the contoured inductive hardening of camshafts with little deformation (Fig. 2). The associated inductor concept consisting of an upper, passive half shell and a lower, active half shell offers the possibility of positioning a complete camshaft in an open inductor, closing the inductor, hardening several cams at the same time, quenching the camshaft in the inductor and concluding the entire process with an inductive tempering procedure. The camshaft is not rotated during this treatment; it is aligned and static in the inductor. Lateral field concentrators on the inductor shells screen the electromagnetic field to limit the heating to clearly defined areas (Fig. 3). When closed, the lower, active inductor induces a current in the upper half shell which flows in the opposite direction to the primary current of the lower half shell. As a result of this mechanism, the inductor, when closed, behaves in the same way as a classic ring inductor with an almost identical field distribution and efficiency level. Marginal differences in the efficiency level are compensated by adjustment of the local coupling distances distributed over the circumference. The inductor profile can also be adjusted to match the local requirements of the workpiece. Thus profiling the inductor cross section specifically for electromagnetic end effects can be utilized to linearize the hardness distribution in the axial direction. The quenching spray is also incorporated into the copper profile. The overall design of the concept requires a complete construction design and manufacture using CNC-based systems.

There are many factors which significantly influence the distortion of a heat-treated workpiece. These include parameters such as the material, the micro-structure prior to heat treatment, the geometry and symmetrical properties as well as the hardness profile itself. Camshafts have a very complex structure with a large degree of asymmetry. One of the critical factors influencing the distortion of the shaft is the amount of heat induced in the workpiece. The more the material is heated, the greater the expansion of the material and the greater the distortion.

One of the greatest advantages of the SHarP-C technology is its ability to produce a uniformly distributed and contoured hardness profile. This technology reduces the heat-affected zone (HAZ) to a minimum and also reduces the expansion of the material by decreasing the total energy induced in the workpiece. As a result of special support technology in the inductor and unlike classical rotating processes, the workpiece is also exposed to no axial forces whatsoever which could be detrimental to the distortion behaviour.

Inductive heat treatment is usually followed by downstream grinding and polishing processes to match the surface roughness to the requirements of subsequent operation and achieve the final dimensions of the camshaft. These finishing processes conceal the potential risk of reducing the performance of the camshaft in later operations by deficiencies in the grinding process which introduce excessive heat. As can be expected, the degree of any necessary grinding is linked to the amount of distortion in the workpiece. The requirement for subsequent grinding reduces with the reduction in distortion.

As a result of the contoured and minimum distortion characteristics of the inductive hardening process used by SHarP-C technology, a large proportion of the subsequent grinding is therefore no longer necessary; the risks are reduced and costs for the mechanical finishing process can be significantly decreased.

LITERATURE


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