Distortion Control by Innovative Heat Treating

TECHNOLOGIES IN THE AUTOMOTIVE INDUSTRY

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Management Summary

The proper control of distortion after thermal treatment of powertrain components in the automotive industry is an important measure in ensuring high-quality parts and minimizing subsequent hard machining processes in order to reduce overall production costs. To fulfil these requirements, innovative heat treatment technologies and corresponding furnace system technologies have in the last few years been developed. Vacuum carburizing with subsequent high-pressure gas quenching is an innovative heat treatment technology for reducing distortion in surface-hardening processes (Ref. 1).

Introduction

Vacuum carburizing induces a high carbon transfer, which leads to a reduction of process time compared with atmospheric gas carburizing. The use of oxygen-free hydrocarbons prevents surface oxidation on the part surface. High carburizing temperatures up to 1,000°C and higher lead to additional productivity. However, there is the risk of grain growth during high-temperature carburizing that can increase the potential for distortion by the formation of a mixed-grain area in the material. But recent developments in the steel industry have shown that it is possible to prevent grain growth at temperatures higher than 1,050°C by using steels with alloying elements such as Nb, Ti and Al (Ref. 2).

High-pressure gas quenching is a dry quenching method that has many important ecological and economical advantages when compared with liquid quenching (Refs. 3–4). The quenching gases used, such as nitrogen and helium, are inert and leave no parts residue, negating the need for additional investment in washing machines or fire monitoring devices.

But the most significant advantage of gas quenching is a very uniform heat transfer. The predictability of movement during quenching is more certain and uniform throughout the load, thereby reducing hard machining costs. High-pressure gas quenching was successfully introduced for the heat treatment of parts in the automotive industry some years ago, and numerous investigations have shown that distortion can be significantly controlled as opposed to liquid quenching. However, there were examples where the simple change from oil to gas quenching did not improve all distortion parameters of a gear, e.g.—lead, profile or run-out data (Ref. 5). Thus there remains a lack of knowledge regarding the dependencies between different gas quenching parameters with respect to the influence on shape and size changes of the parts to be heat treated. In fact, additional factors like quenching chamber design, proper fixtures and loading have to be taken into consideration (Refs. 6–7). Although distortion can be influenced by any facet of heat treatment—including heating, carburizing and diffusion and quenching—the greatest potential for minimizing it is the proper control of the quenching process. Therefore the following is focused on the quenching process.

Gas Quenching Chamber

Proper design of the gas quenching chamber is an important precondition for minimizing distortion. The quenching chamber (Fig. 1) is the result of intensive, numerical flow calculation and experimental studies; it has been successfully integrated in heat treating systems for the automotive industry.

Two high-powered gas circulators, arranged to the left and right of the cylindrical housing, accelerate the quenching gas to a high velocity in the chamber. A very homogeneous flow through the charge is reached by means of several flow guides.

The design of the chamber is modular and can be equipped with a gas flow reverse system. The motors for the circulators are suitable for vacuum start-up in that they accelerate to maximum speed prior to gas flooding and so ensure maximum quenching performance at the outset. This is especially important for hardening of thin-walled parts made of low-alloyed steels. The quench chamber is suitable for standard gas quenching processes with steady gas pressure and gas velocity, as well as for new quenching processes such as dynamic quenching (patent pending), for example.

Fixturing

As in the case of liquid quenching, proper fixtures and optimized loading of the parts are also important for gas quenching. But contrary to liquids, fewer restrictions exist because there is no risk of quenching residue in the parts, such as with blind holes, for example. Alloy fixtures are widely

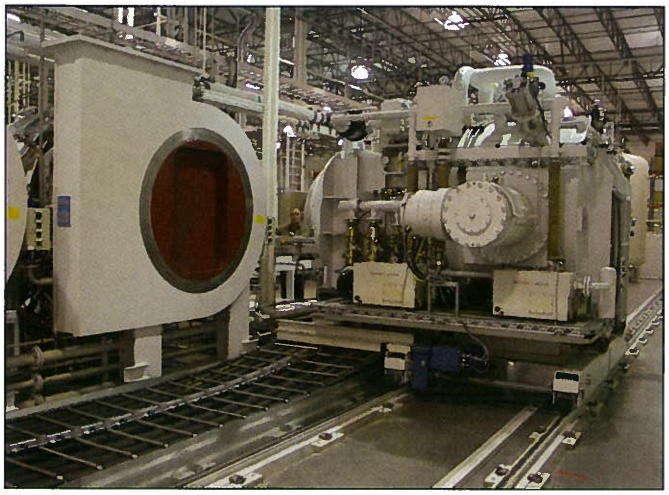

Figure 1—ModulTherm heat treatment system with gas quenching chamber.

Figure 2—Load of internal rings on a graphite composite fixture.

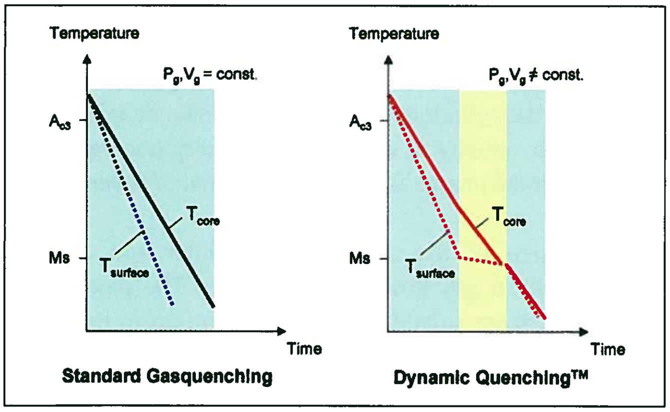

Figure 3—Schematic comparison of gas quenching process.

used for grids in heat treatment. These grids have a rigid design and they have—as long as sufficient high-temperature-resistant material is used—an acceptable lifetime. However, these fixtures limit the net weight to be loaded due to the high fixture weight. After long-term service, the fixtures tend to deform due to high-temperature deformation, which has a negative effect on the distortion of the loaded parts. Moreover, due to the pick-up of carbon and the subsequent formation of carbides, the grids undergo dimensional growth, creating further problems during handling in automated, external transportation devices.

As an alternative, carbon-composite materials—CFC (chlorofluorocarbon), for example—were introduced for use as fixtures in heat treating applications, but with little success due to the liquid quenching process, risk of drastic wear during use in atmospheric pusher-type furnaces and their high price. On the other hand, vacuum carburizing furnaces with high-pressure gas quenching are perfectly suited for the use of CFC fixtures (Fig. 2). By way of walking beam transportation, any wear and overstressing of the fixtures are avoided. The use of oxygen-free hydrocarbons in a vacuum environment, and the inert quenching gases during the quenching process, avoid any surface reactions with the fixtures. In this service environment, one can take full advantage of the excellent material properties of CFC, which has a very high deformation resistance at high temperatures, low thermal expansion coefficient and very low specific weight. Fixtures made from CFC are designed to carry more parts, as they exhibit less gross weight, thereby increasing productivity and reducing energy costs. But the major advantage is that CFC fixtures do not show deformation during the heat treatment process, assuring optimum positioning of the parts. This has a significant, positive effect on part distortion, as shown later.

Gas Quenching Process

To achieve optimum quenching results regarding microstructure, hardness and distortion, the gas quenching parameters need to be well-adjusted. To achieve the required core hardness in gears of low-alloyed case-hardening steels, helium as a quenching medium and a high gas pressure of 20 bar is necessary. The usage of this low-density gas allows quenching with very high gas velocity by using reasonable motor power. In combination with an advanced gas-recovery technology, exhibiting a recovery rate of > 99.5%, gas quenching is very economic despite the helium gas price. The positive experiences with gas quenching have induced gear suppliers to use case hardening steels with better hardenability. This presented the opportunity to reduce helium-quenching pressure and to minimize distortion. Moreover, it provided the chance to use alternative gases with lower quenching capability, such as nitrogen.

To further reduce distortion—particularly of thin-walled automotive parts—a quenching process has been developed where the quenching parameter's gas pressure and/or gas flow velocity are varied during quenching (Fig. 3).

Dynamic quenching starts in the first quenching step with high quenching severity. After a period of time, when a certain part temperature is reached, the next quenching step follows where the quenching severity is reduced for a set time to allow for temperature equalization in the part. This is followed by a third and final quenching step, where the quenching severity is increased again until the end of the quenching process. The control system in the quenching chamber serves to provide differing steps of dynamic quenching with enhanced accuracy and reproducibility.

Distortion Study and Results

Case hardening as a heat treating process was chosen for gears of a new generation of six-speed, automatic transmissions. In order to meet automotive's high quality demands, vacuum carburizing and high-pressure gas quenching are used as heat treating technologies. Due to the geometry and manufacturing process, these parts are susceptible to distortion during heat treatment. Therefore, an intensive process optimization program has been started where transmission manufacturers and furnace suppliers work in cooperation. To optimize the heat treatment process, it is important to differentiate between the distortion created by heat treatment and distortion created by the release of internal stresses resulting from the steps preceding the final heat treatment process. While the former can be minimized by optimizing the heat treatment process parameters, the latter can only be influenced by changes in the pre-processing route after an intensive study of the entire manufacturing chain of the part.

The results of the optimization of the heat treatment with particular focus on the gas quenching process are shown in Figures 4 and 5. Full loads with multiple layers of ring gears of SAE 5130 were heated in a ModulTherm system by using convection and vacuum heating. Convection heating was used to secure a fast but uniform heat-up of the parts and to keep heating-induced stresses to a minimum. After being properly heated, the parts were vacuum-carburized at 900°C to a case depth of 0.3 mm to 0.5 mm by using acetylene. After vacuum carburizing, the temperature was reduced to austenitizing temperature and the parts were then gas-quenched with helium by using different quenching procedures and fixtures. Although the ring gears have a small wall thickness and the base carbon is relatively high, it has been demonstrated in preceding comparison tests that distortion results were better for gas quenching with helium than with nitrogen. Dimensional studies were performed on 15 parts, which were located on different layers in the load. Lead and profile deformation and pitch line run-out were measured using a CNC gear checker.

Figure 4 shows mean values and scatter of lead average after different heat treatments, compared with the green data. After heat treatment using standard gas quenching with constant gas pressure and velocity, the mean value of lead average increases moderately; but scatter increased significantly. By using the same quenching process—but changing from alloy to graphite fixturing—the scatter could be reduced by 50%. The best result was obtained by applying the dynamic quenching technique and by using graphite fixturing.

Figure 5 shows the results of the pitch line run-out after heat treatment. As with lead deformation, pitch line run-out could be significantly improved. The best result regarding mean value and scatter was again obtained by using dynamic quenching and graphite fixturing; with this technology, it is possible to reach the specified values. In all the performed tests, no influence regarding the position of the parts in different layers on the distortion behavior was observed.

In a further test series, internal gears, also made of

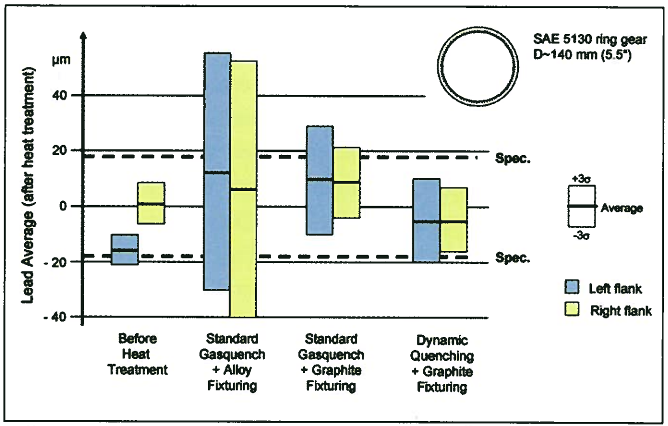

Figure 4—Lead average of ring gears before and after heat treatment.

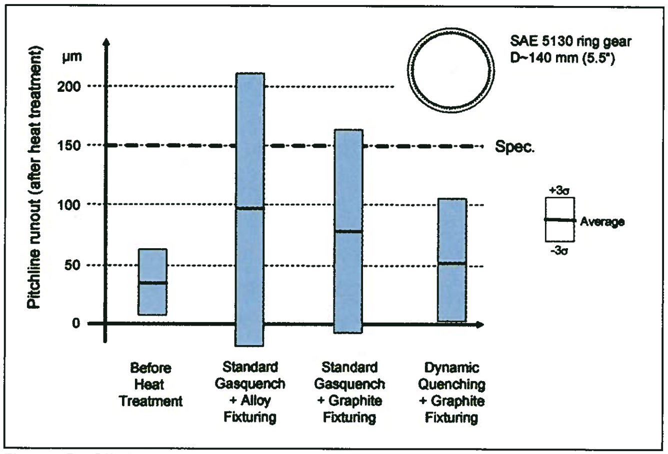

Figure 5—Pitch line run-out of ring gears before and after heat treatment.

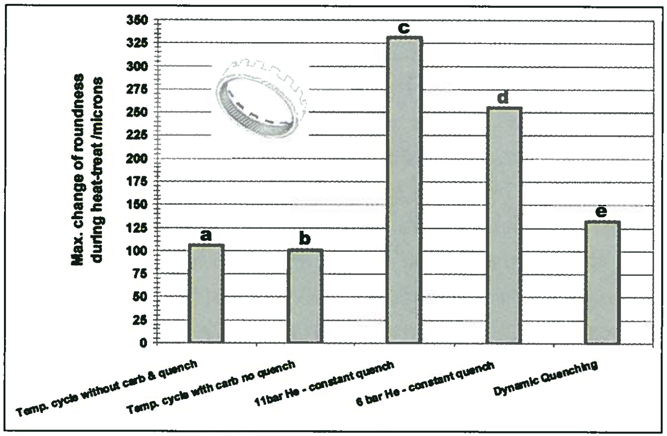

Figure 6—Maximum change of roundness (Dmax –Dmin) during heat treatment (Distance Between Balls (DBB) measurement).

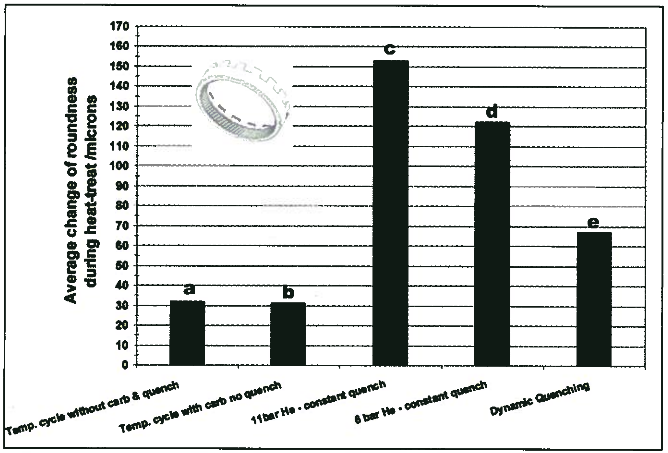

Figure 7—Average change of roundness (Dmax –Dmin) during heat treatment (DBB- measurement).

SAE 5030, were heat treated in a ModulTherm system by using different quenching process routes to investigate the distortion potential. The gears were convection-heated and vacuum-carburized with process parameters as described in the test series before. Graphite grids were used for fixturing in all tests. After the test, roundness measurements on 10 to 20 rings per load were performed using a DBB (distance between balls) machine. The resulting change of maximum and average roundness data before and after the test for the different heat treatment processes is given in Figures 6 and 7.

The first set of parts had an original temperature cycle—but without carburizing. Afterwards, the parts were slow cooled in the furnace (a). This so-called "dead run" releases the internal stresses from the preceding manufacturing processes and forms a baseline for the effort of any quenching optimization for the subsequent heat treatment process. This test was repeated, but the parts were carburized (b); this had no influence on the result. For the next test, the parts were carburized and standard-gas-quenched by using 11 bar helium (c). This led to a significant increase in the maximum and average change of roundness after the heat treatment. Because core hardness after quenching of the parts was well within the specification, the quenching pressure was reduced to six bar in the next trial (d) to minimize distortion. The result was an improvement of the change-of-roundness data. In the last trial (e), the parts were carburized and quenched using the dynamic quenching technology, resulting in a further significant improvement of roundness data. Compared to the data of the dead run, maximum change of roundness is only increased by 25%. Compared to the data of the test using the standard gas quenching practice with constant parameters, distortion could be reduced by almost 60% with dynamic quenching technology. The results shown above are only a small portion of the complete optimization program performed together with the end-user in the automotive industry. However, they demonstrate the potential for distortion optimization using a proper quenching system and process technology, as well as fixturing. As a result, vacuum carburizing and gas quenching in this case were determined as the key technology for the heat treatment of a new generation of 6-speed, automatic transmissions worldwide.

Summary

The proper control of distortion after thermal treatment of powertrain components in the automotive industry is an important measure to ensure high part quality and to minimize subsequent hard-machining processes, thereby reducing the overall production costs. Vacuum carburizing (low-pressure carburizing) with subsequent high-pressure gas quenching represents an innovative heat treatment technology to reduce distortion in surface-hardening processes.

A series of heat treating tests, including distortion measurements on internal gears of a new 6-speed automatic transmission, were performed. It was demonstrated that by using innovative heat treating technologies—i.e., vacuum carburizing and high-pressure gas quenching, distortion of the gears can be effectively controlled. Optimum results were achieved by using proper furnace technology, graphite fixtures and application of dynamic quenching technology.

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