

# Production-integrated vacuum heat treatment systems in the automotive industry

by **Klaus Löser**

To secure the required properties of highly stressed parts from the automotive industry these parts need to be heat treated, in many cases case hardened. This is traditionally performed in central hardening shops. However, the separation between machining and heat treatment involves great efforts regarding transport and buffering of parts leading to extended throughput times and therefore additional costs. The use of modern vacuum heat treatment technologies and the introduction of flexible, modular heat treatment systems allows for the integration of heat treatment into the mechanical production environment, and as of recently also directly into the process chain of part manufacturing.

For decades, the industry has addressed the challenge to produce high performance components in a cost-effective manner, maintaining lean inventories and highly reproducible quality. One way to meet this target is to integrate heat treatment into the mechanical production line of components.

For almost 20 years, it has been possible to integrate heat treatment into the machining facility by applying the technology of Low Pressure Carburizing (LPC) and High Pressure Gas Quenching (HPGQ). After soft machining, the components are collected into larger batches and treated with LPC- and HPGQ-technology [1]. Thereby, all components are loaded on large multi-layered batches and buffered in front of the heat treatment system. After case hardening, the batches are collected in buffers again. The components must be singularized and moved to individual hard machining lines (**Fig. 1a**).

An alternative form of production, however, is to directly integrate heat treatment into the production line [2]. This enables synchronization with soft machining operations, leading to more efficient and ecological production processes (**Fig. 1b**). The goal of this integration is the so-called One-piece-flow, characterized by a single-layer loading of the parts on a fixture. This allows the part-adapted heat treatment of components, which on the one hand reduces process time and improves productivity and on the other hand leads to an increase in part quality in terms of reduced hardening distortion [3–4].

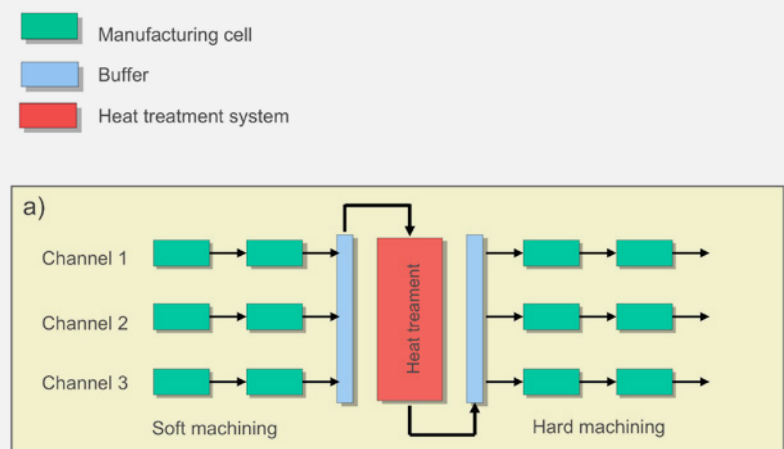
This article describes two methods of heat treatment integration in order to support modern production strategies. The corresponding systems are described and compared. Practical examples from different users operating such kind of technology in the automotive industry are presented.

## PRODUCTION-INTEGRATED HEAT TREATMENT SYSTEMS

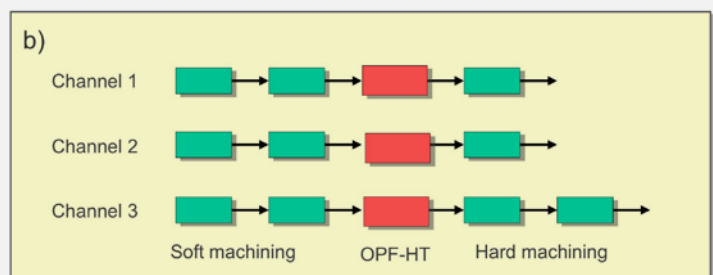
### Flexible, modular multi-chamber system

Flexible, modular plant systems such as the system ModulTherm of ALD Vacuum Technologies GmbH have established themselves in the market for large-scale heat treatment (**Fig. 2**). These plants feature up to twelve separate treatment chambers, arranged in a row. A transport module, moving on rails, supplies the plant with charges.

Heat treatment is performed in the treatment chambers, i. e. when case hardening gear parts, heating, carburizing, diffusing and in some cases lowering to hardening temperature. The treatment chambers are cold wall furnaces, which means the chambers do not radiate heat to the exterior. They always remain under vacuum/nitrogen and process temperature. The chambers require neither heating nor formation during idle times. They are ready for operation shortly after they are switched on. The transport module consists of a transport chamber with an installed fork lift system and



**Fig. 1a:** Production concepts with integrated heat treatment: local, centralized heat treatment



**Fig. 1b:** Production concepts with integrated heat treatment: direct line integration



**Fig. 2:** Flexible, modular heat treatment system

a high-pressure gas quench chamber, where charges are hardened in gas flow using nitrogen or helium following the heat treatment process. The necessary media such as power, gas and cooling water are supplied to the transport module through hoses, installed in an energy chain. The telescopic fork of each transport module loads/unloads the treatment chambers. For the quench process the quench chamber moves in front of the respective treatment chamber resulting in very short transport distances from treatment chamber to quench chamber. The transport distance is the same for each treatment chamber.

The gear components are charged on a charge fixture with the basic dimensions of 1,000 x 600 mm. Flat parts such as gear wheels are normally charged in several layers in order to utilize the maximum charge height of 750 mm. The maximum charge weight is 1,000 kg. The convective heating system in the treatment chamber, respectively the flow reverse system in the quench chamber are beneficial to heat and quench large batches, so-called 3D-charges, as fast and homogeneously as possible.

The production capacity (kg/h, parts/h) of such a plant depends on how the charge carrier is loaded (kg, number of parts), and the furnace cycle, which in turn depends on the number of treatment chambers and the heat treatment process time. For example, for gear wheels with a normal case depth of CHD = 0.65 mm the process time is 180 min at 960 °C, resulting in a plant cycle (180/9) of 20 min with nine treatment chambers. A gross load of 600 kg/charge results in a production capacity of 1,800 kg/h.

In practice, a ModulTherm plant in the manufacturing shop is usually installed locally in-between mechanical soft and hard machining. All gear parts (shafts, wheels) from various production lines are placed on floor rollers and transported to the central heat treatment plant, where the parts are grouped into heat treatment batches, loaded onto the charge carrier and heat treated via recipe control. Normally, creation of the recipes depends on the part. Therefore, they are optimally adapted to the respective requirements regarding structure, hardness and distortion. Following heat treatment, the parts from the production batch are individually returned to the different hard machining lines. The ModulTherm technology comprises the following features:

- Treatment of large-sized charges, multi-layers
- Wide range of parts can be treated in one plant (shafts, gear wheels, synchronizer components)
- Convective heating for fast and homogeneous heating up
- Gas quenching with reverse gas flow technology to reduce hardness scattering and to improve heat treatment distortion
- Charge buffer before and after heat treatment

- Parallel treatment of charges with various carburizing depths without changing cycles.

### Line-integrated, cycled system

For an even more effective and economic production of gear parts, a change from large-scale production to the production of single parts is intended. The goal is to transport single parts from each production step without interrupting the process chain. The targeted concept of "One piece flow (OPF)" guarantees a continuous part flow and prevents the tremendous expenditures for transport and storage of parts between each single process step. The complete integration of all process steps opens entirely new perspectives for automation, which leads to reduced production costs and quality improvement.

In order to enable the direct integration of heat treatment into the production line a new process technology (high temperature carburization) and plant technology (SyncroTherm) were developed (**Fig. 3**). A case hardening process, which follows the cycle of soft machining, requires a drastic reduction in process time. Therefore, the process temperature of the established low-pressure carburization process in the range of 920–960 °C is increased to a considerably higher temperature level of 1,000–1,050 °C. In order to increase the process temperature it was necessary to develop new micro-alloyed materials to prevent grain growth during heat treatment.

In the new plant technology, the parts are charged on a workpiece carrier in one layer instead of in the usual large batch and case hardened in so-called 2D-charges (**Fig. 4**). These 2D-charges offer numerous advantages. They can be heated significantly faster than the large multi-layered 3D-charges. Panel heaters installed above and underneath the parts radiate the heat directly onto each single part. Rapid and uniform heating is guaranteed. The single-layer charge provides optimum conditions for uniform and reproducible results and for the subsequent process steps carburization and high-pressure gas quench. Furthermore, single-layer charging allows performing individually controlled high-pressure gas quench, adapted to the requirements of each part and various part sizes, thus offering the potential to significantly reduce heat treatment distortion.

The system comprises a pressure-tight front chamber which functions as loading chamber and quench chamber. The rear treatment chamber consists of a "cold" wall area with a telescopic loader and up to six heating zones arranged one above the other, which can accommodate one workpiece carrier each. The treatment chamber is always under vacuum and is separated from the loading chamber/quench chamber by a pressure-tight door. The process is described below. A workpiece carrier (2D-charge) enters the quench chamber through the front door. The chamber is evacuated to remove undesired oxygen. The

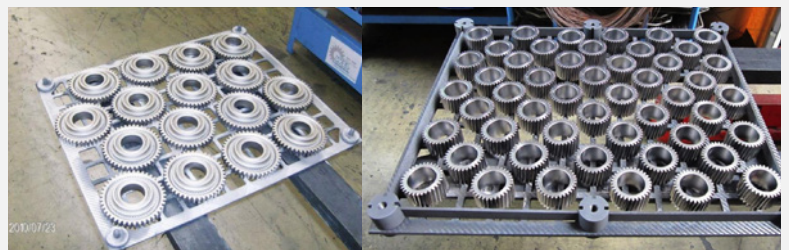


**Fig. 3:** Directly integrated, synchronized heat treatment system

built-in loader transfers the workpiece carrier to one of the heating zones. Treatment pressure is the same in all zones. Temperature and process gas feed are controlled individually for each zone.

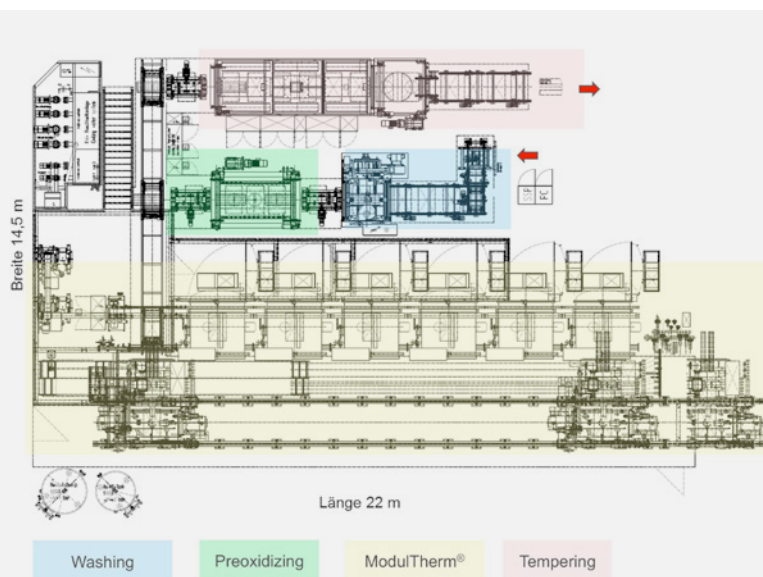
Rapid heating and carburization of the workpieces at high temperatures begin as soon as a workpiece carrier arrives in the heating zone. Following carburization, the built-in loader transfers the workpiece carrier into the quench chamber where the parts are quenched rapidly and homogeneously with the quench gas nitrogen at a pressure of max. 10 bar. A very effective and uniform quench effect is obtained by the single-layer charging of the workpieces. Subsequent to the quench process, the chamber is ventilated and the parts are removed and passed on for tempering. Following the tempering process, a handling system separates the parts and passes them on for hard machining.

The production capacity (parts/h) respectively the performance of such a plant depends on the number of parts/workpiece carrier, the process time and the number of heating zones. The total process time of 40 min applies to a typical case depth of 0.65 mm and a carburization



**Fig. 4:** Loading in 2D-charges





**Fig. 5:** Layout of an integrated heat treatment system for case hardening of automatic transmission parts



**Fig. 6:** Integrated heat treatment system for case hardening of manual and dual clutch transmissions

temperature of 1,050 °C.

Based on a SyncroTherm plant with six heating zones and a charge of 20 gear wheels ( $\varnothing \sim 100$  mm) per work piece carrier, the cycle time is 20 s per gear wheel. The features of this technology are:

- Heat treatment matching the machining cycle
- One-layered (2D) charging, gear wheels, but no long shafts
- Rapid, uniform radiation heating
- Short process times due to high temperature carburization
- Part-adapted gas quench (e. g. nozzle field) of the components, thus offering the potential for less distortion and reduced hard machining

- Integrateable into the production line because of its compact design.

## EXAMPLES FROM AUTOMOTIVE MANUFACTURING

In the following, some practical examples of a successful integration of heat treatment into the production process will be introduced.

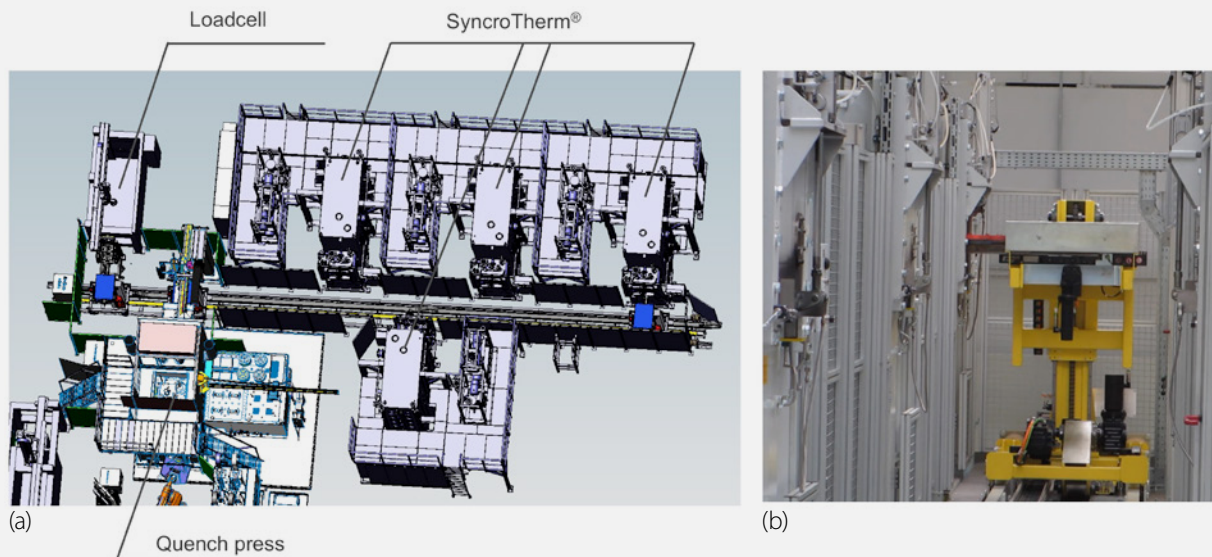
The first example shows a heat treatment furnace system based on the ModulTherm plant, integrated into the production process to case harden geared parts of an automatic transmission (**Fig. 5**). In this example, the green parts from soft machining are transported on floor rollers to the heat treatment plant and loaded onto the charge carrier manually, in some cases automatically. The loaded charge carriers enter the heat treatment plant sequentially from the loading position. The charge data on the route card of the batch is scanned and the appropriate (part-specific) recipe is loaded from the plant's recipe storage into the control system, according to the respective part number. According to the FIFO-principle, the charges pass through the ModulTherm plant's washing machine, pre-oxidation furnace and the loading station, where the railbound transport shuttle takes over and transports the charge into one of the six treatment chambers. Following the carburization process, the transport shuttle moves in front of the treatment chamber. The charge is quenched in the transport shuttle's quench module.

The quench chamber is designed for 20 bar helium in order to obtain the required core hardness for solid parts. Smaller parts, such as planetary wheels and sun gears are quenched at a lower gas pressure respectively gas velocity to minimize distortion. For the same reason, the gas flow is reversed during the quench process of multi-layered charges. Following the quench process, a chain conveyor transports the charges to the tempering furnace. After tempering and cooling, the charges are placed onto the unloading station to remove them from the heat treatment system. The parts are loaded from the charging system onto the floor rollers manually/fully automated and transported to the hard machining area (hard turning, grinding). The total plant operates according to a rigid cycle concept, coordinated with the respective treatment time. There are no buffers in the system except for the three positions in the accumulating conveyor in the area of the loading/unloading station. The advantage of this rather rigid system is the low space requirement. The charge carriers rotate only within the heat treatment area.

The next practice example shows an integrated heat treatment system type ModulTherm for case hardening manual transmissions and dual clutch transmissions in an automobile production plant (**Fig. 6**). The relatively well-alloyed case hardening steel 27MnCr5 is used as part material, so that quenching with max. 20 bar nitrogen is sufficient to obtain the required core hardness. Contrary



**Fig. 7:** Automatically loaded shafts and final drive ring gears



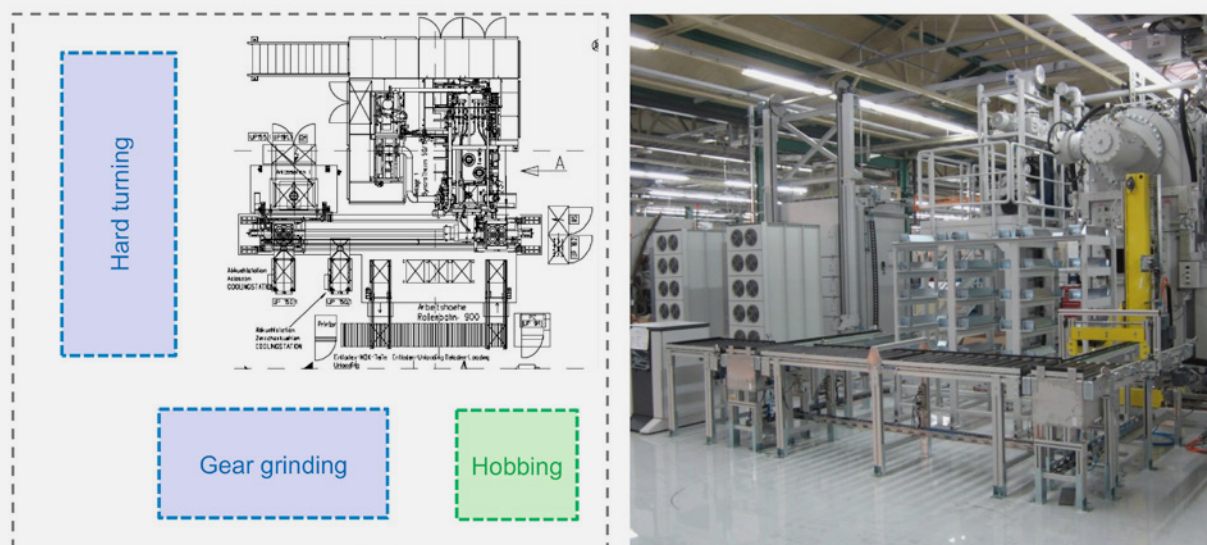
**Fig. 8:** Fully automated heat treatment system for high temperature-low pressure (HT-LPC) carburizing and press hardening of final drive ring gears **(a)**, charge car **(b)**

to the first example, the green parts in the soft machining area are loaded onto the charge carrier fully automated and then transported to the heat treatment plant. Shafts are charged in upright position and gear wheels are charged horizontally in several layers. Only final drive ring gears are charged in hanging position whereby the setup of the charge carriers allows automated loading for these parts (**Fig. 7**). The heat treatment system has a charge buffer with 72 charge positions arranged on three levels. The required production batch can be freely retrieved from the charge storage, thus ensuring a high degree of production flexibility. In order to obtain optimum efficiency with the plant, all parts are treated in the same process time and constant plant cycle, despite different case depths. The various case depths respectively carburizing times are compensated by

adapting the heating time in the recipe accordingly.

In another practice example for production integrated heat treatment, final drive ring gears for dual clutch transmissions are case hardened fully automated (**Fig. 8a**). In this example, several linked plants of the heat treatment module SyncroTherm are used. The special feature of this plant system is the link of high temperature-low pressure carburization technology with an oil-hardening press. The green parts are transported to the plant in baskets, stacked on floor rollers. In a load cell, a manipulator loads four parts at a time on a metallic workpiece carrier. A charge car transports the workpiece carrier to the nearest available SyncroTherm system (**Fig. 8b**). The workpiece carrier is transported into the plant in one of the six hot zones and is heated up to 1,000 °C, followed by carburization to





**Fig. 9:** Integration of heat treatment for final drive ring gears based on cell production

a case depth of  $0.5 + 0.3$  mm. The process time is 60 min, which means in one SyncroTherm plant with six heating zones one workpiece carrier is made available every 10 min. Following carburization, the parts are unloaded without quenching. A high-speed transport car equipped with an insulated chamber takes the parts to the loading station of the hardening press, where a manipulator picks up four final drive ring gears each and places them in the oil quench form. The empty, hot workpiece carrier is returned to the loading station where the next four green gears are loaded. Prior to loading, the metallic workpiece carrier is turned around automatically to prevent the carrier from bending due to the high temperature process. Subsequent to the quenching of the carburized ring gears in the press, the quench oil is removed. The workpieces are washed and transported through a tempering furnace in the available stacking baskets. After tempering, the baskets are placed onto the floor rollers in the loading cell and passed on to the hard machining process.

A further practice example describes the production of final drive ring gears in a manufacturing cell (**Fig. 9**). The work pieces made of 20MnCr 5 are high temperature-low pressure carburized and gas quenched. The pre-machined forging blanks are delivered to the manufacturing cell. Following gear hobbing, an operator places the gears on workpiece carriers made of CFC. The loaded carriers are case hardened at  $1,000^{\circ}\text{C}$  in a SyncroTherm system to a case hardening depth of  $0.7\text{--}0.8$  mm. The process time is 90 min resulting in a cycle time of 15 min per load carrier. After the case hardening process, the parts are tempered and

cooled down to room temperature. The transport of the load carriers within the heat treating system is fully automated using a transportation module with a fork loader. Subsequent to heat treatment, the gears are separated by an operator, hard-turned and gear ground ready to leave the manufacturing cell for assembly.

## CONCLUSION

The cost-efficient production of high-performance components increasingly demands the integration of heat treatment plants into the total production process in order to prevent additional costs for logistics such as transport and buffering parts. Today, this is possible with vacuum-based heat treatment processes and suitable plant systems. Depending on the production strategy different heat treatment solutions are available. Modular, flexible plants (ModulTherm) are placed in the centre between soft respectively hard machining areas. They treat all parts from the production lines in so-called large batches. Meanwhile, long-term production experience with this solution in large-scale production is gained, especially for gear components.

Alternatively, compact, synchronized plant systems (SyncroTherm) are available which are installed in the direct vicinity of production lines. The systems are integrated either into a manufacturing island or directly into the production line where they operate in the cycle of the machining plants according to the One-piece-flow-principle. This heat treatment concept is currently introduced into production. The heat treatment processes, which are adapted to

the parts, offer a high potential for further cost savings in the total production process.

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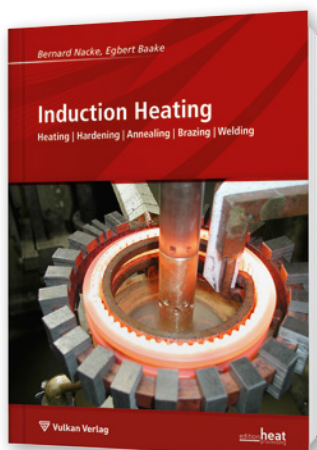


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