Heat treatment of gear parts – possibilities of time and cost savings

by Herwig Altena

Atmospheric furnaces are “state of the art” for case hardening of transmission gear parts for the automotive industry, because many customers appreciate their advantages, like high efficiency, highest availability, process control via oxygen probe, process stability, etc. Increased demands concerning the reduction of process time, reduced heat treatment costs and improved energy efficiency can be met by technical and technological innovations. This paper shows different aspects of time and cost savings for heat treatment of gear parts. Furthermore different energy efficiency measures for continuous furnaces are recommended, including energy savings and energy recovery.

From the point of the manufacturing process of gear parts the heat treatment often can be seen as a necessary, but expensive, time consuming step which causes distortion and interrupts the production chain. Despite of increased parts quality and reproducibility of the heat treatment results it gets more and more important to reduce the heat treatment time and to further reduce the heat treatments costs. Different aspects to fulfil these demands are pointed out below.

HIGH TEMPERATURE CARBURIZING

If we try to define “high temperature” carburizing, it is necessary to do this in correlation with today’s usual range and in correlation with the furnace design. Today the standard temperatures for continuous plants, like pusher furnaces, are between 930 and 960 °C for carburizing, whereas temperatures in sealed quench furnaces are shifted up to 980 or 1,000 °C max. Therefore you can define the high temperature range for sealed quench furnaces with 1,000-1,050 °C and for continuous plants with 960-1,020 °C.

Due to the increased diffusion speed at high temperatures the process duration can be significantly reduced and therefore the through-put capacity is increased. However, there are mainly three limitations for high temperature application:

■ The material has to be suitable for high temperature application, therefore grain stabilized material has to be used. Microalloyed additions of Nb, Ti and N can significantly reduce the grain growth of the austenite grains at temperatures up to 1,050 °C [1-4].

■ Furnace technology has to be adapted to the high temperature application. All critical components have to be designed from high temperature resistant material. Besides that, the increased throughput capacity of continuous furnaces, which are processed at high temperatures, requires increased heating capacity and, because of reduced cycle times, increased cooling capacity of the oil cooler, etc.

■ Distortion of parts might be higher due to the higher carburizing temperature. However, this depends on the wall thickness, weight and design of the parts.

For high temperature application the furnace design and the process technology have to be adapted. The high temperature causes a lower density of the carrier gas, furthermore an increased carbon uptake of the load has to be taken into account. Therefore a high availability of carbon becomes more important than a high circulation speed of the carrier gas. To increase the C-availability the use of propane as enriching gas, combined with a slightly increased CO content, is recommended.

To fulfil the demands of high temperature treatment the thermal insulation has to be improved by the use of microporous material, which allows a reduction of the outer furnace wall temperature of 7 to 10 °C without any increase of the wall thickness. Furthermore different materials for the heating, the circulating fan and the fixtures have to be used. Especially continuous furnaces have to be executed...
with increased heating capacity in the heating zone to allow an increased throughput at higher temperatures.

Table 1 shows the cycle time, throughput capacity and energy consumption of the furnace in dependence with the carburizing temperature. Increasing the temperature from 930 to 980 °C enables a 50 % higher throughput capacity whereas the energy consumption is only 25 % higher. Due to this a serious cost saving potential due to high temperature carburizing can be applied.

If e.g. three sealed quench furnaces or three pusher furnaces are needed to achieve the desired throughput capacity when treated at 930 °C, the temperature shift to 980 °C allows savings of one furnace. Taking the high temperature execution of the remaining two furnaces into account, the overall cost reduction would be up to € 25,000/a for the seal quench furnace line and up to € 300,000/a for the pusher furnace line.

RING HEARTH FURNACES

The ring hearth furnace design allows two different applications: Single part carburizing, followed by press quenching or carburizing of full loads as an alternative to a treatment in a pusher furnace.

Sensitive parts which have to be press quenched are usually carburized and slow cooled in a first step, followed by a second heating up to hardening temperature and press quenching. Depending on the throughput the carburizing takes place in (double) chamber furnaces or pusher furnaces and the reheating is processed in rotary hearth furnaces [5].

Due to direct hardening of press quench parts in ring hearth furnaces (Fig. 1) up to 25 % of the heat treatment costs can be saved in comparison with the conventional single hardening process. This is caused by energy savings of 30 %, reduced man power, reduced space requirement and reduced amount of jigs and trays. Furthermore the overall production time can be reduced for 30 %.

For case hardening of full loads the ring hearth design also offers a 5-10 % time saving potential in comparison with pusher furnaces. This is caused by the different furnace design, showing a certain distance between the loads, increased circulation speed of the carrier gas, and good separation of the process zones. Furthermore the wear of the basic grids can be significantly reduced. The main disadvantage is the reduced flexibility in comparison with the pusher furnace design.

FLEXIBILITY

Two- and three-track pusher furnaces allow different case hardening depth (CHD) or cycle time simultaneously. A similar flexibility can be reached only by using ring hearth furnaces with an adapted furnace design ("Flexicarb®", Fig. 2). This design combines a small pusher furnace for heating the loads to carburizing temperature, a ring hearth for carburizing and

<table>
<thead>
<tr>
<th>Carburizing temperature</th>
<th>930 °C</th>
<th>950 °C</th>
<th>980 °C</th>
<th>1,000 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-potential</td>
<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
<td>1.35</td>
</tr>
<tr>
<td>Process duration (min)</td>
<td>385</td>
<td>330</td>
<td>280</td>
<td>260</td>
</tr>
<tr>
<td>Cycle time (min)</td>
<td>10.1</td>
<td>8.3</td>
<td>6.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Throughput capacity (%)</td>
<td>100 %</td>
<td>123 %</td>
<td>151 %</td>
<td>167 %</td>
</tr>
<tr>
<td>Energy consumption (%)</td>
<td>100 %</td>
<td>110 %</td>
<td>125 %</td>
<td>135 %</td>
</tr>
</tbody>
</table>

Table 1: Correlation between carburizing temperature, throughput capacity and energy consumption. Pusher furnace, 20MnCr5, CHD 1 mm.

Fig. 1: Ring hearth furnace design for carburizing and press quenching of sensitive parts
a pusher furnace for lowering to hardening temperature, followed by oil quenching. Now the carburizing time in the ring hearth can be chosen freely in dependence with to the required case depth, which allows e.g. 1.0-1.5 mm CHD simultaneously. A certain number of small ring hearth furnaces are another option to reach the desired flexibility.

**GAS QUenchING**

High pressure gas quenching usually reduces the distortion of gear parts in comparison with oil quenching. Therefore the cost and time consuming post grinding operation can be reduced. Furthermore no washing is required after the “dry quenching”.

High pressure gas quenching is commonly used in combination with low pressure carburizing furnaces. In combination with atmospheric furnaces some requirements have to be fulfilled to meet the demands. Fig. 3 shows a double track pusher furnace with gas quenching cell. In this plant a good separation of the process gas, containing hydrogen and CO, and the quenching gas (usually nitrogen) was reached. For continuous plants a recycling of nitrogen is necessary, if short cycle times of some minutes are applied. The design of the quenching chamber allows a very constant, high gas speed of about 20 m/s through the load, the distance between the load and walls of the quenching chamber was minimized.

Uniform quenching leads to uniform hardness all over the load and a reduced distortion of the toothing of gears and shafts. For a certain application the grinding operation after quenching could be saved completely. In a further step this measure allowed a reduction of the case depth and therefore a reduction of the case hardening process time. Despite of the high costs of a quenching cell, the cost savings due to gas quenching enabled a return of investment (ROI) of the gas quenching cell of less than 2 years.
Energy efficiency gains increased importance in the last years. However, improvements of the furnace design, the insulation and the efficiency of the burners allowed a reduction of the energy consumption e.g. of pusher furnaces in the range of 45 % in between the last 25 years. Fig. 4 shows a Sankey diagram, which gives a good comparison of the total energy input for a carburizing process in old pusher furnaces, which are still in use, a modern design and the future potential. For new plants further energy saving measures can be considered and implemented directly in the furnace design. For refurbishing elder plants an evaluation of the specific energy consumption has to take place. Improvements concern with the sluice technology, burner efficiency, improved insulation materials, energy management systems and finally energy recovery systems. Most of the waste heat, which can be recovered, is available from the quenching media (usually oil or salt), the flue gas of the burners and the carrier gas [6]. Water based washing machines are the first choice for using the recovered energy. Washing and rinsing fluid can be heated; furthermore recovered heat can be used for parts drying (Fig. 5).

Further applications for recovered energy are generating hot water for workshop heating, showers, etc. and for external use. Taking the today’s gas price into account, the return of investment (ROI) for all these energy optimization measures is in the range between 2.5 and 5 years. Due to long term increase of the energy price and planned governmental restrictions concerning the use of energy for furnaces, the ROI for energy optimizing measures will be reduced in future.

**CONCLUSION**

Conventional atmospheric furnaces show a high potential for time and cost saving measures. High temperature carburizing is an option, if fine grain stabilized material is used and the furnace is suitable for high temperature application. Depending on the throughput requirement, considerable time and cost savings can be achieved.

Direct hardening of press quench parts in ring hearth furnaces allows cost savings of about 25 % in comparison with the conventional single hardening process. For case hardening of full loads the ring hearth design also offers 5-10 % time saving in comparison with pusher furnaces.

Reduced flexibility of ring hearth furnaces can be met with the "Flexicarb"-design, allowing to process different case depths simultaneously.

Gas quenching in combination with atmospheric furnaces helps to avoid post washing, to reduce distortion and grinding operations and finally can shorten process time due to reduced case depth requirement. The cost savings which can be achieved by gas quenching allowed a ROI of the rather expensive gas quenching cell in between 2 years.

Finally some energy saving and energy recovery measures have been mentioned. In comparison with today’s standard, cost savings of about 15-20 % can be achieved by using all available options.
LITERATURE


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