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Precision Case Hardening by Low Pressure Carburizing (LPC) for High Volume Production*

Präzises Einsatzhärten mit Niederdruck-Aufkohlen (LPC) in der Großserienfertigung

Abstract/Kurzfassung

Traditionally, case hardening is based on carburizing in atmospheres and oil quenching; this is carried out in sealed quench furnaces and in continuous lines (pusher, roller or rotary furnaces). They are technologies and devices developed more than 50 years ago and, over the course of time, they have exhausted their development potential. At present, they hardly meet the incoming requirements of the modern industry regarding quality and replicability, integration and organization of production, and environment protection.

A solution for weak points of traditional case hardening is the use of vacuum technologies and equipment. Vacuum carburizing increases the resulting precision and replicability, and the variety of vacuum equipment for heat treatment allows the adaptation to modern industry requirements. Two applications are described in the article. The first one – evolutionary – is based on the triple- chamber vacuum furnace for semi-continuous production as a wide alternative for traditional devices. The second system – innovative – is based on the true single-piece flow method. Both solutions have specific and characteristic properties that predispose them for different applications depending on quality requirements and organization of production. ■

Keywords: Case hardening, low pressure carburizing, LPC, high pressure gas quenching, hardening distortion, in-line production, single-piece flow

Ursprünglich basiert das Einsatzhärten auf dem atmosphärischen Aufkohlen und der Öl-Abschreckung. Dies erfolgt in abgedichteten Härteöfen und in durchgehenden Produktionslinien (Durchstoß-, Rollen- oder Drehofen). Diese vor mehr als 50 Jahren entwickelten Technologien und Geräte haben im Laufe der Zeit ihr Entwicklungspotenzial erschöpft. Derzeit erfüllen sie kaum die eingehenden Anforderungen der modernen Industrie hinsichtlich Qualität und Reproduzierbarkeit, Integration und Organisation der Produktion sowie Umweltschutz.

Eine Lösung für Schwachstellen des ursprünglichen Einsatzhärtens ist der Einsatz von Vakuumtechnologien und Vakuumanlagen. Durch die Vakuum-Aufkohlung wird die Präzision und Reproduzierbarkeit erhöht. Die Vielfalt der Vakuum-Ausrüstung für die Wärmebehandlung ermöglicht die Anpassung an die modernen Anforderungen der Industrie. Zwei Anwendungen sind in dem Artikel beschrieben. Die erste Anwendung basiert auf der Dreikammer-Vakuumofenlinie für die halbkontinuierliche Produktion als eine breite Alternative für herkömmliche Geräte. Die zweite Anwendung ist ein innovatives, auf der echten Single-Piece-Flow-Methode basierendes System. Beide Lösungen verfügen über spezifische und charakteristische Eigenschaften, die sie, je nach Qualitätsanforderungen und Organisation der Produktion, für unterschiedliche Anwendungen einsetzen können. ■

Schlüsselwörter: Einsatzhärten, LPC, Hochdruck-Gasabschrecken, Härteverzug, In-Line-Produktion, Single-Piece-Flow

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1 Vacuum Carburizing Technology and Equipment

Vacuum carburizing began to be used in industry worldwide about two decades ago and it has reached the high level of maturity and reliability to the present day. It is the modern and generally accepted technology in industry. In comparison to traditional technology, it has a high superiority, especially in carburizing precision and evenness, carburizing gas efficiency, energy consumption and post-process product emission. The technology is safe and environment friendly and the vacuum devices are compact and neutral for ambience; they can be installed directly at clean production plants [1–5].

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2 Triple-Chamber Vacuum Furnace Type CaseMaster Evolution CMe T12

2.1 Structure and operation

The triple-chamber furnace is designed for the case hardening process based on low pressure carburizing (LPC) and oil quenching – using semi-continuous production (Figure 1). It is built of three functional chambers (Figure 2):
I. loading and pre-heating chamber
II. process chamber (LPC)
III. oil quenching and unloading chamber
After loading to the process chamber, the batch is preheated up to 750 °C in the inert gas (nitrogen) or in the air (pre-oxidation). Then it is transported to the process chamber where, after the final temperature is reached, the vacuum carburizing takes place. After carburizing, the load is moved to the oil chamber where it is quenched through immersion in the oil with intense circulation. The final stage is the unloading of the batch from the opposite side of the furnace.

Contrary to single- and double-chamber furnaces, at the triple-chamber furnace the loads pass by the next chambers one-by-one in the semi-continuous mode. At the same time, three batches are found together in the furnace (one piece in each chamber) and the working cycle of the furnace is determined by the longest cycle in one of the chambers (usually in the process chamber). In comparison to the double-chamber furnaces, the triple-chamber furnaces can reach even twice throughput.

The exemplary furnace, CMe T12, is characterized by the following technical data:

• working space size (W × H × L)	900 mm × 900 mm × 1200 mm
• load gross mass	1200 kg
• temperature	1250 °C
• heating power	350 kW
• installation area	5 m × 9 m

The parameters above allow implementation of fast, LPC high-temperature processes of high capacity with little space demand.

There are also available CMe furnaces equipped with high pressure gas quenching and many variations in chambers configuration as well as working space size.

Fig. 1. Triple-chamber vacuum furnace for case hardening, type CaseMaster Evolution CMe T12

Bild 1. Dreikammer-Vakuumofen zum Einsatzhärten, Typ CaseMaster Evolution CMe T12

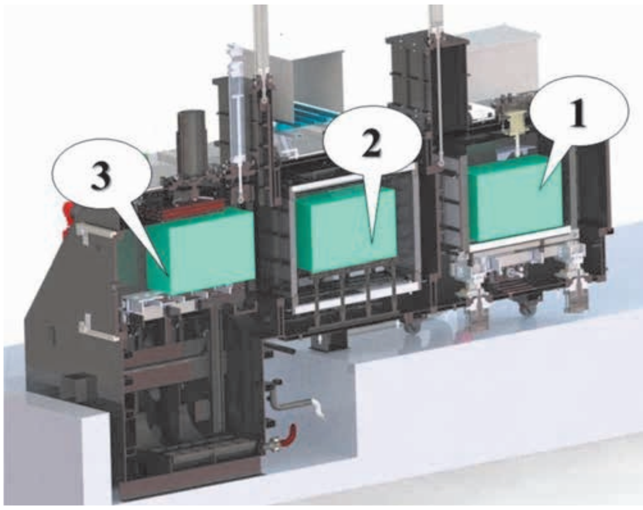

Fig. 2. Construction of the triple-chamber vacuum furnace

Bild 2. Aufbau des Dreikammer-Vakuumofens

2.2 Technological results

Vacuum carburizing allows the process shortening by temperature increase that accelerates carbon diffusion into steel. Temperature above 1040 °C is commonly used for LPC; then carburizing can be shortened even five times in comparison to traditional processes. This is essential for thicker layers and steels insensitive to austenite grain growth or when the grain size is not of a critical parameter.

In view of inherent austenitic grain size, (usually ASTM 5), typical steels can be carburized safely at temperatures up to 980 °C; this shortens carburizing by two or three times. In addition, use of the triple-chamber furnace shortens the process time even more and increases capacity.

This exemplary process was considered: the case hardening of steering system elements (Figure 3) carried out in the furnace CMe T12. The batch include 3-4.5 thousand parts arranged in baskets (Figure 4) with a net mass of up to 800 kg and a huge surface area of approx. 35 m^2. The elements are made of a steel grade of 16MnCr5 and they should obtain the case of the following parameters:

• effective case depth	0.7–1.1 mm
• surface hardness	60–64 HRC
• retained austenite	< 10 %
• austenitic grain size	> 5 ASTM
• intergranular oxidation (IGO)	inadmissible
• carbides network	inadmissible

Fig. 3. Steering system elements (automotive industry)

Bild 3. Elemente des Lenkungssystems (Automobilindustrie)

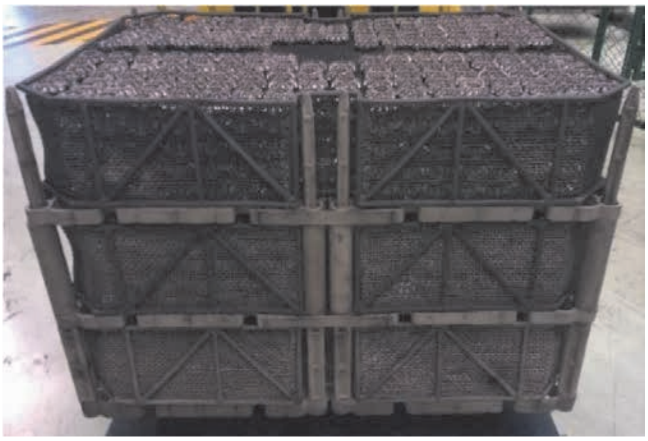

Fig. 4. Full batch for case hardening, 1200 kg, 35 m^2

Bild 4. Volle Charge für das Einsatzhärten, 1200 kg, 35 m^2

	Unit	Average	Minimum	Maximum	Variation
Effective case depth	[mm]	0.89	0.82	0.96	0.14
Surface hardness	[HRC]	62.3	61.9	63.1	1.2
Retained austenite	[%]	< 10	-	-	-
Austenite grain size	ASTM	7-8	-	-	-
IGO	[µm]	absent			
Carbides network	[%]	absent			

Table 1. Summary and variation of the case hardening process results

Tabelle 1. Zusammenstellung der Ergebnisse des Einsatzhärteprozesses

The process was designed for an effective case depth of 0.90 mm according to the following parameters: preheating up to 750 °C, vacuum carburizing at 960 °C, lowering temperature before quenching, oil quenching and tempering at 160 °C. The actual process run is shown in Figure 5. The furnace cycle time depends on carburizing time in the process chamber (LPC) and it is only 210 min (3.5 h).

The process result has been examined on 40 parts taken from different places of the whole load; the results are shown in Table 1 and in Figure 6.

As result of the process, the correct microstructure of the hardened surface was obtained in the form of the tempered martensite. An average effective case depth of 0.89 mm was obtained with total dispersion within the narrow range of 0.14 mm, i. e. ±10 %. The surface hardness is, on average, about 62 HRC and it distributes within a range insignificantly above 1 HRC. The remaining requirements concerning retained austenite, IGO and carbides network have been also met.

The obtained technological results considerably exceed the traditional technology achievements with respect to accuracy, evenness and repeatability of the hardened layer shaping, and elimination of the IGO problem.

2.3 Process capacity and costs

The presented process is carried out in the furnace CMe T12 with a cycle time of 3.5 h. This means that every 3.5 h, the full batch of gross mass 1200 kg (net 800 kg) is loaded to the furnace from one side and unloaded from the other side after the process. So, the capacity in this cycle is about 230 kg/h (net parts) for an effective case depth of 0.9 mm. When using thinner layers or higher temperatures the cycle time can be 2–3 h and capacity 400–600 kg/h (gross load) or 300–400 kg/h (net parts) respectively, and even more when using a fixture made of graphite composite. The productivity can be increased easily by multiplying the number of devices. Groups of 2, 4, and 6 furnaces can manufacture 1–2 × 10^3 kg/h of parts to reach the productivity of huge atmosphere continuous lines while maintaining a compact footprint and full-operating flexibility.

The direct costs of the process depend on energy and technological media consumption. They include: electrical energy to sup-

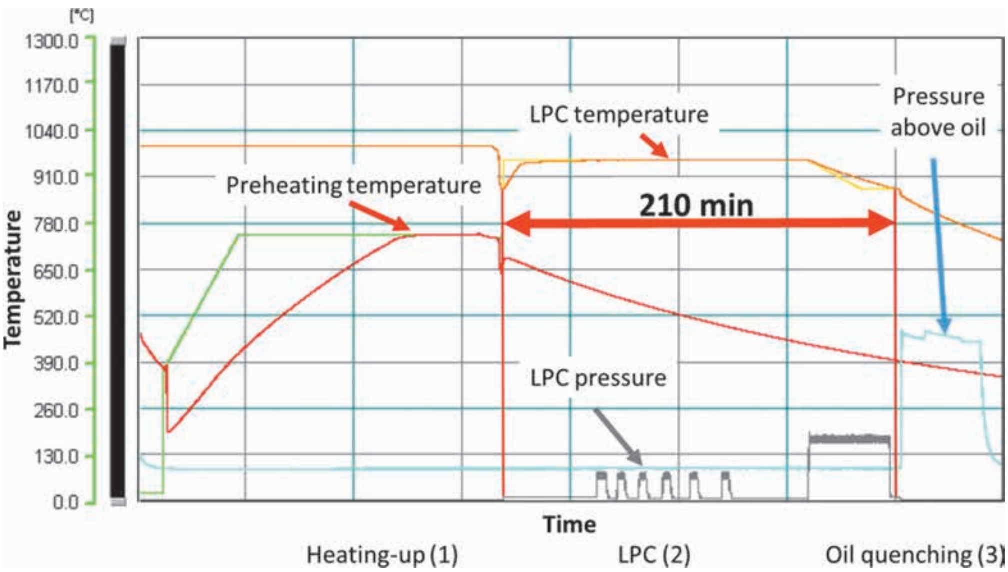

Fig. 5. Case hardening process for an effective case depth of 0.90 mm in the triple-chamber vacuum furnace, (1) heating-up to 750 °C, (2) LPC at 960 °C, and (3) oil quenching

Bild 5. Verfahren des Einsatzhärtens für eine effektive Einsatzhärtetiefe von 0,90 mm im Dreikammer-Vakuumofen, (1) Erwärmen auf 750 °C, (2) Niederdruck-Aufkohlen bei 960 °C und (3) Öl-Abschrecken ply heating systems of the furnace, motors and control system including water-cooling and compressed air systems, carburizing gas mixture (LPC) and nitrogen used in different process phases as the inert gas. In the objective process, consumption of these media was as follows:

- electrical energy 1100 kWh
- carburizing mixture 3.5 m^3
- nitrogen 30 kg

On the assumption of average rates for the above-mentioned media, the cost of one process can be estimated at about 150 Euro. After converting to the part mass, the unit costs are below 0.20 Euro/kg, i. e., within the range of traditional technology costs [6].

2.4 Summary for CMe T12

The triple-chamber furnace CMe T12 for case hardening by means of vacuum carburizing and oil quenching is the modern and reasonable alternative for the traditional devices. It can replace the classic sealed quench furnaces and lines for high-volume production such as pusher, roller or rotary furnaces. It is distinguished by a significant improvement of the process result quality, capacity and production flexibility, and the compact system. It can be installed directly in production halls (it does not require any separated area) and meets safety and environment protection requirements. The capacity of the single furnace can reach even 400 kg/h and it can be multiplied by using groups of many furnaces. The direct costs of the process are within the range of traditional technology costs.

CMe T12 is also an attractive alternative for modular vacuum systems for mass production. The advantages include initial capital costs as well as operating independence and flexibility.

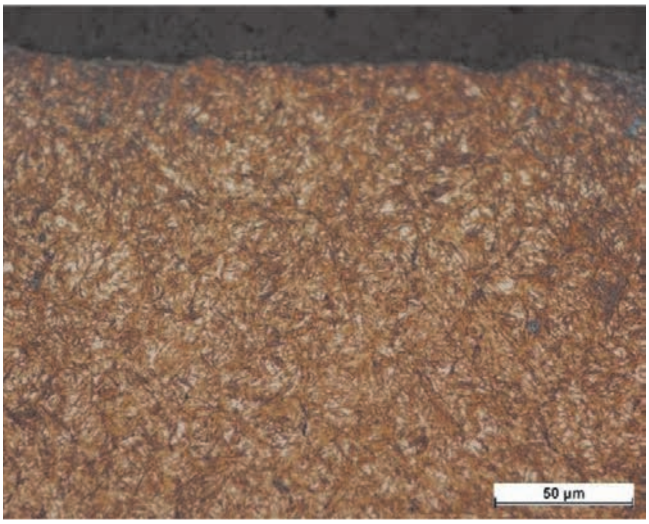

Fig. 6. Case hardened microstructure of 16MnCr5 after the process: tempered martensite, retained austenite content below 10 % (etched by Nital 3 %)

Bild 6. Mikrostruktur der gehärteten Schicht: angelassener Martensit, Restaustenitanteil unter 10 %

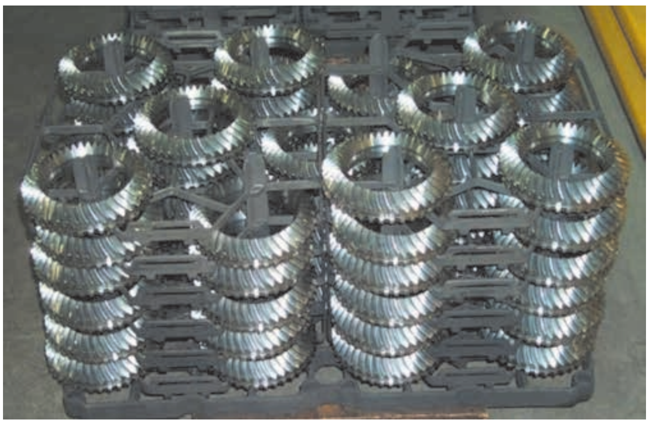

Fig. 7. Typical batch composition

Bild 7. Typische Chargenzusammensetzung

3 Revolutionary UniCase Master® – Single-Piece Flow

3.1 Weaknesses of the batch method

In both, traditional and modern case hardening systems, parts are configured and processed in batches on special fixtures (Figure 7) and undergo the whole case hardening process in such a configuration. This means that each part in a batch is affected by the process conditions in a unique manner, based on its position within the batch. Each part is affected differently regarding the heating rate, composition of the process atmosphere, and intensity and direction of the cooling medium. There is no doubt that the parts in the outer layers of a batch are heated more quickly and to a different temperature (according to the temperature distribution within the batch), as the atmosphere around them is "richer," and they are quenched more intensely, compared to the parts toward the center of the load. The result is that parts inside the batch have different physical and metallurgical properties than those on the outside of the batch, e. g., surface and core hardness, microstructure, and especially the effective case depth [7, 8]. That's why forced and accepted by industry requirements of case depth variation is ±30 %, what even for industry is very, very tolerant.

Non-uniform quenching results in temperature gradients within each part resulting in thermal stresses and a non-uniform transformation of the microstructure. This ultimately results in large deformations of the part being quenched. Quenching results are made even worse by the fact that the quenching stream within the batch is dispersed and each part is cooled differently based on its position within the batch. A critical summary of batch 2D quenching (especially oil quenching) shows that it is an uncontrolled and non-uniform process, producing great deformations within each part and little consistency within the batch. Distortions have to be removed finally by final machining or others correction method. Costs of these operations are huge, only for German industry it's about 2 billion Euro/year (including 0.85 billion Euro/year from automotive and transmission industries [9]), while global estimation is around 20 billion Euro.

Material handling of batch loads is typically complicated and costly. Gears are produced individually. After being shaped, they are collected, packed, protected, and transported to the case hardening department (captive) or to an external firm (commercial), which can range from hundreds of meters to hundreds of kilometers away. The gears are then unpacked, washed, and racked in order to form batches

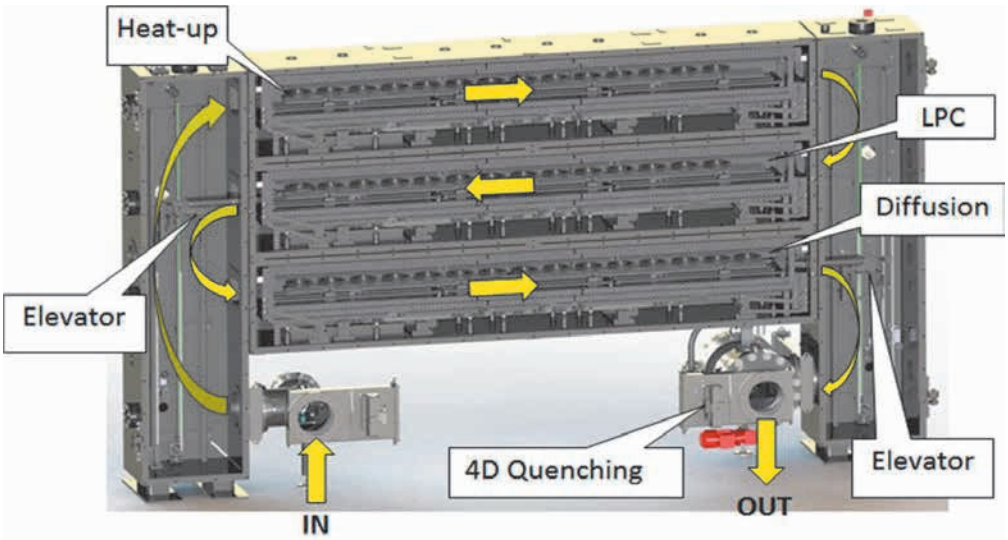

Fig. 8. The vacuum furnace for single-piece flow case hardening

Bild 8. Vakuumofen für Single-Piece-Flow-Technologie zum Einsatzhärten

on fixtures designed specifically for the case hardening process. Following an oil quench, the parts are washed again, dismantled, packed, protected, and transported back to the mechanical processing department. The whole undertaking may be divided into more than ten operations and takes days. These material handling costs consume considerable resources, including time, materials, money and damages.

Batch processing also has other quality, material handling, and cost pitfalls. For example, monitoring and reporting on the case hardening process is for the entire batch and not for individual pieces within the batch. That makes it difficult, or even impossible, to introduce and implement tighter quality standards.

Mentioned above weaknesses come from the batch method and cannot be overcome. If more improvement is necessary in terms of result's precision and repeatability, distortion's reduction and control and in-line production's integration, the only way is the real single-piece flow heat treatment which guarantees ideally the same process parameters for every single part in a series.

3.2 A single-piece flow case hardening by LPC and 4D Quenching

Figure 8 shows a vacuum furnace for case hardening of gears or rings using LPC and high pressure gas quench (HPGQ). This system fully meets the criteria of a single-piece flow method and has all the accompanying advantages in the contrary to other solutions [10, 11]. The furnace consists of three horizontal chambers: the first one for heating up, the second for low pressure carburizing, and the third for diffusion and pre-cooling before quenching. Additionally, a separate loading chamber and a quenching chamber (that doubles as an unloading chamber) are connected. Parts are transported between chambers by two vertical transport elevators attached to each side of the system.

The single-piece flow process runs in the following manner:
- a single gear is placed inside a loading chamber;
- it is then transported and loaded into the heating chamber;
- a walking beam mechanism indexes the gear through all the positions until the gear reaches the target carburizing temperature;
- the gear is then transported and indexed through the LPC chamber where the surface is saturated with the right amount of carbon, by a boost and diffusion sequence on every position;
- the part is then transferred and indexed through the diffusion chamber where the desired carbon profile is achieved and the temperature is decreased before quenching;
- the gear is then transferred to the gas cooling chamber where it is quenched;
- the gear is then removed from the quenching chamber and is ready for tempering.

Each gear follows in sequence and is processed the exact same way, with the exact same process parameters, guaranteeing the highest level of precision and repeatability.

3.3 4D Quenching®

The new concept also allows for significant improvements in the quenching process, specifically the reduction of distortion. This is done primarily using a high-pressure gas quenching system installed in the quenching/unloading chamber (Figure 9). The system utilizes a proprietary arrangement of cooling nozzles that surrounds the part and ensures a uniform flow of cooling gas from all sides; top, bottom, and side. We refer to this as "3D" cooling. In addition, a table spins the part, further enhancing quench uniformity. We refer to the spinning motion as the fourth dimension, allowing us to "4D" quench gears for the best possible uniformity. The cooling nozzles allow us to achieve up to 10 bar quenching re-

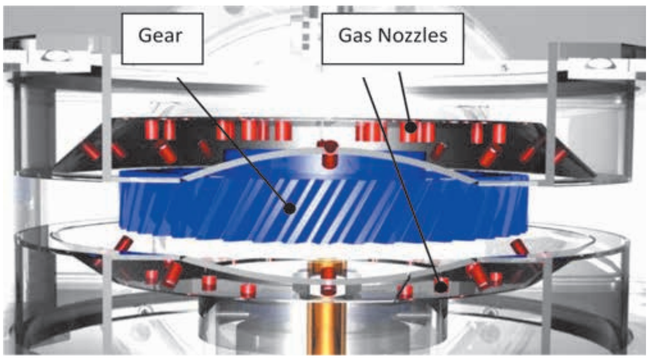

Fig. 9. 4D Quenching chamber (high pressure gas quenching) with a gear inside

Bild 9. 4-D-Abschreckkammer mit einem Zahnrad

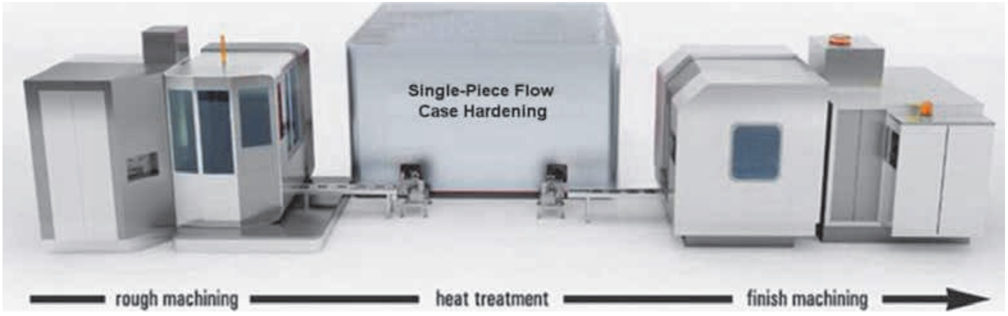

Fig. 10. Integration of the single-piece flow case hardening in lean manufacturing

Bild 10. Einbeziehung der Single-Piece-Flow-Technologie zum Einsatzhärten in der Schlanken Produktion

sults – comparable to oil quenching – without the use of Helium. Because the cooling nozzles can be adjusted to fit the gear's precise size, quenching is optimized and distortion significantly decreased.

3.4 Lean manufacturing

The new concept of single-piece flow case hardening is intended to be installed and operated directly on the manufacturing floor next to a CNC machine and was designed so that its footprint was similar to a CNC machine (Figure 10). It can be installed on new production floors or at sites previously occupied by other machines, including CNC machines. A newly machined gear can be introduced into and released from the case hardening system every 30–60 s (throughput up to 1 million parts/year). The system can be completely integrated into the continuous, lean production manufacturing line, thus eliminating many, if not all, batch material handling steps. It corresponds very well with an idea of Industry 4.0 too.

Also, please notice that the system does not use fixtures for load racking. As noted previously, this helps to reduce operating costs, including the cost to purchase and replace fixtures, as well as the consumption of energy.

3.5 UniCase Master® – the first, real single-piece flow case hardening

The first complete and automated single-piece case hardening line has been developed based on the furnace UniCase Master®. The line consists of the main furnace and accompanying devices and systems necessary for the process realization from beginning to end, among other things: manipulators, a tempering furnace, cooling chambers, a gas system, a vacuum pumping system, etc. (Figure 11). The line has the following technical parameters:

• part diameter	200 mm
• part height	50 mm
• part mass	4 kg
• number of positions in process chambers	15
• cycle	min. 30 s
• temperature	1100 °C
• quenching	10 bar, Nitrogen
• LPC	Acetylene (FineCarb)
• installation area	7.5 m × 9.5 m

The carried-out tests have confirmed the correctness of the technical solutions and the operating and technological parameters. Transport mechanism reliability and full control of the technological result have been achieved. The system has been tested in hundreds of tests over a wide range of parameters: at temperatures between 840 °C and 1060 °C and effective case depth within 0.30–1.5 mm.

A high-result precision and replicability as well as significant reduction of hardening deformations have been obtained. Figure 12 shows the real pictures of the part being processing in and transporting through the system.

3.6 Precise carburizing

To confirm the accuracy and repeatability of carburizing (LPC), two types of tests were carried out on a part series. The first test consisted of checking the evenness of carbon transfer from the atmosphere to the part surface through a measurement of the mass

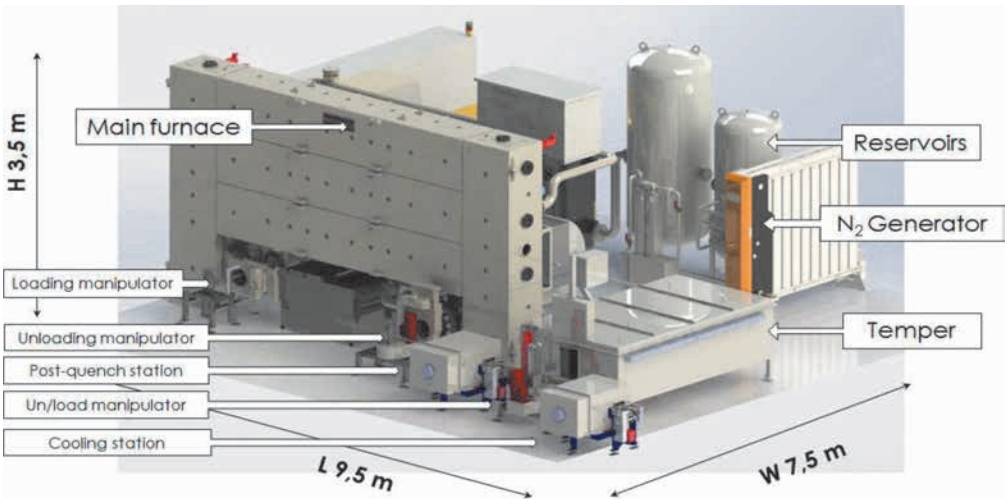

Fig. 11. A complete, automate line for single-piece flow case hardening

Bild 11. Eine vollständige, automatische Produktionslinie für die Single-Piece-Flow-Technologie zum Einsatzhärten

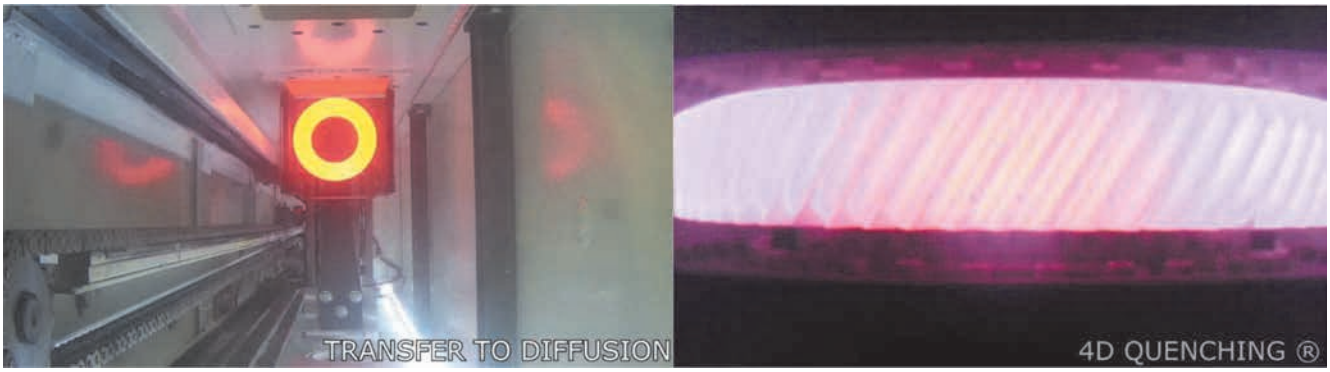

Fig. 12. Transportation of the gear between the process chambers (left), the gear introduced into the 4D Quenching chamber just before quenching begins (right)

Bild 12. Transport eines Zahnrades zwischen der Prozesskammer (links) und dem Zahnrad beim Abschrecken (rechts)

of carbon introduced during the process (gravimetric method). To this end, the parts were weighed before and after the process; the weight increase reflects the absorbed carbon mass. The test was carried out on wheels of diameter 96 mm and mass 550 g; their weight was specified with an accuracy up to ±2 mg. Figure 13 shows the diagram of the weight increase measurements for the part series. Except for the first three wheels that were introduced to the empty device and show slightly greater weight increase, the whole series is within the range between 583 mg and 595 mg. This means accuracy and repeatability unattainable in no other method, i. e. ±1 %.

However, the same carbon absorption does not have to mean that the parts have obtained the same carbon profile and hardness profile. Therefore, to confirm the results, the second type of test was carried out where the hardness profile was measured. The test was carried out on gear wheels with a diameter of 180 mm, carburized and quenched within the effective case depth 0.9 mm (550 HV). The results are shown in Figure 14. Of the wheels selected from the series, the correct hardness profile was obtained and the effective case depth was (0.90 ±0.03) mm, i. e., repeatability has been ±3 %. This result is unattainable with traditional methods. In addition, special attention should be paid to the hardness profile measurement accuracy itself is stuck with the comparable error, so in all probability, the repeatability of actual results is even better.

3.7 Deformation reduction

To check and compare deformation, tests of quenching in the 4D Quenching chamber and with the traditional method of batch in oil were performed. The tests were carried out on parts with a

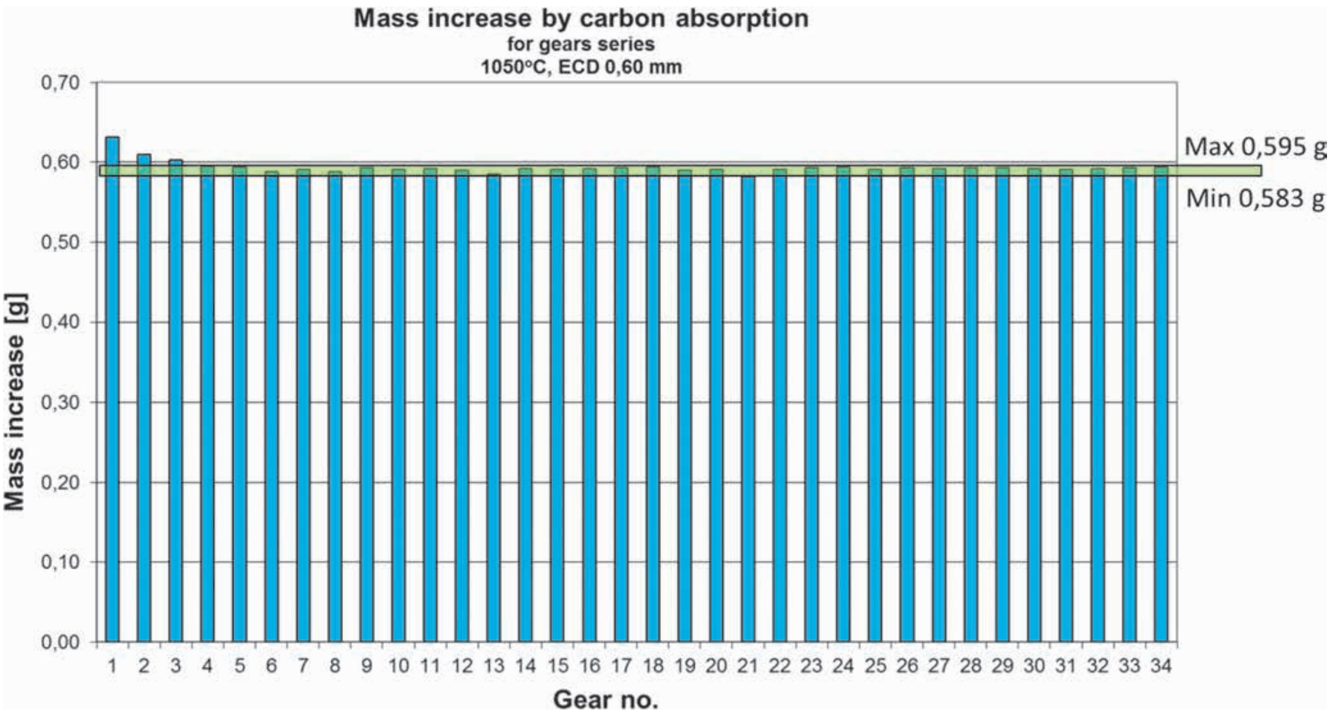

Fig. 13. Carburizing uniformity according to the gravimetric method (the absorbed carbon mass)

Bild 13. Gleichmäßigkeit von Aufkohlen nach der gravimetrischen Methode (die absorbierte Kohlenstoffmasse)

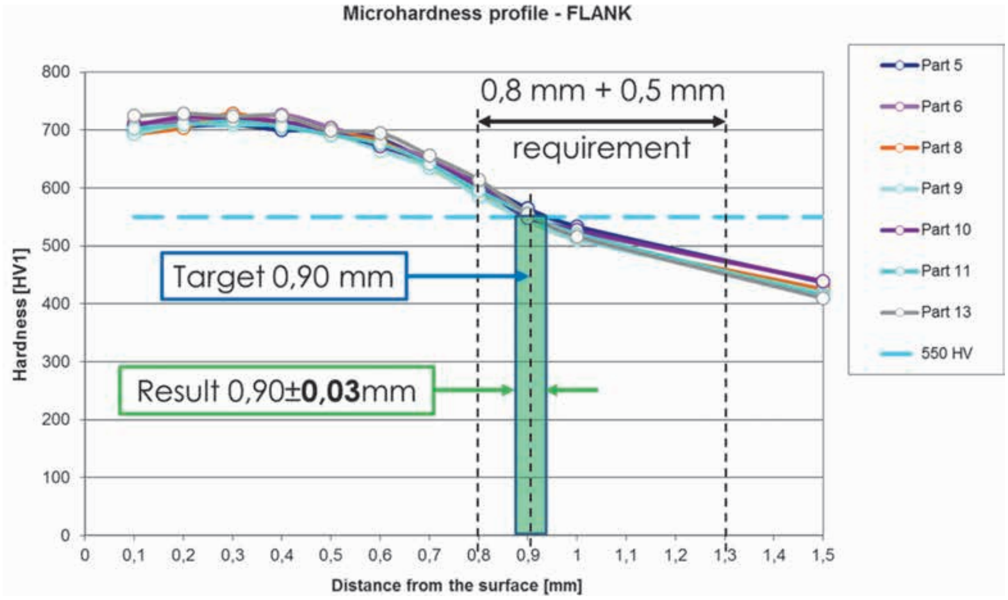

Fig. 14. Carburizing uniformity according to the hardness profiles

Bild 14. Gleichmäßigkeit von Aufkohlen nach den Härteprofilen

diameter of about 200 mm. The gears were carburized and quenched to obtain an effective case depth of 0.8 mm and tempered at 180 °C.

The deformations were measured in the following places (Figure 15):

- flatness of top surface of the internal hole,
- axial runout of bottom surface of the internal hole,
- roundness deviation of the internal hole.

The results are shown in Figure 15. The flatness deformations have reached up to 25–75 µm for the traditional quenching in oil, while in the 4D Quenching chamber the result obtained was 5–25 µm, i. e., or three times less. In the case of the axial runout, the deformations are 55–120 µm for oil and 20–65 µm for the 4D Quenching chamber, i. e., two-times less. The roundness deviation behaves similarly and they are 30–95 µm for oil and up to 40 µm for 4D Quenching. In general, the possibility of a significant (double or even quadruple) lowering of the hardening deformations of parts in the individual quenching chamber (4D Quenching) has been confirmed although these results are not final. Further researches will focus on the cooling nozzles configuration and quenching process parameters and their influence on distortion control and reduction.

4 Summary

Two solutions specifically for case hardening in a mass production that completely satisfy the needs of the global industry are presented in the article.

The triple-chamber furnace CaseMaster Evolution is the modern alternative to traditional atmosphere devices, sealed-quench furnaces and continuous operation units. It exceeds them with regard to technological result accuracy and replicability while direct unit costs of the process are comparable (below Euro 0.20 per kg).

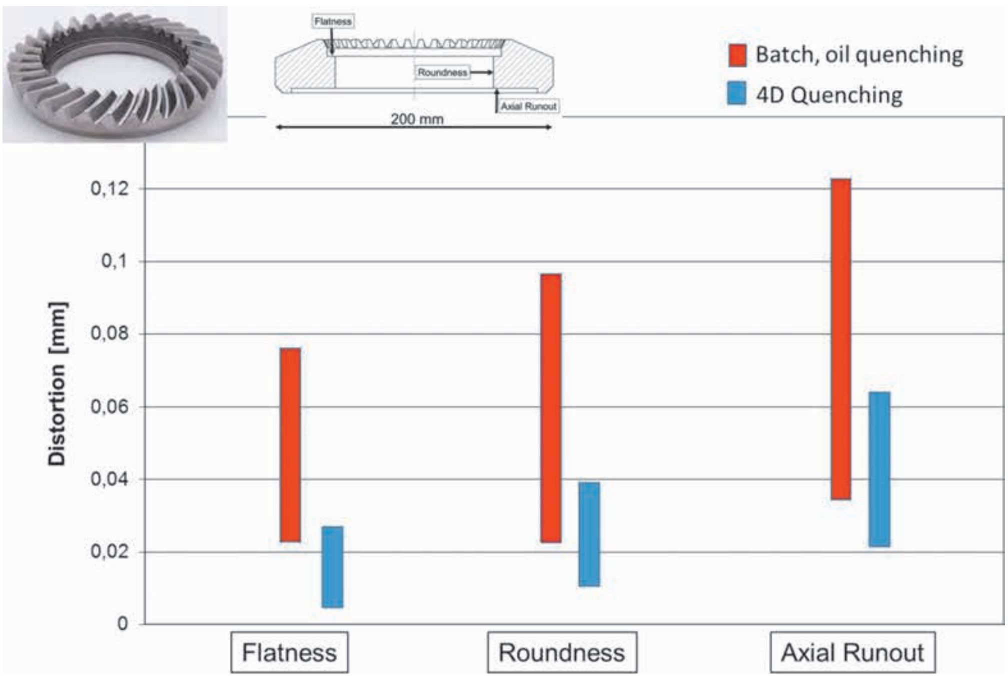

Fig. 15. Comparison of distortion on hypoid gears after batch oil quenching and after 4 D Quenching

Bild 15. Vergleich der Verzerrung bei Hypoidzahnrädern nach dem Ölabschrecken der Charge und nach 4-D-Abschreckung

Its capacity is up to 400 kg/h, i. e., two-times the capacity of traditional chamber furnaces, and a group of CMe furnaces can manufacture amounts equal to those of the largest atmosphere systems. CMe furnaces have a compact structure and are neutral in terms of ambience, therefore they can be operated directly at production halls and not at dedicated hardening plants. They are not dangerous and are environmentally friendly. CMe furnaces compete with vacuum modular systems as well regarding initial capital costs, operating elasticity and independence.

In turn, at the innovative system, single-piece flow – UniCase Master®, the technological result precision and replicability have reached an as yet unattainable level, while their dispersion has been reduced tenfold. However, the quenching chamber, 4D Quenching, allows for deformation control and reduction by several times. This results in a significant reduction of the finishing operation and its costs and in many cases in its elimination. The integration of the heat treatment directly into the production chain eliminates the material logistics costs and shortens the production time as well as it allows for 100 % traceability and an inline check of each part during production.

Both solutions determine an evolutionary and revolutionary direction of changes and development of heat treatment technology and equipment for the modern industry and they fully comply with present and upcoming requirements.

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Discussion

Veltrop: … but even when you quench more directional you have a variation in dimension change and it´s lower than in the conventional carburized products. Did you find out any difference in structure or bending or deviations in both materials that could cause the difference of conventional in a single piece?

Korecki: We did not find out any difference in the structure – of course in case hardening is a tempered martensite and the core is a mix depends on the steel grade but definitely the quenching show us that the efficiency of such a gas system is comparative like in oil quenching. But the quenching allowed us to design the system to provide a cooling gas in the area depending to the cross-section of parts to allow a uniform removal of heat. It is an advantage. But we are also realize that sometimes we can produce a system which will focus for quenching from outside left the quenching inside or opposite. Everything depends what kind of result of distortion and what distortion we are focus on, because if we consider distortion of entire gear it´s about 20 factors. Then we can focus and design the system exactly for the distortion what we want to control.

Veltrop: But does that mean that you can also control opener and closer jets?

Korecki: No, I can’t control a particular nozzle. I can control the entire system (by pressure and velocity); the collector of nozzles is designed for particular gear for the best distortion results. Of course, you can change the design and exchange it very quickly, so it is a exchangeable element (like a tool).

Discussions

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